University of Nairobi

School of Engineering

Trend Detection in Precipitation and River Discharge to Assess Climate Change in the Upper Tana Basin

BY

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Declaration

I, Ntoiti Daniel Mwenda, hereby declare that this thesis is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

……………………………………………… 11th June, 2019

Ntoiti Daniel Mwenda Date

This thesis has been submitted for examination with our approval as university supervisors.

……………………………………………… 24/6/2019

Prof. Patts M.A. Odira Date

……………………………………………… 11th June 2019

Prof. Ezekiel Nyangeri Nyanchaga Date

Dedication

Dedicated to my wife, Loise and daughter, Jasmine.

Acknowledgement

I acknowledge the invaluable guidance of my supervisor, Prof. Odira. Indeed, I had nearly given up; but he would not let me. Special thanks to Professor Nyangeri for taking the time to check my work and ensure that it is polished.

Abstract

With Climate Change being a point of focus in modern times, this research study was done to detect the existence of a statistically significant trend in the hydro-meteorological characteristics of the upper Tana catchment to deduce whether Climate Change had occurred. The methodology involved subjecting mean monthly and mean annual precipitation and river discharge data to the Mann-Kendall trend detection tool from the XLSTAT software. Further, the one-tail trend tests (upper-bound test and lower-bound test) were done to confirm whether the trend detected was increasing or decreasing. In order for Climate Change to be reasonably implied, at least 50% of the mean monthly data needed to exhibit a statistically significant trend and secondly, have mean annual data return a statistically significant trend as well. The results suggested that for mean monthly rainfall, there was a statistically significant decreasing (negative) trend detected in the months of August and September (16.67%). With regard to river discharge, a statistically significant positive trend was observed in the months of January, February, March and November (33.33%). However, for mean annual discharge, there was an overall positive statistically significant trend for the years spanning 1966-2006. These results for mean annual discharge were inclusive of data that had perceived outliers (2001-2003). When the same Mann-Kendall trend test was done on mean annual discharge data between 1966-2000, no statistically significant trend was observed. In conclusion, the results obtained from this study could not conclusively imply Climate Change for two reasons: first, only 16.67% and 33.33% of mean monthly rainfall and mean monthly discharge respectively detected a statistically significant trend; both results were below the (50%) threshold set in the objectives. The mean annual rainfall did not detect any statistically significant trend and although the mean annual discharge data for the period 1966-2006 detected a statistically significant positive trend, when the Mann Kendall tool was run on the mean annual discharge omitting the 2001-2003 data, no statistically significant trend was detected. The second reason why Climate Change could not be reasonably implied is due to the fact that the rainfall data obtained had a relatively short span (1980-1994) and only six rainfall stations were analyzed in the vast upper Tana catchment. This sample dataset could be viewed as disproportionate to the size of the catchment and therefore relatively inadequate to give a proper representation of the catchment characteristics. It was recommended that a study be done on a comparable catchment with a longer record of data to check trend; advanced methods to check data accuracy be deployed to validate rainfall data for years 2001-2003; an independent study of catchment degradation be done to determine its contribution to increased runoff in the rivers and finally a trend detection study be carried out on extreme rainfall and river flow values.

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List of Abbreviations

WRMA –	Water Resources Management Authority
WRA –	Water Resources Authority
MET DEPT	Meteorological Department
GWC –	Green Water Credits
IFAD –	International Fund for Agriculture Development
SCD –	Swiss Agency for Development Co-operation
MCMC -	Markov Chain Monte Carlo
MAR	Missing at Random
MCAR	Missing Completely at Random
MNAR	Missing Not at Random

CHAPTER 1: INTRODUCTION

1.1 Background

All over the world, historical hydro-meteorological data remains the primary starting point when planning water infrastructural projects. The existence of a statistically significant trend in the annual low, mean and maximum stream flows may be a pointer to climate change, a fact that is of influence in the management and development of water as a resource. Other than changes in the stream flows, the existence of a statistically significant trend in rainfall patterns in a basin could also infer climate change in a basin. With the Tana basin being identified as one of the four important basins in Africa for study by the *Green Water Credits*, an investigation to find out if climate change has affected the upper Tana basin was deemed an important area of study.

According to the World Bank (2010), Kenya is a water-scarce country. It has been projected that by the year 2025, Kenya's renewable water per capita will have dropped to 235 cubic metres down from the current per capita of approximately 650 cubic metres. The internationally recommended benchmark per capita is 1000 cubic metres of renewable freshwater supplies (Wafula, 2010). From this realization, Kenya embarked on Water Sector Reforms by enacting the Water Act (2002). These reforms gave birth to the Water Resources Management Authority which was tasked with the management of water resources in the major catchment areas (WRMA, 2009). The Water Act (No. 43 of 2016) has since taken effect and was meant to align the Water Act (2002) to the Constitution of Kenya 2010. The water resources management authority (WRMA) has since been replaced by the water resources authority (WRA). Figure 1.1 shows the water availability per capita in the Tana Basin (WRMA, 2009).

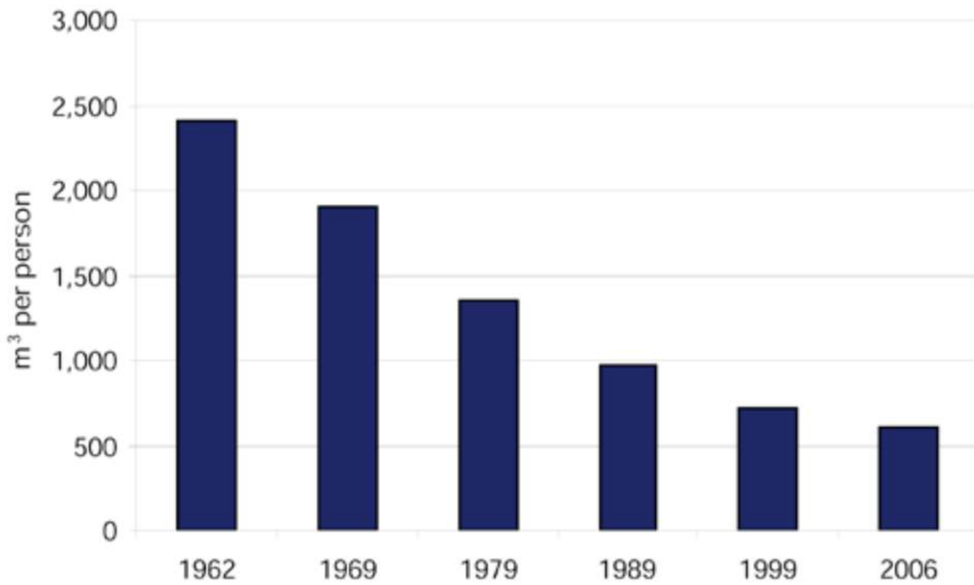


Figure 1.1: Water availability per capita in the Tana basin

According to Adebayo *et. al.,* (2014), by obtaining a historical statistically significant trend from Hydro-meteorological variables, catchment characteristics can be established to evaluate the past, present and predict the future water resource status in a catchment basin. It is only through the analysis of the precipitation and flow data that hydrological modeling, climate change assessment and urban environmental planning can be done effectively (Ebru *et. al.,* 2012). Several studies worldwide on trend-detection have been done on hydrological time series and research has suggested that statistically significant trends in extreme value time-series cannot be a reliable means of proving climate variability as compared with mean series (Lindstrom *et. al.,* 2004).

Other studies have suggested that time-series trend tests for precipitation data and discharge data are not necessarily correlated. This means that hydrological time-series may be found to be negative despite meteorological time series trend being positive (Wang et. al., 2009; and Woo et. al., 2008). This has been attributed to possible human activities, causing increased run-off despite decreasing trend in precipitation.

1.2 Statement of the problem

Climate change has drawn significant interest in the research community. This has led to studies that seek to evaluate the existence of a statistically significant trend in temperature, meteorological data, hydrological data among other parameters. Prior to this study, there had never been a study to evaluate the impact of Climate Change on the hydro-meteorological properties in the Upper Tana, specifically on the two tributaries of the Tana river (river Kathita and Mutonga). Studies have been carried out in the middle and lower reaches of the Tana for changes in the maximum and mean annual stream flows, but no study so far has sought to independently examine rainfall and stream-flow data for statistically significant trend to draw conclusions on climate change.

This study was intended to bridge this gap in knowledge by examining two variables for a more comprehensive and definitive conclusion.

1.3 Objective of the study

The objectives of the study was to evaluate the existence of a statistically significant trend in mean monthly and mean annual precipitation and discharge in the Upper Tana catchment.

1.3.1 Specific objectives

The specific objectives are as follows:

a) To evaluate the existence of statistically significant trend in the mean monthly rainfall for six rainfall stations (in the catchment area where Kathita and Mutonga rivers also found) over the period between 1980-1994. statistically significant

b) To evaluate the existence of a statistically significant trend in the mean monthly and mean annual stream flows for Kathita and Mutonga rivers between 1966-2006.

For purposes of this study, only rainfall data from six stations was available and had data spanning between the years 1980 – 1994. The Kenya Meteorological Department had, under its custody, rainfall data from twenty-six (26) collaborating stations in the catchment. However, data from twenty (20) out of twenty-six (26) collaborating stations was found to have been inconsistently collected and had missing data entries which were as high as 60% of the total dataset in each station. Only six rainfall stations were found to have collected consistent data between 1980 and 1994. No station in the entire catchment had data earlier than 1980 and likewise none had data beyond 1994. For stream flow data, however, data was available from the Water Resources Authority (WRA) for two tributaries of the Tana River (Mutonga and Kathita) at the “last” gauging station before they joined the River Tana between the years 1966 – 2006.

1.4 Justification of the study

The purpose of this study was to evaluate the upper reaches of the Tana basin for trend-detection in the hydro-meteorological time-series. The results of this study would enable the assessment of climate change / climate variability over the period of study and would become a useful tool to Water Sector Managers and Policy-makers in the management and development of the water resources in the Upper Tana.

1.5 Scope of the study

This study was restricted to rainfall data from six stations between the years 1980 – 1994 and stream flow data of two rivers (Mutonga and Kathita) at the last gauging station before they join the river Tana between the years 1966 – 2006.

1.6 Limitations of the study

The study has the following limitations:

1) The Meteorological Department had, under its custody, rainfall data from twenty six (26) collaborating stations within the sub-catchment. The data from these collaborating stations was not found to be consistently collected and indexed. Only six rainfall stations were found to have collected consistent data between 1980 and 1990. A few went up to 1994 but none had data beyond 1994, from the data that was under the custody of Meteorological Department. This study focused on these six stations out of the network of twenty six in the sub-catchment.
2) The full extent and impact of human activity in the area and how this could have affected the runoff characteristics was not considered.

1.7 Assumptions of the study

The main assumption in the study was that basin characteristics, including rainfall intensity is homogenous throughout the area under study. This was the reason behind picking as many rainfall stations as possible to give a fair and balanced picture of rainfall variability in the area under study over the period stated.

CHAPTER 2: LITERATURE REVIEW

2.1 The history of Climate Change Mitigation and Adaptation

According to the World Meteorological Organization Sörlin et. al.. (2018), the discussion on Climate Change began as early as the mid-19th century when scientists began postulating the likely link between emission of greenhouse gases and the melting of the ice-caps. With time, more convincing ties were made between increased carbon dioxide emissions and general global warming. With technological advancements, research has deepened mankind's understanding of climate change by numerically modelling climate change causal relationships.

According to Shamima (2015), in view of the threat posed by Climate Change, an international environment treaty – the United Nations Framework Convention on Climate Change (UNFCCC)- was adopted on 9th May 1992 with the main objective of stabilizing the greenhouse gases to "prevent dangerous anthropogenic interference with the Earth's climate system". This treaty paved way for the Earth Summit in Rio de Janeiro between the 3rd and 14thJune, 1992. Grubb et. al.. (2002) noted that the United Nations Conference on Environment and Development (UNCED), also known as the Earth Summit was seen as an important milestone since the adoption of the Montreal Protocol (on substances that deplete the ozone layer) that sought to phase out production of certain halogenated hydrocarbons (Chlorofluorocarbons) which was believed to deplete the stratospheric ozone. The Earth Summit brought together 154-member states and set non-binding commitments to addressing Climate Change through proposing a series of mitigation and adaptation measures (Shamima, 2015).

2.1.1 The Kyoto Protocol

According to Ruhil (2017), the Kyoto Protocol, adopted on 11thDecember, 1997, was an international treaty meant to extend the UNFCCC's objective of committing parties to the treaty that sought to reduce greenhouse gas emissions and it came to effect on 16th February 2005 with the first commitment period expiring on 31st December, 2012. On expiration of the Kyoto Protocol, a second commitment period was agreed upon and referred to as the Doha Amendment to the Kyoto Protocol. This Protocol has not yet come to effect as it requires acceptance by at least 144 state parties although as at January 2018, only 112 state parties had made formal acceptance. Annual negotiations under the UNFCCC Climate Change Conferences meant to come up with measures to be taken after the expiration of the Doha Amendment on Kyoto Protocol in the 2020, led to the adoption of the Paris Agreement in 2015 (Ruhil, 2017).

2.1.2 The Paris Agreement

According to Clémençon (2016). The Paris Climate Accord is an agreement within the UNFCCC adopted by consensus on 12thDecember, 2015 which sought to deal with greenhouse gases mitigation, adaptation and financing starting from the year 2020 after expiry of Doha Amendment to the Kyoto Protocol. The goal of the agreement is to keep the increase in global average temperature to well below 2° C above pre-industrial levels and to limit the increase to 1.5 ̊ C. This is expected to significantly reduce the risks and impacts of Climate Change. Under the Paris Agreement, each country has the leeway to set its own targets (and timelines) on reduction of greenhouse gas emissions and makes such plans and report on progress. There is no provision for enforcement of the targets set (Clémençon, 2016).

2.1.3 United Nation's Action on Climate Change

The United Nations has not been left behind in the discourse on Climate change. According to Ruhil (2017), all the 189-member states to the United Nations (UN) signed the United Nations Millennium Declaration in September 2000, committing themselves to achieving eight (8) Millennium Development Goals (MDGs) by the year 2015 in the areas of hunger, poverty, disease, illiteracy, environmental degradation and on empowerment of women.

Kristian (2013) notes that the seventh (7th) Millennium Development Goal on environmental is based on the premise that approximately thirty percent (30%) of the planet is under forest cover and this is a source of direct livelihood for approximately 1.6 billion people, in addition be being the source of clean air and rainfall catchment areas. Forests form natural habitat for numerous species of animals and birds and the over-exploitation of forests has been seen to be directly correlated to hunger and poverty. Among the salient issues that this MDG sought to address was to have the principles of sustainable development incorporated in each Country's Principles and Policies to reverse the depletion of natural resources, reduce biodiversity loss, reduce by half the proportion of global population without access to clean and safe drinking water and basic sanitation, and lastly to achieve significant improvement in the quality of life for at least one hundred (100) million slum dwellers by the year 2020.

Stig (2018) notes that in September 2015, the United Nations General Assembly passed and adopted seventeen (17) Sustainable Development Goals (SDGs) which was in essence a culmination of the Rio de Janeiro Conference in 2012 (Rio+20 Conference). The goal on Climate Change that was previously one broad area in the Millennium Development Goals, was split into smaller, more specific goals. Goal thirteen (13) was set as Climate Action while other complementary goals were set as stand-alone such as Goal 6 – Clean Water and Sanitation; Goal 7 – Clean and Affordable Energy; Goal 11 – Sustainable Cities and Communities; Goal 14 – Life Below water and Goal 15 – Life on Land. Figure 2.1 shows the SDGs.

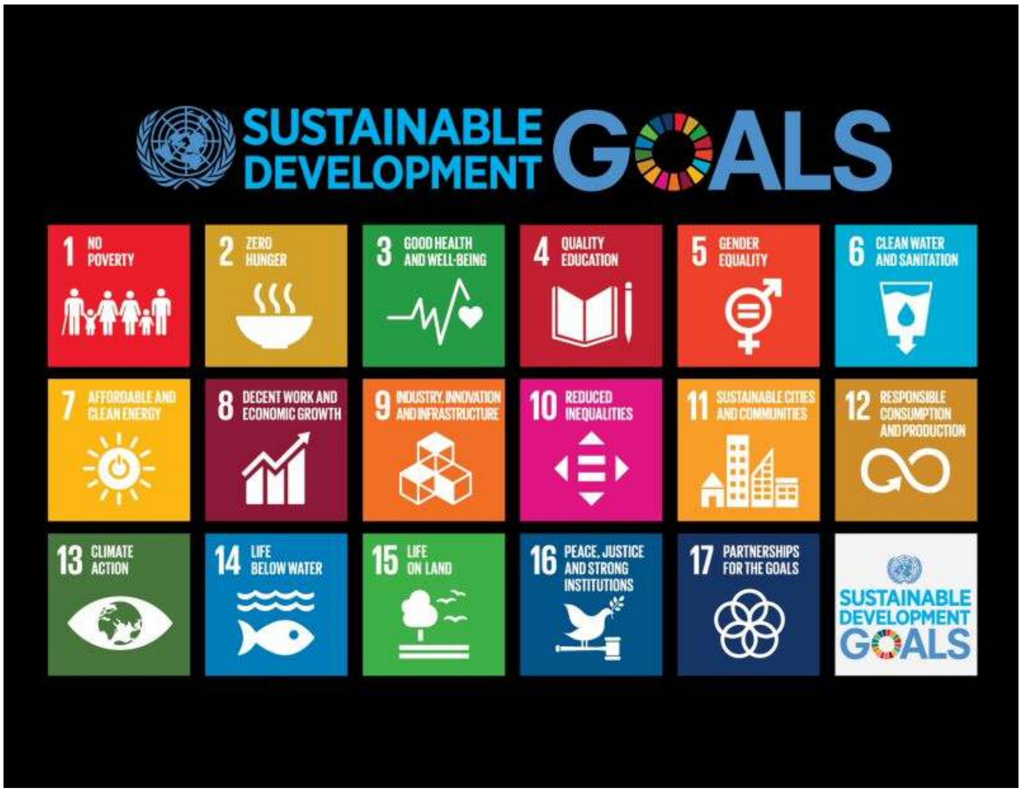


Figure 2.1: Sustainable Development Goals

2.2 Global Efforts in Climate Change Mitigation and Adaptation

According to Ochieng' et. al.. (2016), the effects of Climate Change have become more complex and any mitigation or adaptation initiatives need to take an integrated approach to be effective. Besides sensitizing the general public on the effects of Climate Change and having significant spending on research activities, a more practical and holistic strategy needs to be adopted to arrest the current situation. There has been extensive funding in the areas of research as well as the implementation of mitigation and adaptation initiatives to arrest Climate Change. According to Kristian (2013), the World Bank, along with other Non-Governmental Actors such as the Nordic Development Fund, have continued to fund interventions aimed at Climate Mitigation and Adaptation. The Nordic Development Fund, in particular, has set up the Nordic Climate Facility, which is a challenge fund that seeks to evaluate and fund innovative proposals in low-income countries through a competitive process. The Nordic Water Facility on the other hand, focusses more on proposals that focus on water resources conservation and protection. Kenya has been a beneficiary of these projects such as the Kenya-Nordic Green Hub, Climate Resilient Low Cost Buildings in Marsabit County, Creation of Green Local Economy through the Commercial Production of Biomass Briquettes from Agro-Industrial Residues in Kenya, Improved Water Economies in Sub-Catchments of Kenya, among other projects.

2.2.1 Mitigation and adaptation initiatives in Kenya

The Government of Kenya (GoK) has also made strides in efforts to arrest Climate Change, according to Ochieng' et. al.. (2016). Through planning, legislation, regulation, administration, management and development of land use patterns, water resources, effluent discharge, forest cover, development of clean energy sources, developing mitigation initiatives in arid and semi-arid lands (ASAL) and enforcement.

According to Saidi et. al. (2012), Article 4.1 of the UNFCCC identifies six mitigation sectors which are form the basis of the Kenya Climate Change Action Plan. These sectors are energy, transport, industry, waste, forestry and agriculture. This Action Plan, developed by the National Climate Change Council (NCCC) notes that Kenya's ambitious development blue-print (Vision 2030) is likely to have gains eroded should Climate Change adaptation and mitigation measures be taken casually.

With regard to Agriculture, Saidi et. al. (2012) notes that the sector is the economic backbone of Kenya, and contributes to food security, poverty alleviation and rural livelihoods. With Kenya having only about sixteen (16%) percent arable land and the remaining eighty four (84%) percent being arid and semi-arid lands (ASAL), agriculture is particularly vulnerable to Climate Change shocks. Erratic rainfall pattern has resulted in flooding and drought spells that have caused agricultural output to be and, in some instances, resulting in total crop failure. This situation has been aggravated by the illegal settlement of squatters in the Country's water towers, leading to deforestation and forest degradation.

Stiebert (2012) observes that the GoK, through various Ministries and Agencies has embarked on mitigation measures such as sensitization of farmers on better farming methods, inputs and technologies that put less strain on land and other natural resources. As part of the Vision 2030 flagship projects, the government has gone ahead to revive the Galana irrigation scheme to boost food production, procured fertilizer for farmers and deployed the Electronic Animal Identification as part of efforts to adapt to the impact of Climate Change on food security (Stiebert, 2012).

Droogers et. al.. (2011) observes that with regard to the Transport sector, emission of greenhouse gases GHG from motorized traffic such as buses, passenger cars, heavy commercial trucks and motorcycles contributes a more significant proportion of carbon footprint compared with other forms of transport such as railway, aviation and marine vessels. The National Transport and Safety Authority (NTSA) in collaboration with the Traffic Department of the National Police Service (NPS) have conducted vehicle inspections in a bid to weed out unroadworthy vehicles that pollute the environment by discharging harmful fumes. This initiative at reducing GHG emissions in the country has seen the Cabinet Secretary in charge of Industrialization make proposals to lower the eligibility for the import of second-hand vehicles from eight (8) to five (5) years (Omulo, 2019).

According to Geetsma et. al.. (2009), the Ministry of Infrastructure, Housing, Urban Development and Public Works has been the greatest proponent in the integration of green technology in the planning, design, construction and operation of infrastructure through adoption of progressive designs that make use of natural lighting, rainwater harvesting, solar technology and water evaporation cooling systems. By taking the lead in ensuring that upcoming government buildings are energy efficient, electricity demand is reduced and this contributes overall to reduced reliance on thermal power that is a significant source of GHG emissions.

The Energy Sector, through the Ministry of Energy has contributed to Climate Change mitigation by advocating the generation of clean energy from sources such as Geothermal, wind and engaging in Public-Private Partnerships to set up solar farms. In addition, the Ministry, through its Agencies such as Rural Electrification Authority (REA) and the Kenya Electricity Transmission Company (KETRACO) have expanded the ‘reach’ of the national grid to households in rural and remote areas in a bid to reduce reliance on wood fuel and kerosene for cooking and lighting, and this has further reduced pressure on the Country’s forest cover (Saidi et. al.. 2012).

Saidi et. al.. (2012) noted that the Ministry of Lands and Physically Planning, through the National Land Use Policy (Sessional Paper No. 1 of 2017), has provided the legal, administrative, institutional and technological framework needed sustainable and optimal use of Land. The policy has sought to address environmental degradation, inefficient land practices, unplanned settlement and food security.

According to the Water Act (2016), the Ministry of water and sanitation, whose functions among others include development of a water resources management policy, water catchment area conservation, control and protection, waste water treatment and disposal, land reclamation, water storage and flood control. The Ministry has various agencies that discharge specific mandate on its behalf and which contribute towards Climate Change mitigation and adaptation. The Water Resources Authority has been tasked with the mandate of formulating and enforcing standards, procedures and regulations relating to management and use of water resources and flood mitigation. By determining applications for water abstraction, water use and recharge, the Authority is charged with the responsibility of ensuring that a healthy ecological and social system is maintained in an equitable, economical and sustainable manner (Mogaka et. al.. 2006).

Mango et. al.. (2018) highlights that under the Ministry of Environment and Forestry, Climate Change mitigation and adaptation has been handled through re-forestation programmes, encouraging agro-forestry, restoration of strategic water towers and in the protection and conservation of the natural environment. To achieve this, institutions such as the National Climate Change Council (Climate change Act, 2016) which offers an advisory role on matters relating to climate change, the National Environmental Management Authority (NEMA), the Environment Tribunal, the Kenya Forestry Services (Forest Act, 2005) and the Kenya Forestry Research Institute (Science and Technology Act, No. 28 of 2013). According to the Kenya Forestry Services (2015), Kenya's forest cover as at 2015 stood at 7.8%.

2.3 Study area

According to Knoop et. al., (2012), the Tana River basin stretches over an area of over 126,000 square kilometers. The upper Tana catchment is composed of a number of tributaries that come from the slopes of Mount Kenya and the Aberdares. Among these rivers are the Chania, Kazita, Thika, Thiba, Sagana and Mutonga. These tributaries converge to form the longest river in Kenya, covering a distance of over 1,000km to the Indian Ocean at Kipini. Figures 2.2 show the geographical location of the Tana Basin (WRMA, 2009) with relation to other catchment basins in the country while figure 2.3 shows a detailed look at the Tana Basin.

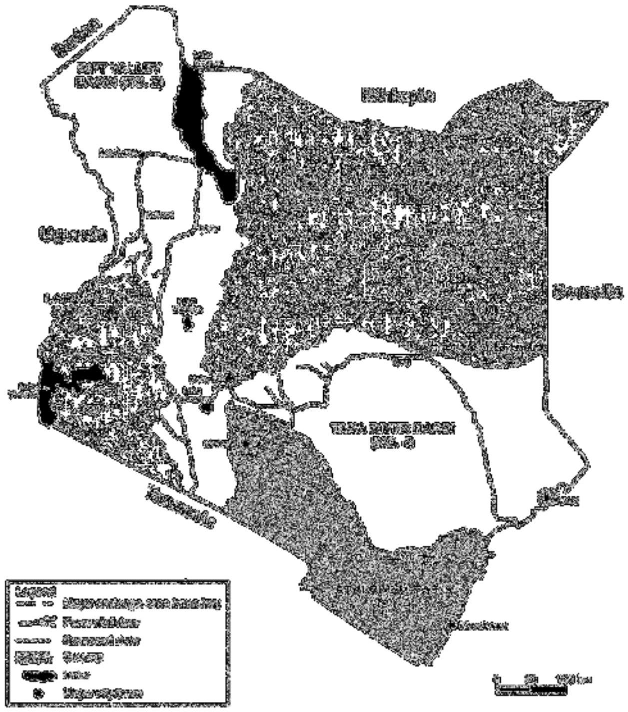
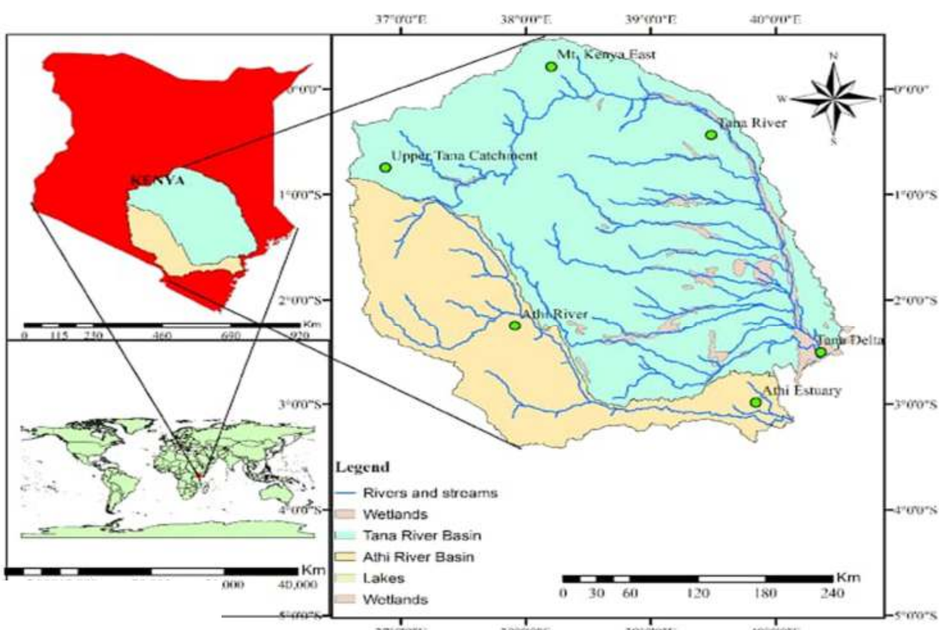


Figure 2.2: The Tana Catchment Basin



3: Geographical location of the Tana Catchment

The Climatic conditions in the basin, particularly with respect to precipitation, are a function of altitude. Higher altitudes in the basin receive an annual average rainfall of about 1,050 mm while the lower basin experiences an annual average of about 500 mm. Figure 2.4 shows the relief in the Tana Basin (Baker, 2015). In the higher altitude areas, rain-fed agricultural activities take place. Cash crops such as tea and coffee are most predominant. The Middle and Lower Tana, that are a bit drier, have pastoralist activities and the Bura and Hola irrigation schemes.

Knoop et. al.. (2012), observed that the soil types change with altitude as well. Upper Tana has predominantly volcanic ash, the middle catchment has deep well-structured nutrient rich clay soils while the lower catchment has poor-drained clay soils.

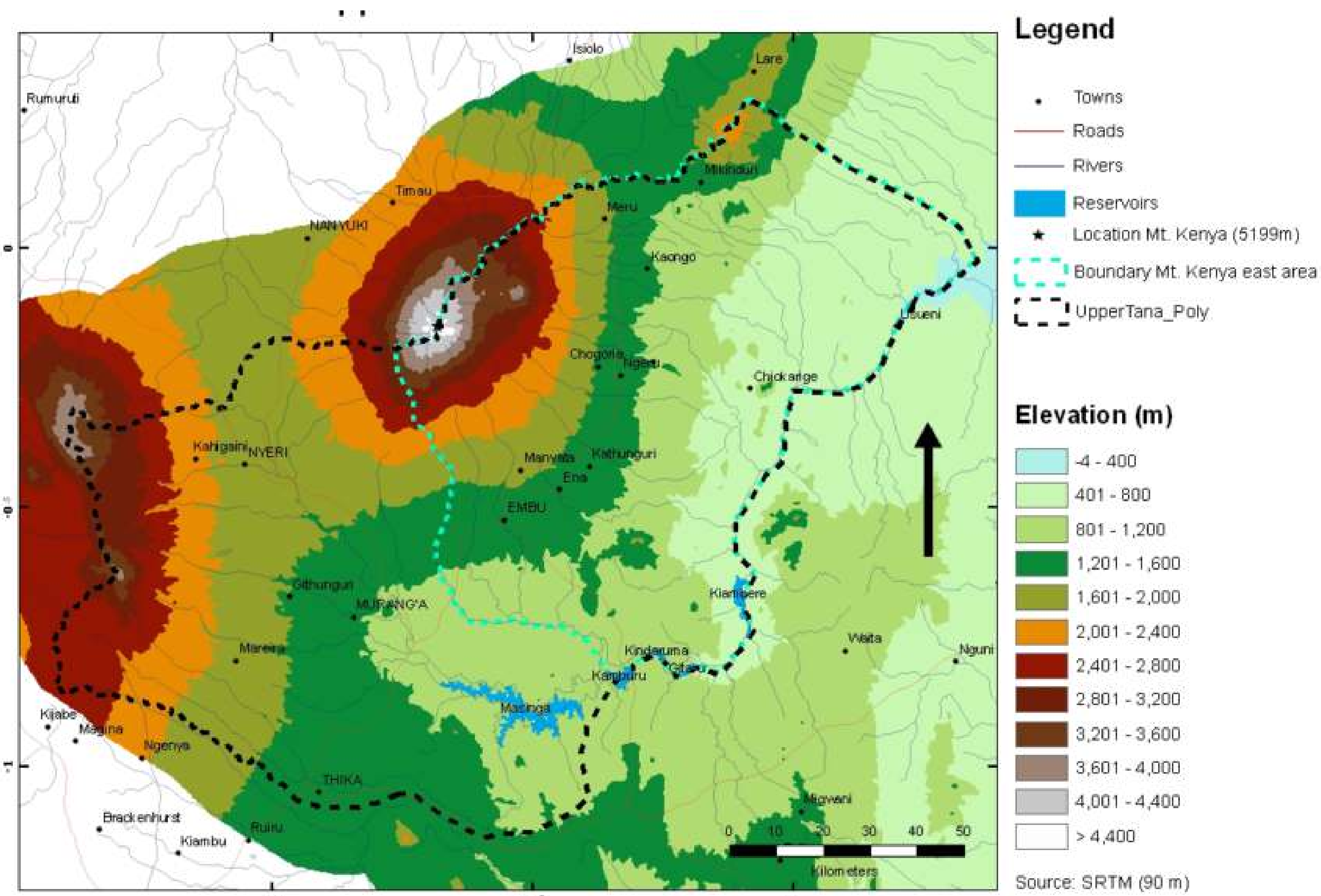


Figure 2.4: Elevation in the Tana Basin

Knoop et. al, (2012) noted that the Tana river has immense economic significance as the main source of Hydro-power through the seven-folks scheme, meets 80% of Nairobi's water demand through the

Ndakaini Reservoir and also supports the Bura and Hola irrigation schemes. Figure 2.5 shows the agro-ecological zones in the Upper Tana while Table 2.1 shows the various climatic zones.

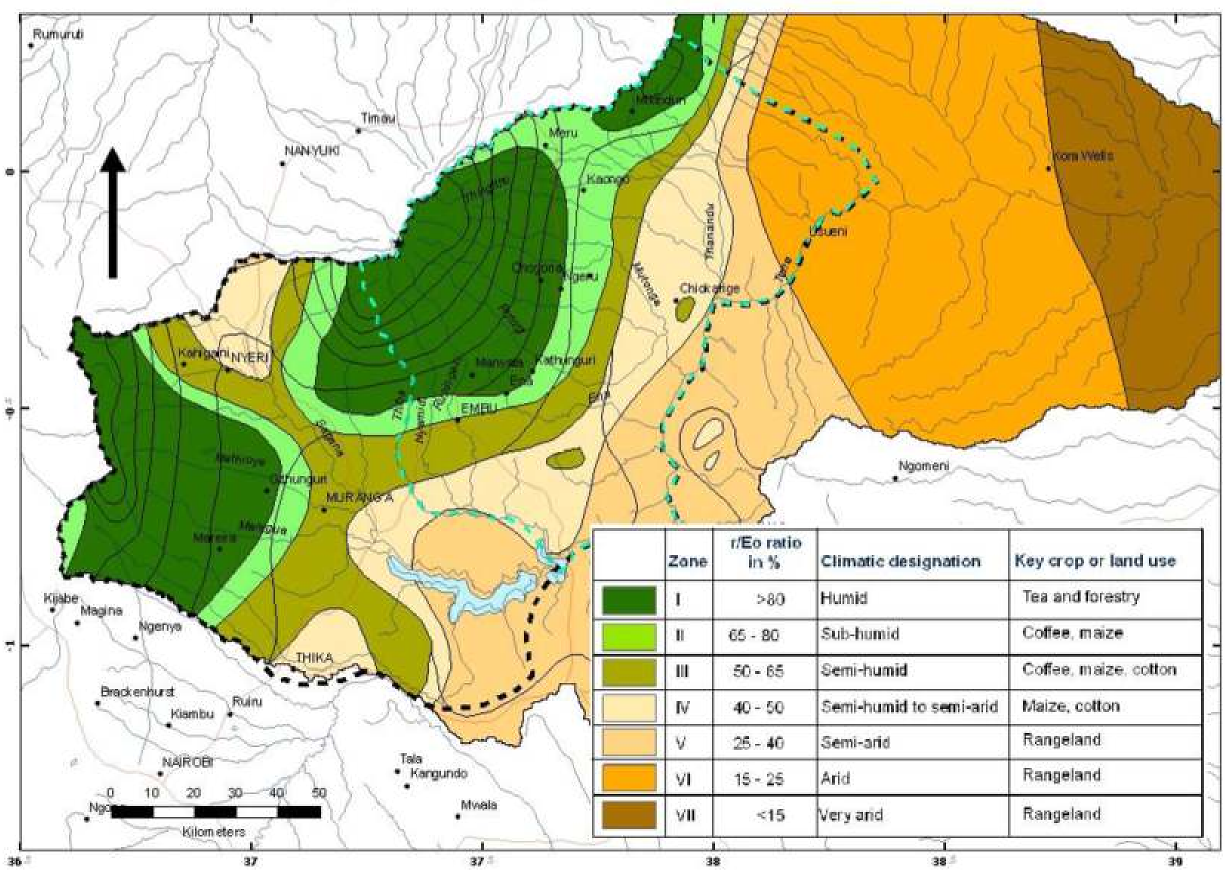


Figure 2.5: Agro-Ecological zones in the Upper Tana

Table 2.1: Climatic conditions of the Tana Basin

Zone	Ratio RF/ Ep (%)	Class	Rainfall (RF in mm)	Potential Evaporation (Ep in mm)	Vegetation	Potential for plant growth
I	>80	Humid	1100-2700	1200-2000	Moist forest	Very high
II	65 – 90	Sub-humid	1000-1600	1300-2100	Moist forest & dry forest	High
III	50 – 65	Semi-humid	800-1400	1450-2200	Dry forest & moist land	High to Medium
IV	40 – 50	Semi humid to Semi arid	600-1100	1550-2200	Dry woodland & bush land	Medium
V	25- 40	Semi-arid	450-900	1650-2300	Bush land	Medium to low
VI	15 – 25	Arid	300-550	1900-2400	Bush land & scrub land	Low
VII	<15	Very arid	150-350	2100-2500	Desert scrub	Very low

(source: Kenya Meteorological Department)

Odhengo et. al. (2012) observed that the Tana basin supports a population of about 5.7 million people and has tremendous socio-economic value to the ten counties it traverses through, before discharging into the Indian Ocean. They noted that the long-term sustainability of the Tana basin is hinged on the comprehensive integration of community livelihoods, natural resources and security in a Land Use Framework. In the report on the Strategic Environmental Assessment of the Tana river, all key parameters are examined exhaustively to come up with an equitable and sustainable utilization of the waters of the Tana. Table 2.2 gives an overview of the Tana catchment characteristics using the 1999 population census (Kenya Bureau of Statistic, 1999).

Table 2.2: Overview of the Tana catchment characteristics

Parameter	Units	Kenya	Tana	Tana %
Catchment area	km^2	580,370	126,026	22%
Population	inhabitants	28,686,607	5,100,800	18%
Annual average rainfall	mm	621	679	109%
Annual average runoff	mm	13	29	223%
Renewable surface water	million m^3/capita/year	647	726	112%
Surface water abstractions rates	million m^3/year	1071.7	595.4	55.6%
Groundwater abstractions rates	million m^3/year	57.21	4.79	8.4%
Average borehole yield	m^3/hr	6.25	6.58	105%
Borehole specific capacity	m^3/m	0.20	0.17	85%
Hydropower production	MW	599	477	80%
Irrigation potential	ha	539	205	38%

2.3.1 Discharge Characteristics

The Tana River is fed by tributaries that begin from the slopes of Mount Kenya and the Aberdare ranges. The river gets its peak discharge predominantly in the months of May and November which coincide with the seasonal rains. A study of discharge in the middle Tana by Hiromu et. al. (2009) showed the average discharge to be between 57 cumecs and 423 cumecs as measured at the Garissa station. Another study by Kitheka et. al. (2005) on the Tana estuary (Lower Tana) in Kipini showed that discharge ranged between 60 cumecs and 750 cumecs.

It is worth noting that any studies on the Upper Tana would need to be very specific and well defined because the river-discharge would be a function of discharge from the individual tributaries. Table 2.3 highlights the twenty five monitoring stations and their classification (WRMA, 2009).

Table 2.3: WRMA Classification of Monitoring Stations along the Tana

1. National Importance	The Garissa Station (4G01) in the Tana basin
2. Regional importance	Six stations in the Tana (4F19, 4EA, 4DD2, (Thiba), 4CB4, 4BE10, 4AC4
3. Management unit stations	16 Stations in the Tana basin
4. "special stations"	2 Stations in the Tana basin
Station type 4 is a temporal station which is set up at outlets where data is needed for the management of a specific project. (e.g. outlet of a smallholder farm-field using overland flow irrigation). A locational map of the gauge station is not yet available.	

2.4 Related Studies on the Tana River Catchment

According to Samantha (2011), the water crisis in Kenya is as a result of multiple causes such as forest degradation, floods, droughts, poor water resource management, water contamination and increase in population. In her observation, while some of the problems such as water contamination and management are avoidable, others like severe flooding and droughts can be attributed to the on-going Climate Change and Climate Variability. Samantha notes that in the absence of proper policy formulation and implementation, the persistent population increase will pose a problem in future.

Odhengo *et. al.,* (2012) noted that land use in the Tana basin has hitherto not been systematically and strategically planned. The existence of the Physical Planning Act (Cap 236) has mainly been applicable for urban development. This has necessitated need for a Strategic Environmental Assessment of the Tana river to ensure that Land Use is planned in a manner that guarantees water is available for all, not just as a social good, but also for economic gain. The study's prime focus is on issues such as human-wildlife conflict in the Tana Basin, proposed developments and their water demand, current and expected changes in the hydrology of the catchment and how this is likely to affect water use, resource use conflict, governing Laws and regulations among other parameters. The study can fairly be viewed as a qualitative study of internal and external factors affecting the current and future resource use and how these conflicts can be harmonized or mitigated in a more universal context to ensure long-term equity and sustainability.

Kitheka et. al., (2005), also carried out a study on the Tana catchment. The study sought to establish the sedimentation properties experienced in the Tana estuary in the Kipini area. In the detailed study, a number of parameters were measured, including river discharge, Total Suspended

Sediment Concentration (TSSC) and Populate Organic Sediment Concentration (POSC) over a period of over two years. The study yielded interesting results whose applicability with respect to discharge and sedimentation were on the lower Tana. The authors made reference to the fact that the rate of sedimentation could be affected by the construction of dams upstream of the Tana basin.

The Green Water Credits (GWC) reports, which began with *Report 1: Basin Identification*, isolated four major catchments in Africa, of which the Tana river basin was part (Droogers *et. al.,* 2006). The Tana was identified for study due to its socio-economic importance as the source of 80% of Nairobi's water demand, its waters were harnessed to generate hydroelectricity through five dams along its course and finally due to its agricultural importance as the source-water for two-thirds of all irrigated schemes in the Country. The first report, therefore, sought to establish the baseline data on the hydro-meteorological conditions, soil, land-use among other parameters. The GWC *Report 2: Payment for environmental Services* (Grieg-Gran *et. al.*. 2006) sought to review lessons from Payment for Environmental Services in the world while GWC *Report 3: Water Use and Demand* (Kauffman et. al.. 2007) specifically focused on green water management techniques in the Upper Tana by proposing efficient farming (agricultural) methods / technology and better surface water storage / conservation methods.

GWC *Report 4: Water Use and Demand* (Hoff et. al.. 2007) analyzed water demand by main water users in the upper Tana against supply by use of the Water Evaluation and Planning tool (WEPA), and from these, three proposed technologies for green water management were evaluated by their cost-benefit. GWC *Report 5: Farmers' Adoption of GWC* (Porras *et. al.*, 2007) was a product of household survey to assess the level of appeal to adopt and adapt the proposed GWC techniques by farmers and the motivation behind this. The report revealed a number of findings, among them being the need to understand the various incentives and how they appeal differently to the different gender. Meijerink *et. al.* (2007) in the *GWC Report 6: Political, Institutional and Financial Framework*, sought to assess how the implementation of the GWC in the Upper Tana catchment would be affected / influenced by the political, institutional and financial framework. The report noted the need for involvement of the farmer during planning stage to ease adoption of the proposed techniques. GWC Report 7: Dent (2007) Synthesis report summarized all major findings in the previous six reports and was meant to underscore the fact that the GWC concept had been proven. From this report going forward, a GWC operational programme would be drawn.

Geertsema *et. al.* (2011) in the GWC *Report 8: Baseline Review of the Upper Tana*, was the ushering in of the second phase of the GWC programme where Pilot Operation was started after Phase 1 (proof-of-concept) in the Upper and Middle Tana. In the report, a detailed look into the bio-physical traits of the Upper Tana Catchment characteristics were evaluated and the report went ahead to evaluate a number of on-going projects for co-operation. Capacity building was emphasized and the relevant government agencies were identified to aid in this. Wilschut (2010) uses remote sensing to come up with the Land use map in the Upper Tana while Hunink et. al. (2011) uses the Soil and Water Assessment Tool (SWAT) to evaluate the impacts of various land management options in the same Upper Tana.

A soil and terrain database of the Upper Tana is created by Dijkshoorn et. al. (2010) with Muriuki et. al. (2011) analyzing the existing water and soil conservation measures and creating an inventory of the same in the Upper Tana. Batjes (2011) estimates the changes in soil organic carbon in the same Upper Tana as Droogers et. al. (2011) and Onduru et. al. (2011) both examine the cost-benefit of Land Management options in the Upper Tana. Muchena et. al. (2011) identifies the institutes for implementing the GWC, and in a subsequent report, Muchena et. al. (2011) analyzes the financial mechanism for GWC in the Upper Tana.

Besides the GWC reports, Hiromu et. al. (2009), studied the precipitation and discharge data for the middle Tana in the town of Garissa, (0°29'S, 39°38'E). Discharge data from the Kenya Meteorological Department span 52 years from 1944 to 1995 (presently managed by Water Resources Authority WRA) while rainfall data was for a period of 47 years (1959 – 2006). The data was analyzed using the Economic Planning Agency (EPA) method to detect a statistically significant trend. The analysis took into account the long-term trend T, the cyclical variation C, the seasonal variation S and the irregular Variation I to determine discharge.

Kristian (2013) in a report funded by the Nordic Climate Facility (NCF) titled "Rainfall-Runoff Modelling – Assessing the Impact of Climate Change on the Water Resources in Kenya", identified eight catchments on the western side of Mount Kenya (Laikipia County) and using historical data, attempted to predict how rainfall and runoff would be like in future. The results predicted that there would be increased discharge in all eight basins under consideration in the near future by (5-30%) and a much more significant increase in runoff in the far future (25-60%).

In summary, therefore, the literature reviewed has had the upper Tana evaluated with a view to obtain the catchment characteristics. Factors looked into related to the upper Tana include rainfall characteristics, soil properties and river discharge characteristics. The Literature reviewed does not show studies done in the upper Tana catchment area to evaluate the possibility of Climate Change having occurred. This study will therefore seek to examine historical rainfall and streamflow data to determine if a statistically significant trend exists in these hydro-meteorological properties.

CHAPTER 3: MATERIALS AND METHODS

3.1 Introduction

This chapter highlights the research methods applied in the study including the research design, sample description and methods of data collection and analysis.

3.2 Research design

For this study, the causality research design is used. This type of research makes use of tests of hypotheses to infer that the occurrence of 'X' makes the occurrence of 'Y' more probable. It is worth noting that the occurrence of 'Y' is not limited to the occurrence of 'X' alone, rather, 'X' is just one of the many possible causes.

In this particular instance, the study sought to detect any significant positive or negative statistically significant trend in the precipitation and stream flows in the upper Tana to infer climate change.

3.3 Data collection methods

For the purposes of this project, precipitation data was collected from six standard rainfall stations located in Upper Tana catchment but within the sub-basin where Mutonga and Kathita rivers are situated. The Meteorological department then digitized records of the six (6) rainfall stations identified from the collaborating stations, since the Meteorological Department only had one rainfall gauge station in the area of study. Table 3.1 lists all the rainfall stations from collaborating stations.

Table 3.1: List of Meteorological Stations in the catchment (including collaborating stations)

Station ID	Station Name	Longi-tude	Lati-tude	Data Available
8937000	District Office - Meru	37°39"E	0°03"	1960-1972
8937004	Miathene Agricultural Camp	37°48'E	0°09'N	1960-1990
8937021	Meru College of Technology	37°44'E	0°09'N	1960-1999
8937031	Tigania Water Supply	37°49'E	0°13'N	1960-1991
8937041	Laare Coffee Factory	37°56'E	0°20'N	1980-1993
8937059	Maua Divisional Headquarters	37°56'E	0°14'N	1980-1990
8937060	Michii-Mikuru Tea Estate	37°51'E	0°11'N	1960-1996
9037085	Mitunguu-Meru	37°57'E	0°06'S	1960-1997
9037086	Marine Coffee Research Sub-Station	37°46'	0°03'N	1960-2004
9037150	Egoji T.T. College	37°40'E	0°10'S	1969-2000
9037160	Marimanti W.D.D. Met Site	37°59E	0°09'S	1969-1998
8937072	Giaki Experimental Farm	37°46'E	0°01'N	1980-1992

9037184	Tunyai Rural Afforestation Estate	37°50'E	0°10'S	1973-2003
9037191	Gaitu Scheme - Chaaria	37°43'E	0°02'N	1973-1992
8937078	Mucheene Forest Station	37°32'E	0°06'N	1973-2003
8937086	AthiruGaiti Coffee Factory	37°58'E	0°12'N	1980-1990
8937087	Kangeta Chief's Camp	38°03'E	0°17'N	1974-1996
8937088	Ruiri Farmers' Co-operative	37°39'E	0°09'N	1974-1997
8937096	Meru Teachers' College	37°38'E	0°04'N	1980-1994
8937097	Meru Technical Secondary School	37°37'E	0°03'N	1980-1992
9037214	Kaguru Farmers' Training	37°40'E	0°5'S	1977-2003
9037219	Kiburine Tsetse Fly Research	37°46'E	0°02'N	1982-1992
9037232	KaruaMutonga River	37°54'E	0°05'S	1983-1993
8937105	Ngare-Ndare Farm	37°23'E	0°10'N	1984-2003
8937020	Ngusishi D.O.'S Office	37°17'E	0°05'N	2001-2003
8937024	Embori Centre	37°21'E	0°10'S	2001-2003

Preliminary information from the Kenya Meteorological Department indicated that out of the twenty-six rainfall stations, twenty (20), that were from collaborating stations, had significant missing data values to the point that it would have been impractical to use simulation techniques to impute the missing values, without introducing errors. To elaborate further, all twenty stations had irregular data entries with majority recording rainfall for only two months in a year (one month when long rains are experienced and a further one month during short rains). All other months did not have any entries. It was found imprudent to assume that the entries for missing values were zero (0). As a result, only six stations, whose data entries were found to be relatively complete and reliable were picked to act as the sample for the study. Table 3.2 shows data from these six stations also had missing entries but the proportion of missing values was less than ten percent (10%) of the total data values.

Table 3.2: list of rainfall stations sampled for the study

Station ID	**Station Name**	**Longi-tude**	**Lati-tude**	**Data Available**
8937041	Laare Coffee Factory	37°56'E	0°20'N	1980-1993
8937059	Maua Divisional Hqs	37°56'E	0°14'N	1980-1990
8937072	Giaki Experimental Farm	37°46'E	0°01'N	1980-1992
8937086	AthiruGaiti Coffee Factory	37°58'E	0°12'N	1980-1990
8937096	Meru Teachers' College	37°38'E	0°04'N	1980-1994
8937097	Meru Technical Secondary	37°37'E	0°03'N	1980-1992

With regard to the stream flow data for the Mutonga and Kathita rivers, data was provided by the Water Resources Authority, Embu regional office. Daily stream flow records were provided in form of discharge in units of cubic metres per second. Preliminary information from the regional office confirmed that the data was complete and had no missing data whatsoever. Table 3.3 shows the raw data available from the Water Resources Management Authority (WRMA).

Table 3.3: List of River Monitoring Stations

Station ID	**Station Name**	**Data available**
RGS4F19	Kathita	1966-2014
RGS4E07	Mutonga	1966-2006

3.4 Missing Data

Missing data is not a unique phenomenon in any dataset. According to Allison (2000), missing data, whether by design or by chance is inevitable in any real-life study. These can drastically reduce statistical power, cast credibility issues on generalized findings and inevitably amplify standard errors. A whole lot of research has gone into methods of filling in missing data with the three predominant methods being imputation, weighting and likelihood approaches.

According to Rubin (1976) missing data occurs generally under three mechanisms: MAR (Missing at Random); MCAR (Missing Completely at Random) and MNAR (Missing Not at Random). Rubin (1976) defined MAR as a condition in which missing data depends only on observed data. In the example given by Dong et. al., (2013), if a test were administered to a group of students before a calculus tutorial (pre-test) and later after the tutorial (post-test), an assumption may be made that students who score low during the pre-test are likely to drop out of the math class before the tutorial is over. As a result, in the event that some data is missing after the post-test, and it is reasonably assumed that the probability of missing test scores in the post-test is attributable only to the pre-test scores, then it can be said that the mechanism of the missing data is MAR.

According to Allison (2000), MCAR is a special case of MAR where missing data is neither dependent on observed data, nor on missing data. Where this assumption is held valid, the observed data can be viewed as a random sample of the dataset. This means that missing data may not introduce bias but may magnify the standard error. In MNAR, the condition is that the probability of missing data is dependent on the missing data itself. Such mechanisms for MNAR must be clearly specified and incorporated into the analysis. An example of MNAR is sampling the residence locations of a group of people in an area; in this case, the residence of foreign dignitaries and military official is deliberately omitted for security reasons.

For purposes of this study, XLSTAT software was used to simplify the process of imputing missing data. The Multiple Imputation method was used to perform five (5) imputations by the Markov Chain

Monte Carlo (MCMC). According to Schafer (1999), the multiple imputation method begins by foremost imputing (filling in) missing values multiple times by use of the existing observed data. The regression method is particularly useful in this method. The second step is applying statistical analysis to come up with parameter estimates from various analyses. The third step is to combine the various estimates to come up with one value.

3.5 Data Analysis

For the purposes of analyzing data, the Mann-Kendall trend detection tool of the *XLSTAT* software was used. The test, categorized as *Non-Parametric*, is widely accepted in identifying statistically significant trends in time-series hydro-meteorological data values. The strength in this test comes from the fact that the dataset need not conform to any probability distribution and as a result, the outcome of such an analysis is normally very robust. In addition, the test allows for the existence of missing data as only ranks are assigned and used in the analysis. Data values reported as *non-detects* are assigned a common value smaller than the least reported value in the entire data set. The trend analysis assumes that there is only one data value in a given time period. Where multiple data entries exist for the same time period, the median is computed and used. The data values in the time series are ranked each data value being evaluated by comparing it with subsequent data values. The underlying principle in this test is comparing two consecutive data values for a positive or negative value (the relative magnitudes of data are compared as opposed to the actual data values themselves).

According to Morin (2011), the Mann-Kendall statistic *(S)* is presumed to be zero (0) where no statistically significant trend exists. When a data value in a subsequent time period is compared against data value from a preceding period, and it is found that the data value in the subsequent period is greater in value (rank) than the data value in the initial (preceding) time period, Mann-Kendall statistic assumes a positive one value (+1). Likewise, when the preceding and subsequent data values are compared and the subsequent becomes lower than the preceding, a negative one (-1) S-statistic value is assigned.

According to Kunkel et. al.., (2010), by the Mann- Kendall test, the null hypothesis H_0 presumes that there is no statistically significant trend (data values are randomly ordered in time) is tested against the Alternative Hypothesis H_1 that there is an increasing / decreasing statistically significant trend. As indicated earlier, data is evaluated as an ordered time series. By letting $X_1, X_2.....X_i, X_j....X_n$ be data values in a given dataset with *n* values. The Mann-Kendall *S-statistic* is computed as follows, where $X_j$is the subsequent data value in an ordered time series while X_i is the preceding data value.

$$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}Sgn(X_j-X_i)$$

$$Sgn(X_j-X_i)=\begin{cases}+1, & X_j \rangle X_i \\ 0, & X_j = X_i \\ -1, & X_j \langle X_i\end{cases}$$

(3.1)

According to Morin (2011) for a dataset of more than eight (8) values, the *'S'* value has an approximately normal distribution for the data set. The variance can be computed by the following formula.

$$\sigma^2=\frac{1}{18}\left[n(n-1)(2n+5)-\sum_{p=1}^{g}(t_p-1)(2t+5)\right]$$

(3.2)

In order to determine the significance of the statistically significant trend, the Z_s statistic is computed. The resulting value of Z_s tests the null hypothesis (H_0) at given significance level of say 5%. The value of $Z_{0.05}=1.96$.

$$Z_s=\begin{cases}(S-1)/\sigma & for \quad S\rangle 0 \\ 0 & for \quad S=0 \\ (S+1)/\sigma & for \quad S\langle 0\end{cases}$$

(3.3)

Thus, for $Z_s>Z_{0.05}$ the trend is considered to be statistically significant (Null Hypothesis rejected)

For $Zs < Z_{0.05}$ the trend is considered to be statistically insignificant (Null Hypothesis accepted).

The Mann-Kendall analysis is found to be a robust tool for trend detection and was used in the analysis of precipitation data and stream-flow data in this study. For the purposes of this study, the p-value was be computed and used as a basis of determining whether the trend observed has statistical significance.

3.6 Data Interpretation

The Mann-Kendall two-tail trend technique was employed to test the hypothesis at 5% significance level (H_0 – no statistically significant trend in time series and H_a – a statistically significant trend exists in time series) on mean monthly rainfall (independently evaluating each month over the fourteen-year period); and also evaluating the mean annual rainfall historical data for six rainfall gauging stations in the upper Tana catchment between 1980 and1994. If a statically significant trend is observed, it would be implied that climate change is the cause of this trend.

The same Mann-Kendall two-tail trend technique was used to test the hypothesis at 5% significance level (H_0 – no statistically significant trend in time series and H_a – a statistically significant trend exists in time series) on mean annual streamflows for the two key rivers Mutonga and Kathita at the *"last"* gauging station, just before each of these tributaries joins the River Tana over the period of 1966-2006. A statistically significant trend would imply climate change but could also imply human activity in the area that may have resulted in change in the run-off characteristics into the two streams.

Interpretation of the analyzed data was done separately, bearing in mind the possibility that one variable such as rainfall data, may have a statistically significant trend, while the other variable (streamflow data) showing no statistically significant trend. Results of Kendall's trend tests on mean monthly rainfall are shown in appendices 4.1 to 4.3 while Kendall's trend tests for mean annual rainfall are in appendices 4.4 to 4.6. With regard to discharge, mean monthly discharge trend tests are shown in appendices 4.7 to 4.9 while mean annual discharge in appendices 4.10 to 4.12. Results of discharge data analyzed between the years 1966-2006 are shown in appendices 4.13 to 4.15.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Introduction

The general sub-catchment under study and the relative positions of the six rainfall stations (Laare Coffee, Maua Divisional, Giaki Experimental Farm, Athiru Gaiti, Meru Teachers College and Meru technical Training College) are shown in Figure 4.1.

Figure 4.1: Relative positions of the six rainfall stations (Courtesy of Google Maps)

Raw data from the six stations was processed into comparative bar graphs. The graphs indicate that there was consistent data collection and recording between 1980-1990. From the year 1991, Maua Divisional and Athiru Gaiti Stations did not record any data while from 1992, Meru Technical and Giaki Experimental stations followed similar fate. This left only two stations, Meru Teachers' College and Laare Coffee that also stopped data collection by close of the year 1994. Figures 4.2 to 4.4 represent this.

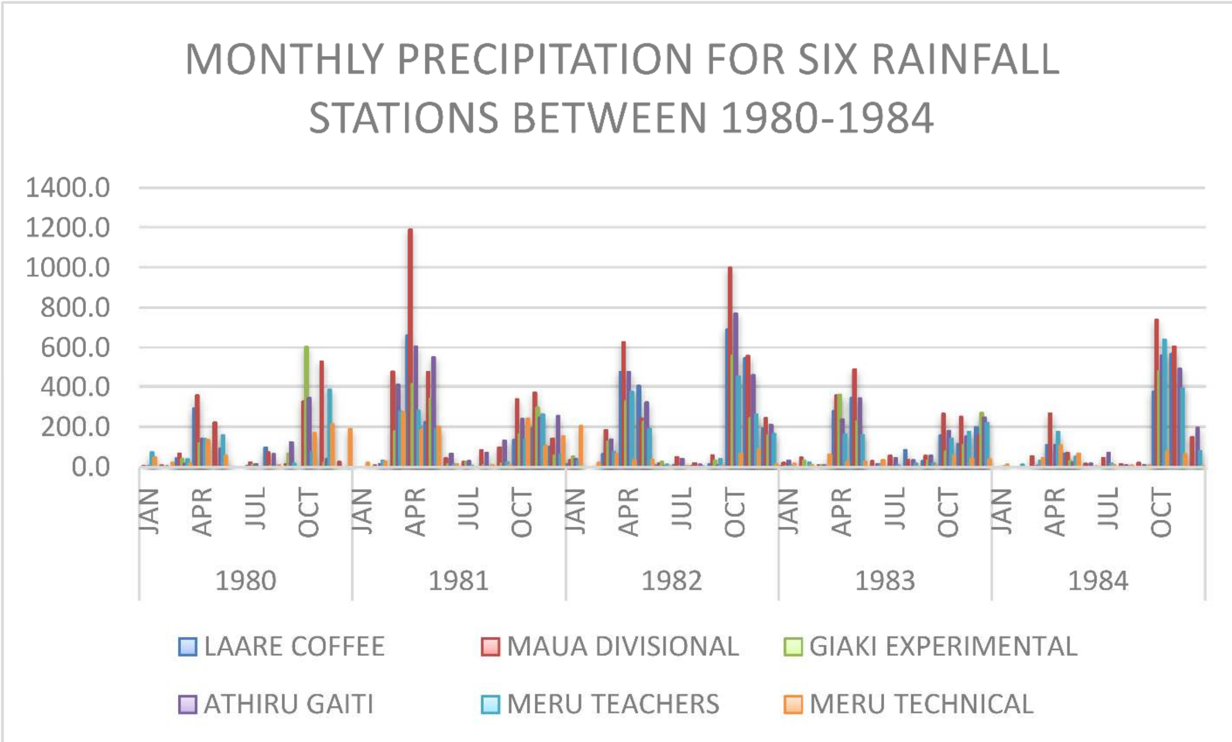


Figure 4.2: Comparative Bar Graphs for Rainfall Stations between 1980 – 1984

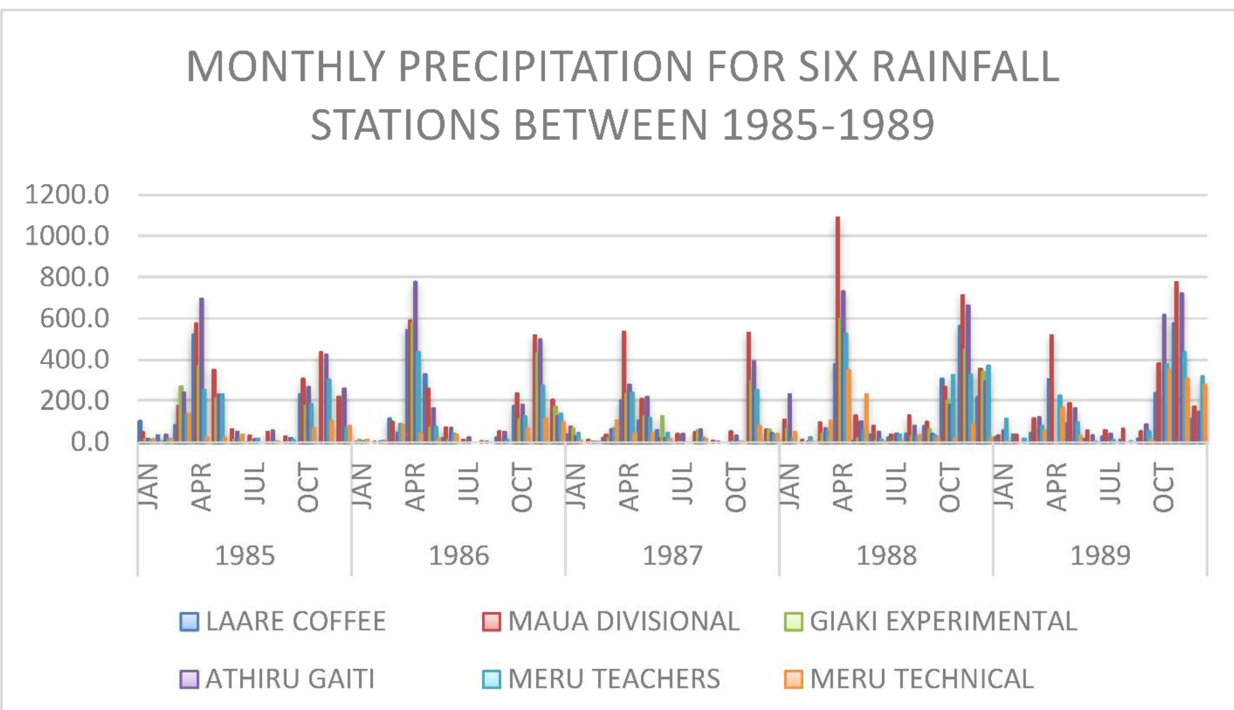


Figure 4.3: Comparative Bar Graphs for Rainfall Stations between 1985 – 1989

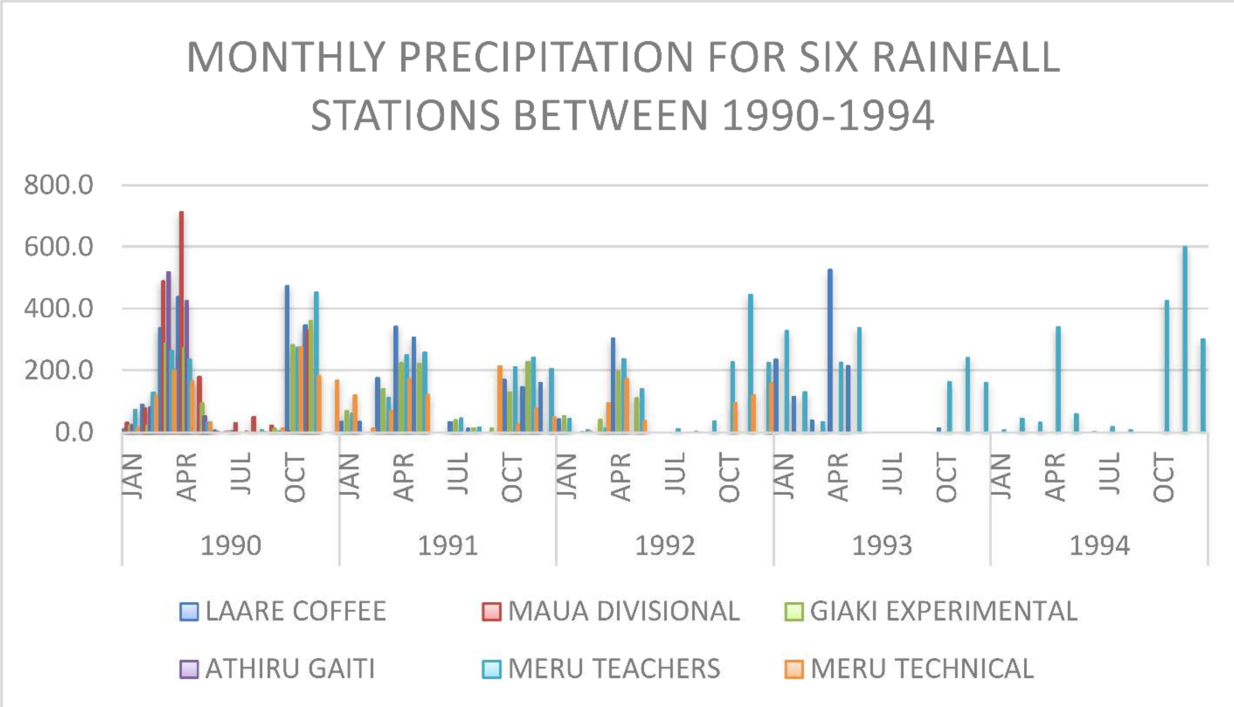


Figure 4.4: Comparative Bar Graphs for Rainfall Stations between 1990 – 1994

With regard to river discharge, there was consistent data collection for rivers Kathita and Mutonga from the years 1966 – 2006. Incidents of missing data were very few and accounted for less than 0.1%. Figures 4.5 to 4.9 show raw data for the two rivers.

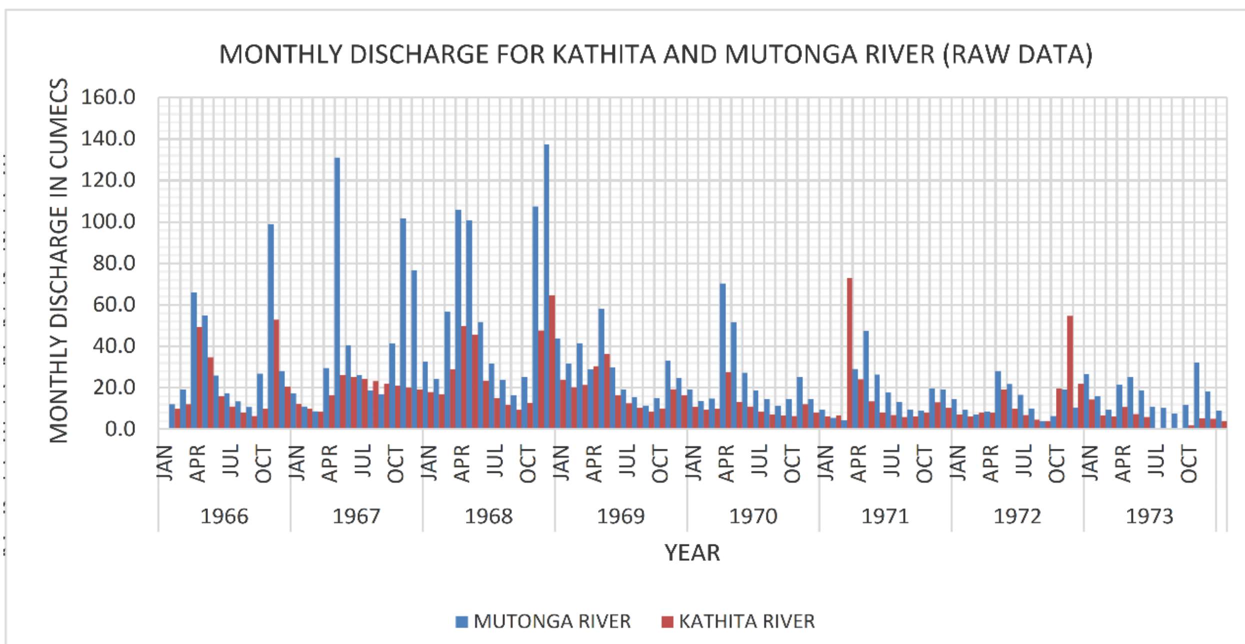


Figure 4.5: Comparative Discharge of Mutonga and Kathita river between 1966-1973

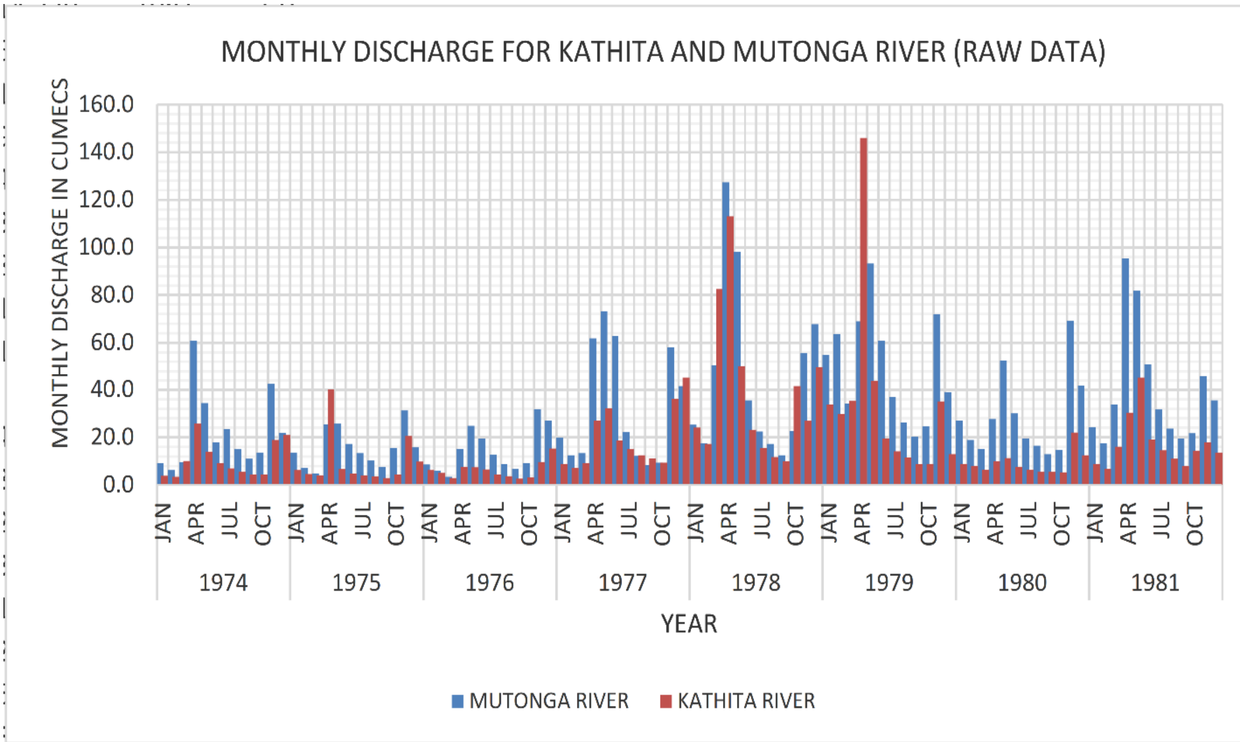


Figure 4.6: Comparative Discharge of Mutonga and Kathita river between 1974-1981

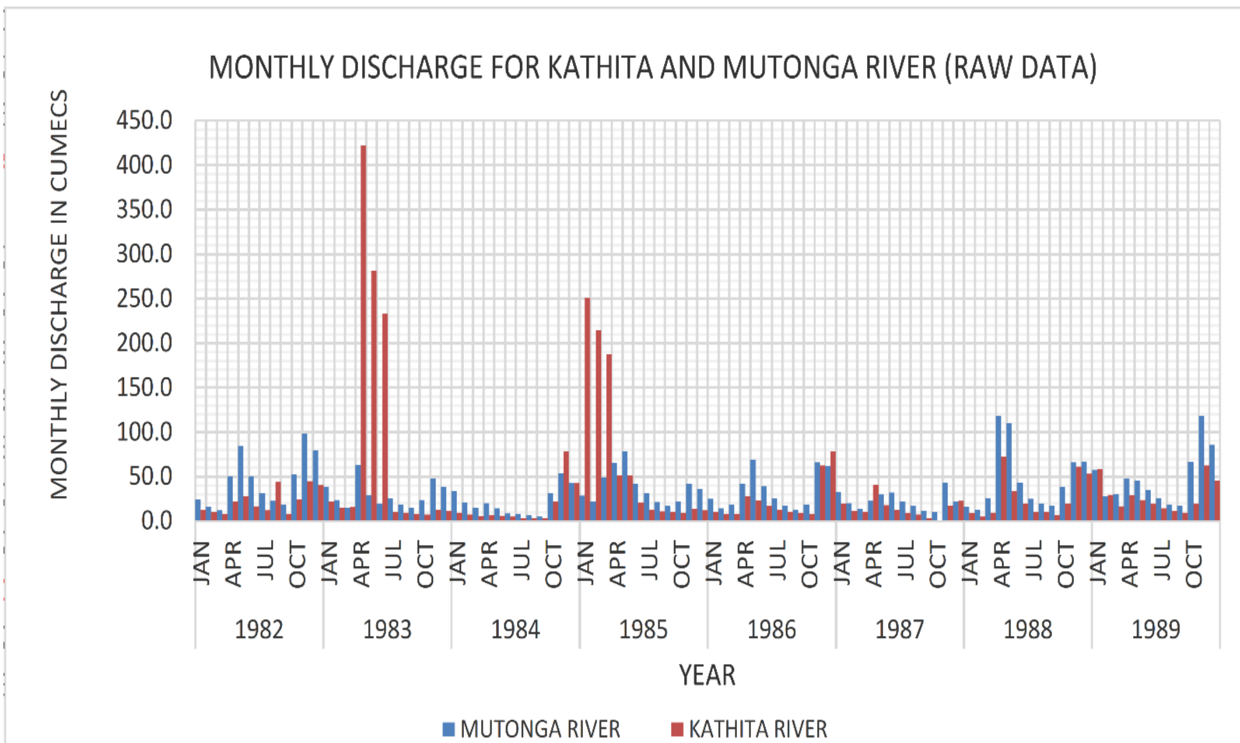


Figure 4.7: Comparative Discharge of Mutonga and Kathita river between 1982-1989

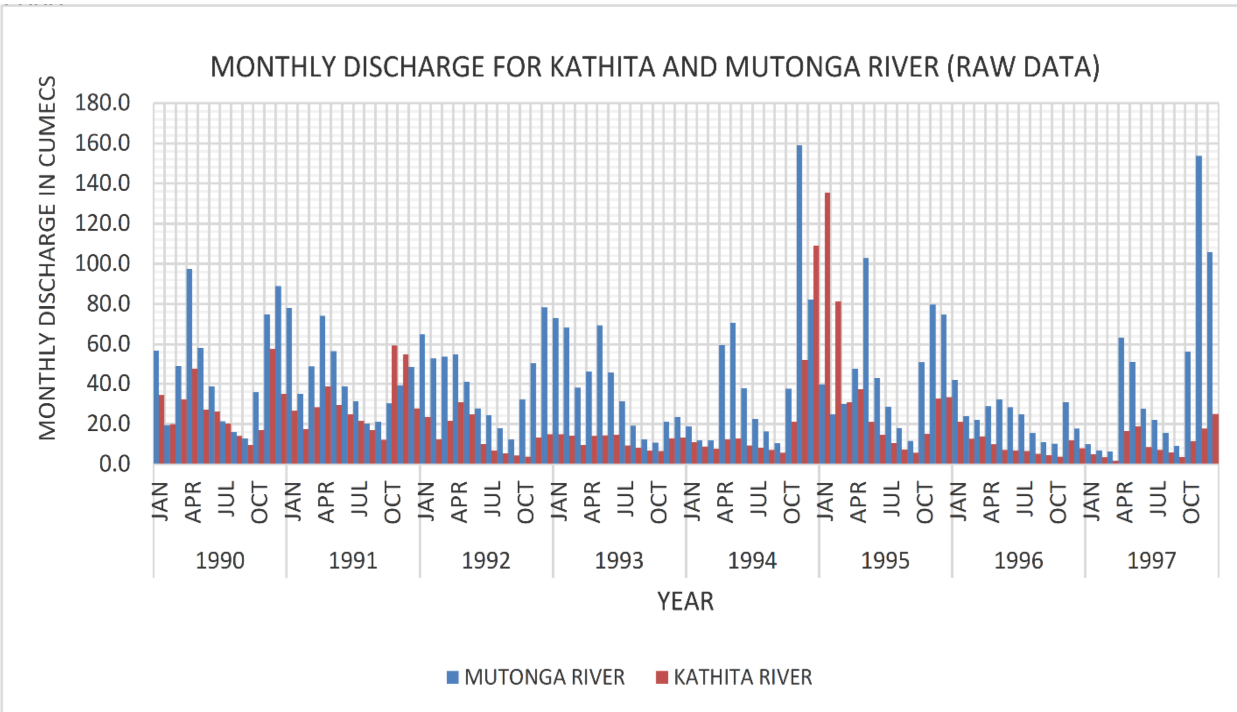


Figure 4.8: Comparative Discharge of Mutonga and Kathita river between 1990-1997

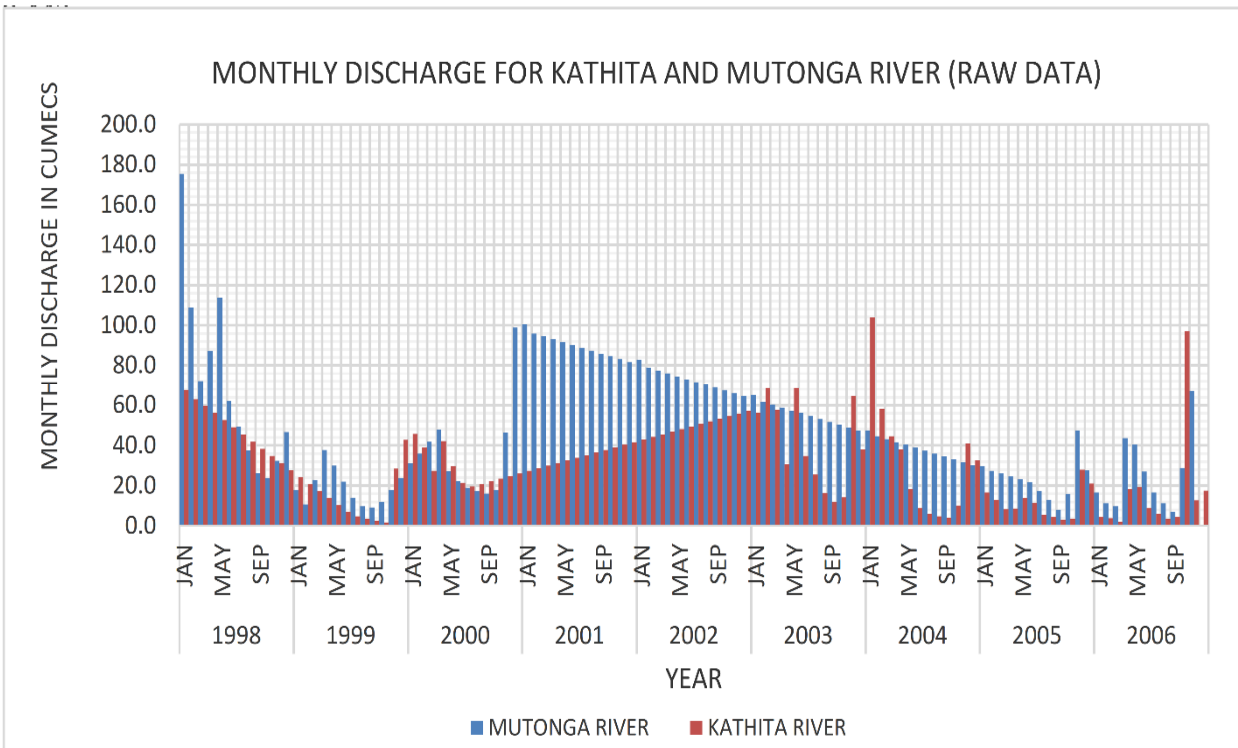


Figure 4.9: Comparative Discharge of Mutonga and Kathita river between 1998-2006

4.2 Descriptive Characteristics of Rainfall Data

Raw precipitation data was processed into mean monthly and mean annual data before being checked for statistically significant trend. Table 4.1 shows the processed data for mean monthly and mean annual rainfall

Table 4.1: Processed Mean Monthly and Mean Annual Precipitation data

	Mean Monthly Rainfall (mm)												Annual Average (mm)
	January	February	March	April	May	June	July	August	September	October	November	December	
1980	22.2	5.2	37.5	197.6	88.0	0.7	9.1	42.0	37.4	253.3	198.9	36.2	77.3
1981	3.3	13.8	270.8	556.6	331.4	25.1	14.3	29.1	46.9	209.9	246.8	129.8	156.5
1982	62.0	3.6	109.3	387.1	237.6	12.1	18.2	7.1	26.2	591.1	360.7	164.2	164.9
1983	14.4	18.6	15.5	238.0	265.8	15.2	19.0	29.3	33.4	147.2	141.3	189.1	93.9
1984	3.4	2.1	22.8	128.6	51.0	6.0	23.7	5.7	6.7	479.5	354.5	71.7	96.3
1985	34.9	17.8	173.2	407.2	175.2	28.5	11.2	19.2	10.1	205.9	211.3	104.4	116.6
1986	5.6	2.7	71.7	495.9	152.3	40.6	6.2	1.2	22.4	149.0	306.9	122.6	114.8
1987	43.1	4.0	52.3	255.7	136.5	46.7	13.4	34.2	1.9	14.3	258.8	40.2	75.1
1988	79.3	6.0	60.5	612.8	90.5	30.9	25.0	56.7	55.1	216.7	468.2	267.2	164.1
1989	38.3	15.2	69.3	202.6	94.7	18.1	22.8	13.5	36.0	328.2	470.2	171.4	123.4
1990	29.1	86.6	349.2	374.9	65.2	2.5	6.2	9.6	8.2	218.3	278.4	27.8	121.3
1991	70.5	11.7	123.5	246.8	227.0	0.0	29.5	10.3	56.5	134.1	173.4	103.4	98.9
1992	34.4	3.1	36.7	227.1	72.0	0.0	2.8	0.6	8.7	80.4	141.5	95.8	58.6
1993	281.	122.5	35.6	375.9	275.7	0.0	0.0	0.0	0.0	88.0	120.2	79.8	114.9
1994	6.7	44.6	31.5	340.0	58.9	1.5	17.0	7.1	0.0	425.4	599.0	301.0	152.7

Table 4.2 show some basic descriptive statistics concerning the data. It was observed that the minimum mean monthly rainfall was found to be zero (0) over the months of June, July August and September, while the maximum mean monthly rainfall was to be in the month of April (612.83 mm - long rains season) and November (599.00 mm – short rains season). With respect to the mean annual rainfall, the minimum, mean and maximum precipitation were found to be 27.85mm, 127.01mm and 301.00mm respectively. The standard deviation for the annual rainfall was 80.23mm. All these are based on 15 observations (1980-1994). A graphical plot of the mean Monthly rainfall is presented in Figures 4.10 and 4.11while the annual mean rainfall is shown in Figure 4.12.

Table 4.2: Descriptive Statistics for Mean Monthly Rainfall Data in the Sub-catchment

Statistic	January	February	March	April	May	June	July	August	Septe-mber	October	Nove-mber	December
Number of observations	15	15	15	15	15	15	15	15	15	15	15	15
Minimum	3.3	2.1	15.5	128.6	51.0	0.0	0.0	0.0	0.0	14.3	120.2	27.8
Maximum (mm)	281.0	122.5	349.2	612.3	331.4	46.7	29.5	56.7	56.5	591.1	599.0	301.0

Range	277.7	120.4	333.7	484.1	280.3	46.7	29.5	56.7	56.5	576.8	478.8	273.1
1st Quartile	10.5	3.8	36.1	232.6	80.0	1.1	7.7	6.4	7.5	140.6	186.1	75.7
Median	34.4	11.7	60.5	340.0	136.5	12.0	14.3	10.3	22.4	209.9	258.8	104.4
3rd Quartile	52.5	18.2	116.4	397.1	232.3	26.8	20.9	29.2	36.7	290.8	357.6	167.8
Mean	48.5	23.8	97.3	336.4	154.3	15.2	14.5	17.7	23.4	236.1	288.7	127.0
Standard deviation	68.7	35.1	97.3	140.7	91.8	15.8	8.6	16.9	19.9	158.9	139.7	80.2

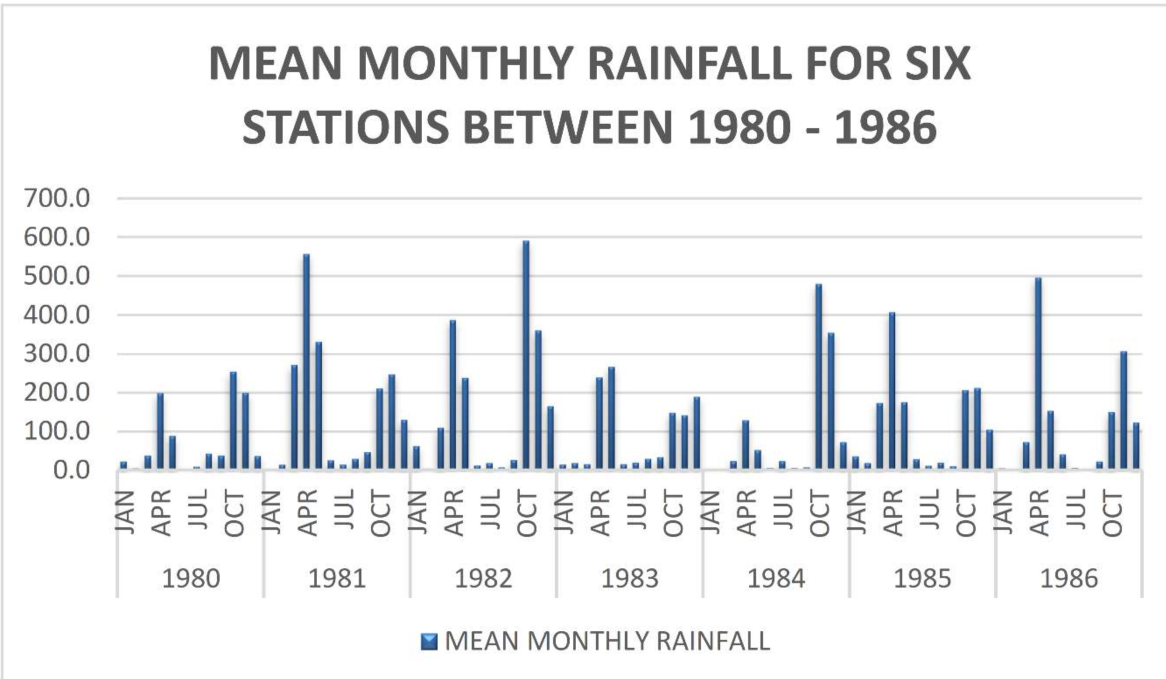


Figure 4.10: Mean Monthly Rainfall between 1980 - 1986

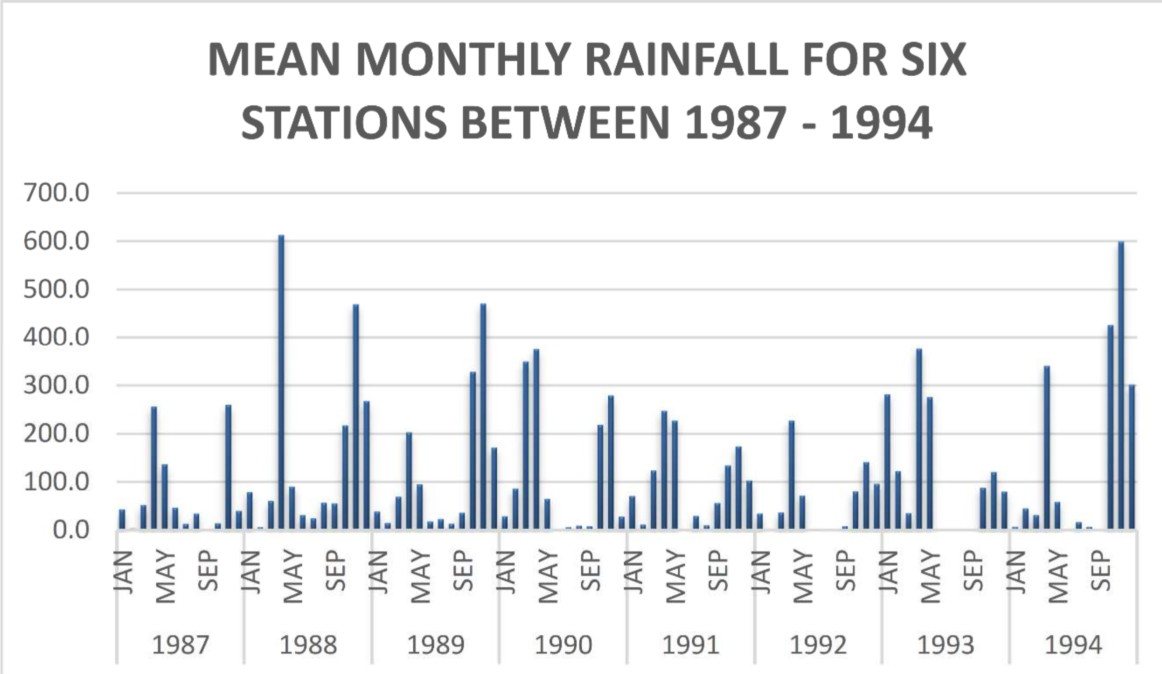


Figure 4.11: Mean Monthly Rainfall Between 1987 – 1994

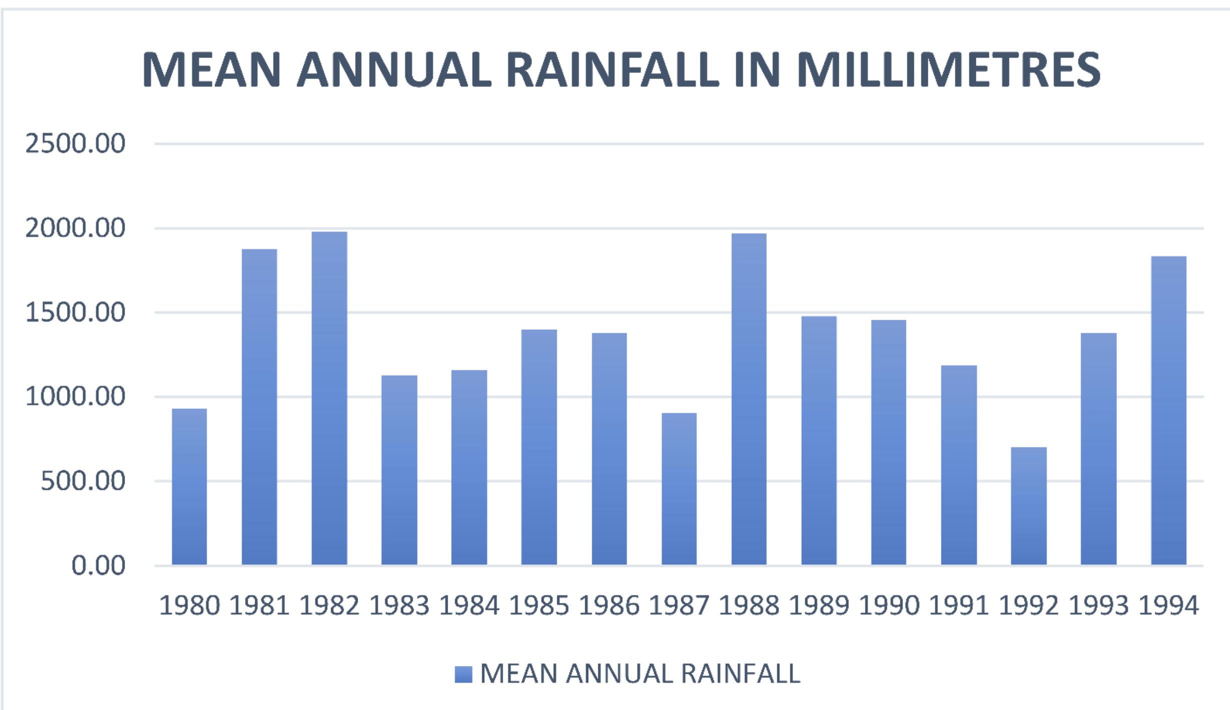


Figure 4.12: Mean Annual rainfall between 1980-1994

4.3 Trend detection in the Mean Monthly Rainfall

The mean rainfall data was processed using the Mann-Kendall tool to check for statistically significant trend. Each of the twelve months in a year were evaluated separately to take into account the seasonal variability of rainfall. Three different approaches were used for this purpose:

1) Trend detection at 95% confidence interval for tau=0 (two-tail test)
2) Trend detection at 95% confidence interval for tau>0 (upper bound-one tail test)
3) Trend detection at 95% confidence interval for tau<0 (lower bound-one tail test)

4.3.1 Mann-Kendall two-tail test for Mean Monthly Rainfall

A plot of the times-series mean rainfall for each of the twelve months was done. The average p-value for the data set was computed and the respective P-values for each month referenced against the average p-value to determine if any statistically significant trend existed. A sample of the time-series plot for the month of January is shown in Figure 4.13. The other time-series plots for each of the twelve months are shown in appendix 4.1. If the p-value of any of the twelve months were found to be below the cut-off p-value, then this would suggest the existence of a statistically significant trend in the monthly rainfall. However, the two-tailed test would only suggest the existence of a statistically significant trend but it would not tell whether the trend is an increasing or a decreasing trend in rainfall. The summary statistics for the Kendall's tau and p-values is shown in Table 4.3 and a graphical representation of the p-values in Figure 4.14.

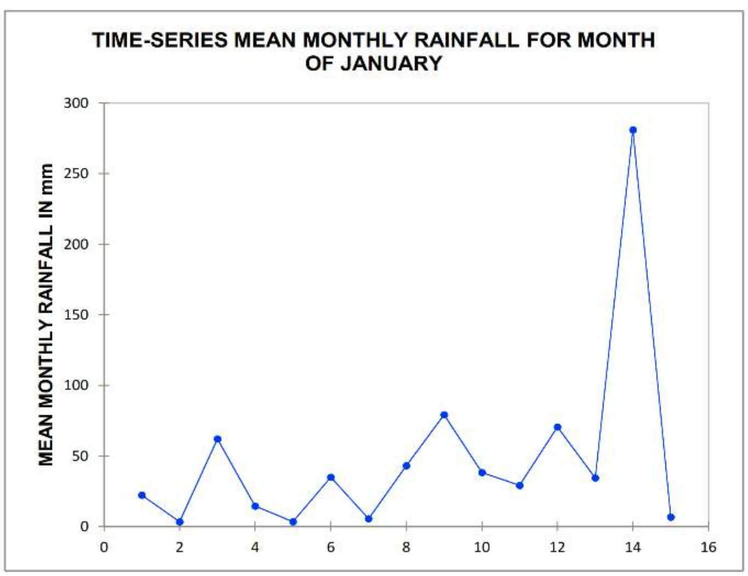


Figure 4.13: Time-series mean monthly rainfall – January

Table 4.3: Mann-Kendall's two-tall Summary

Series	Kendall's tau	p-value
January	0.276	0.169
February	0.276	0.169
March	-0.124	0.559
April	-0.010	1.000
May	-0.257	0.202
June	-0.251	0.196
July	-0.086	0.697
August	-0.390	**0.046**
September	-0.325	0.092
October	-0.219	0.282
November	0.029	0.923
December	0.029	0.923

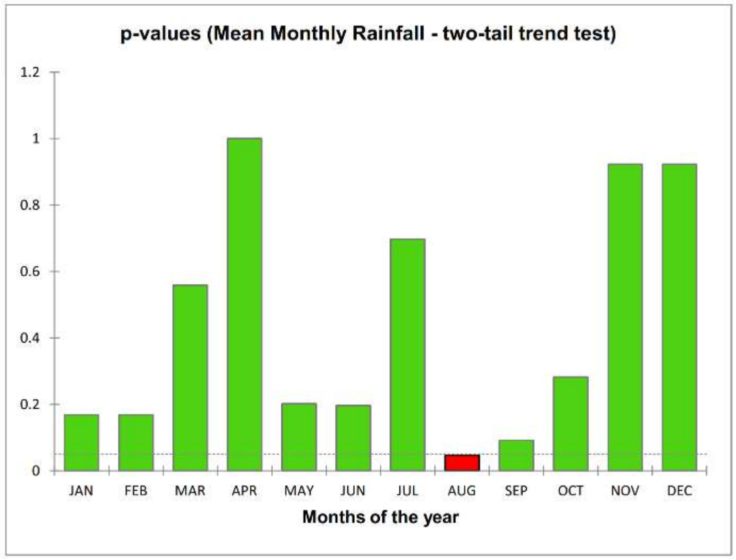


Figure 4.14: Plot of p-values (two-tail test)

4.3.2 Mann-Kendall one-tailed test for Mean Monthly Rainfall

From the two-tailed test, the existence of a statistically significant trend was detected in the month of August. To further enhance the sensitivity of the test, an upper-tailed and a lower-tailed trend test were conducted at the same significance level to check if the trend was a positive / increasing trend or negative / decreasing.

The mean monthly dataset was subjected to a seasonal Mann-Kendall upper-bound trend test and the respective monthly p-values checked against the threshold p-value. The summary statistics and plot are shown in Table 4.4 and Figure 4.15 respectively. If any p-value were to be found to be lower than the threshold, then that would confirm the existence of an increasing statistically significant trend in the mean monthly rainfall. The same operation was done to determine the existence of a decreasing statistically significant trend. Figure 4.16 and Table 4.5 give the p-values plot and the summary statistics for the lower-tailed trend test. Detailed results for each month can be found in appendices 4.2 and 4.3 for upper-bound and lower-bound trend tests respectively.

Table 4.4: Mann Kendall's Upper-tail summary

Series	Kendall's tau	p-value
January	0.276	0.084
February	0.276	0.084
March	-0.124	0.752
April	-0.010	0.539
May	-0.257	0.916
June	-0.251	0.902
July	-0.086	0.687
August	-0.390	0.982
September	-0.325	0.954
October	-0.219	0.880
November	0.029	0.461
December	0.029	0.461

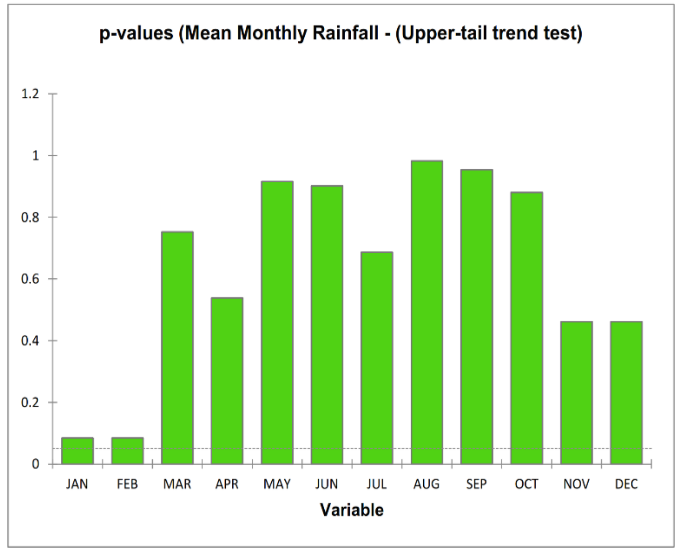


Figure 4.15: Plot of Mann-Kendall's Upper Bound p-values

Table 4.5: Mann Kendall's Lower-tail summary

Series	Kendall's tau	p-value
January	0.276	0.930
February	0.276	0.930
March	-0.124	0.279
April	-0.010	0.500
May	-0.257	0.101
June	-0.251	0.098
July	-0.086	0.349
August	-0.390	**0.023**
September	-0.325	**0.046**
October	-0.219	0.141
November	0.029	0.577
December	0.029	0.577

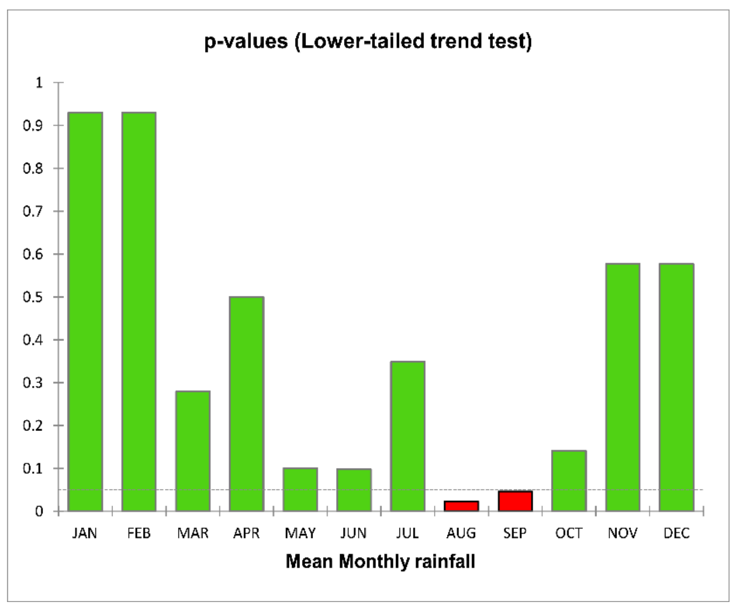


Figure 4.16: Mann-Kendall's Lower-tail plot of p-values

4.4 Trend detection in the Mean Annual Rainfall by Mann-Kendall Tool

A plot of the mean annual rainfall against time is shown in Figure 4.17. The overall mean of rainfall over the fourteen-year period was observed to be 1,383.8 millimetres. These summary statistics are found in Table 4.6.

Table 4.6: Summary Statistics - Mean Annual Rainfall

Variable	Minimum (mm)	Maximum (mm)	Mean (mm)	Std. deviation
Mean Annual Rainfall (mm)	703.5	1979.5	1383.8	398.0

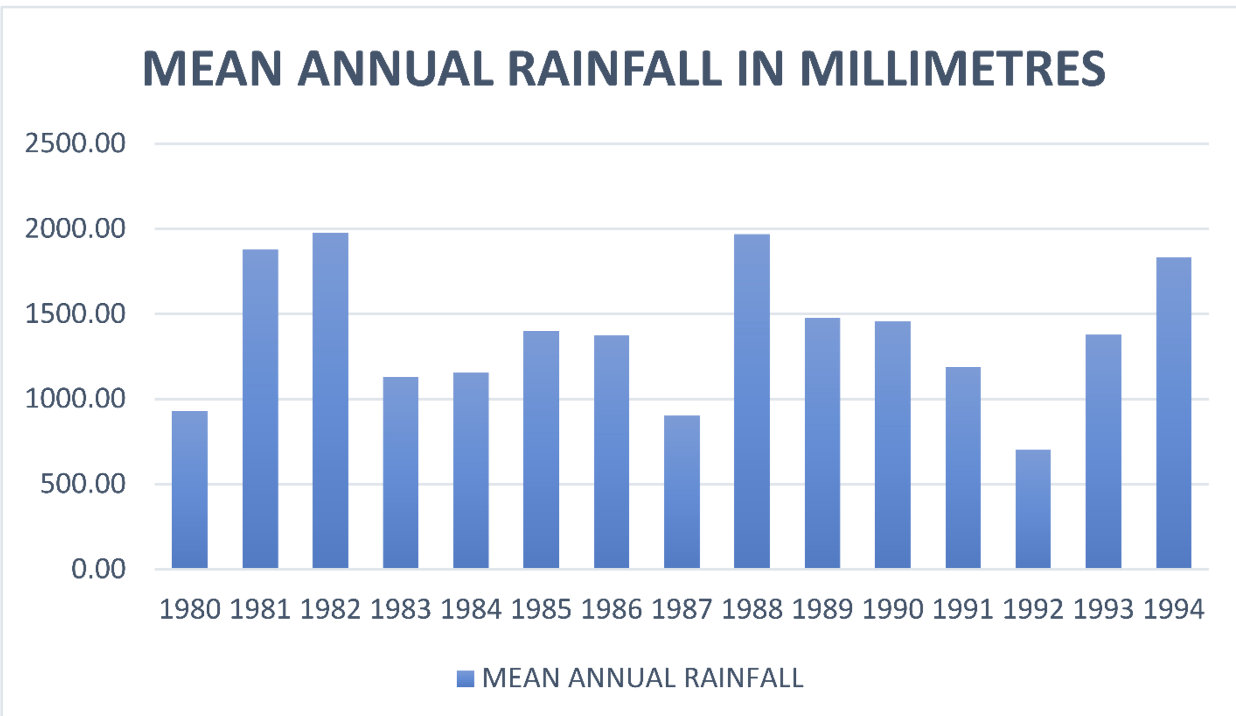


Figure 4.17: Mean Annual Rainfall between 1980 – 1994

Just like with the mean monthly rainfall, the mean annual rainfall was also subjected to analysis by the Mann-Kendall tool to check statistically significant trend. The two-tailed trend test was performed first, then followed by the one-tailed test as a confirmatory test. A sample time series plot is shown in figure 4.18 while the plot of p-values for the two-tailed test is shown in Figure 4.19. Detailed results can be found in appendix 4.4.

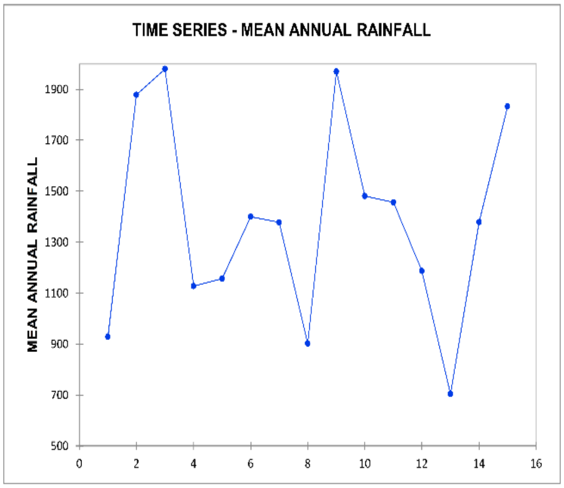


Figure 4.18: Plot of p-values for mean annual rainfall

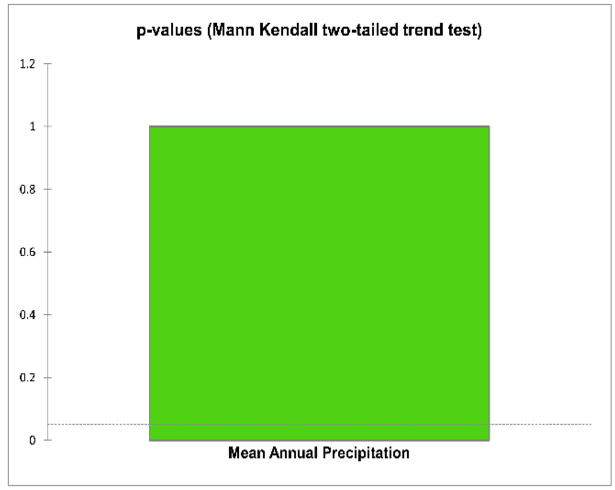


Figure 4.19: Time-series plot of mean annual rainfall

From the above, there was no statistically significant trend detected. To verify that no subtle statistically significant trend existed, a lower-tailed and upper-tailed test were also conducted. The resulting plots of p-values are found in Figures 4.20 and 4.21. The outcome of the plot suggested that no statistically significant trend exists in the mean annual precipitation. Detailed results can be found in appendices 4.5 and 4.6 respectively.

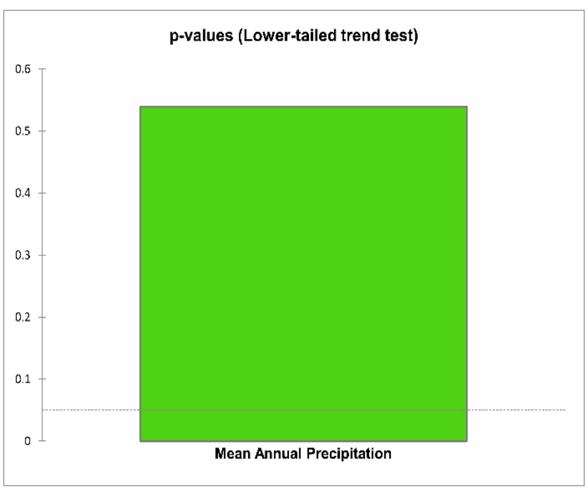


Figure 4.20 Plot of p-value for Lower-tailed trend test

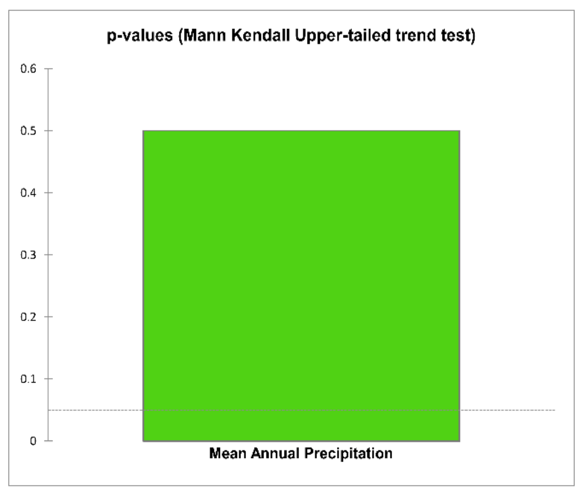


Figure 4.21: Plot of p-value for Upper-tailed trend test

4.5 Evaluation trend in discharge using Mann-Kendall tool

This study focussed on discharge between 1966-2006. The two rivers, Kathita and Mutonga drain the entire sub-catchment under consideration. Raw data from the two rivers was plotted next to each other for comparison purposes as shown in Figures 4.22 to 4.26. From these figures, it can be seen that Mutonga river has relatively higher mean monthly flow readings than Kathita, also Kathita displayed higher peaks in the years 1971, 1972, 1979, 1983, 1985, 1995 and 2004. A percular pattern of flow was recored between 1998 – 2005. In the said period, Kathita river assumes a nearly perfect straight-line decline in discharge between January 1998, reaching its lowest flow in October 1999, before starting a steady increase that peaks in April 2003. This pattern does not conform to the seasonal nature of flow in other months of previous years. There is an external factor that could have caused the sharp rise in flow in January 1998 (attributed to the 1997 El-Nino rains) but this does not adequately explain the steady rise observed from mid-2000.

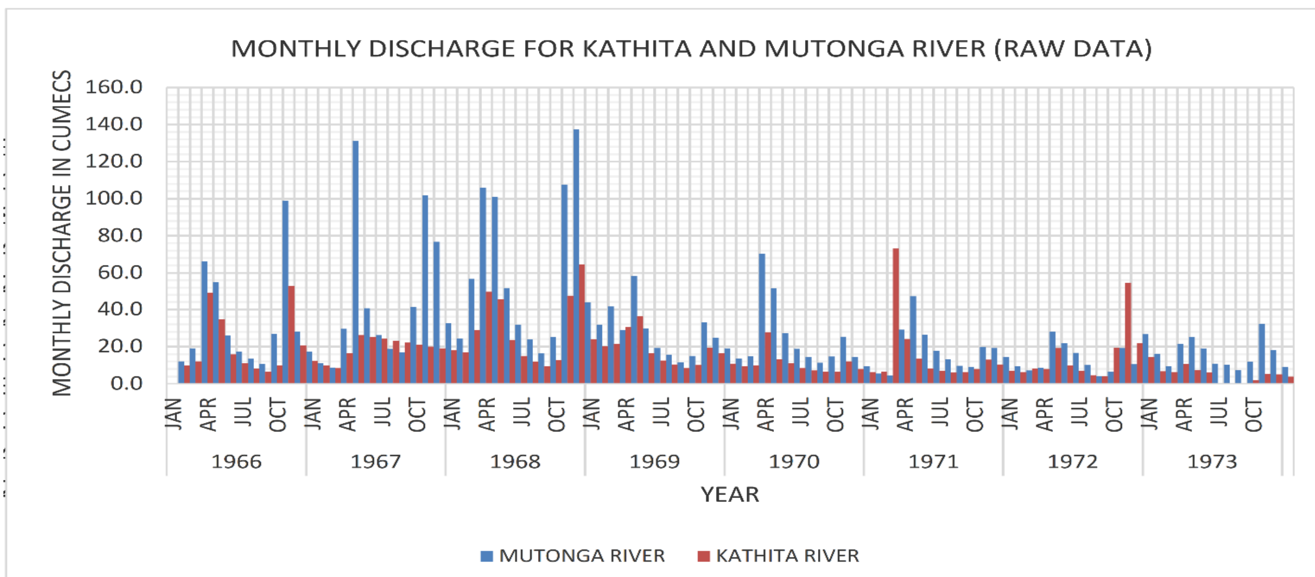


Figure 4.22: Mean monthly flow 1966-1973

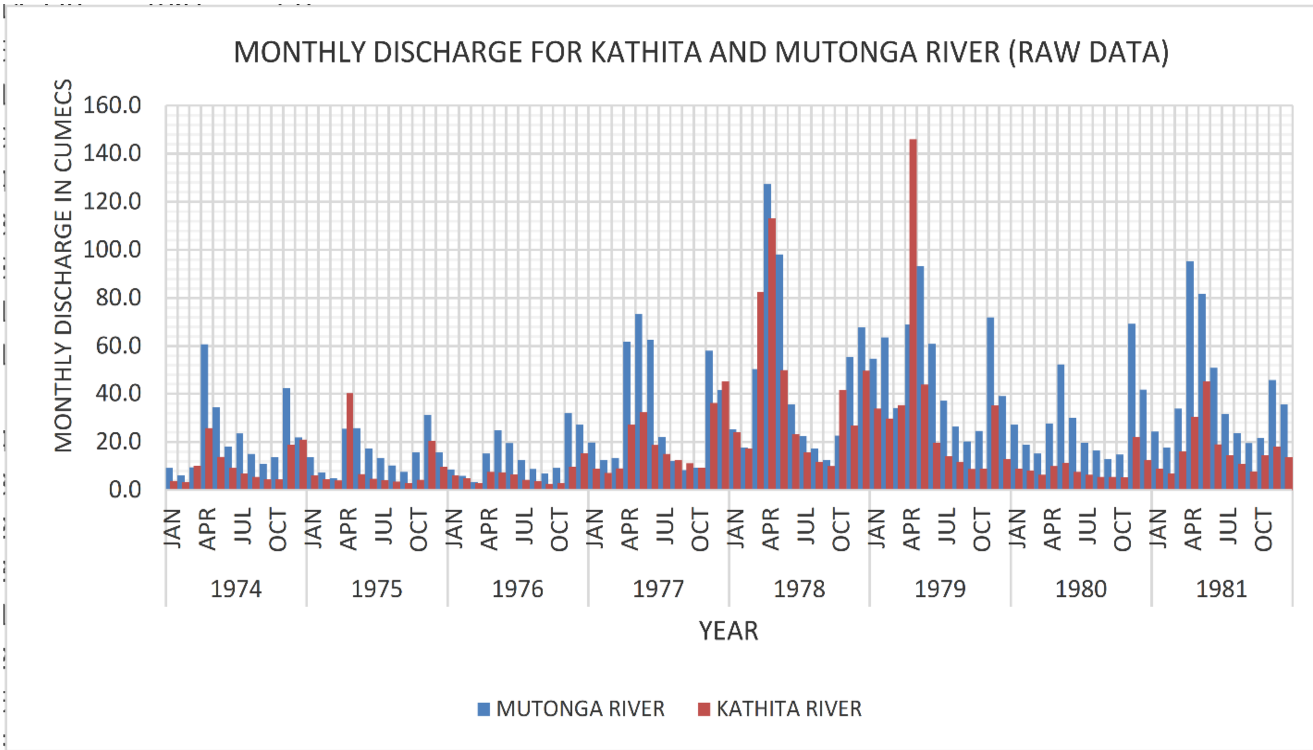


Figure 4.23: Mean monthly flow 1974-1981

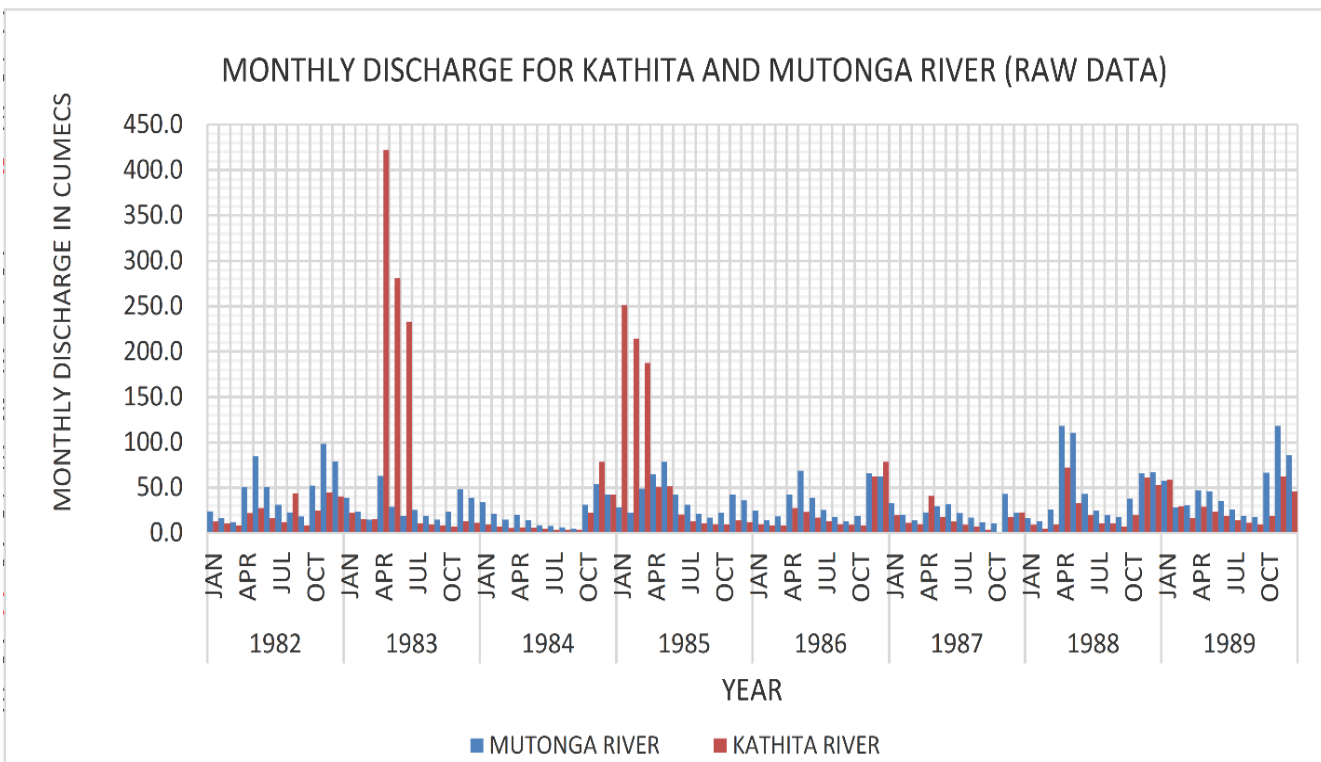


Figure 4.24: Mean monthly flow 1982-1989

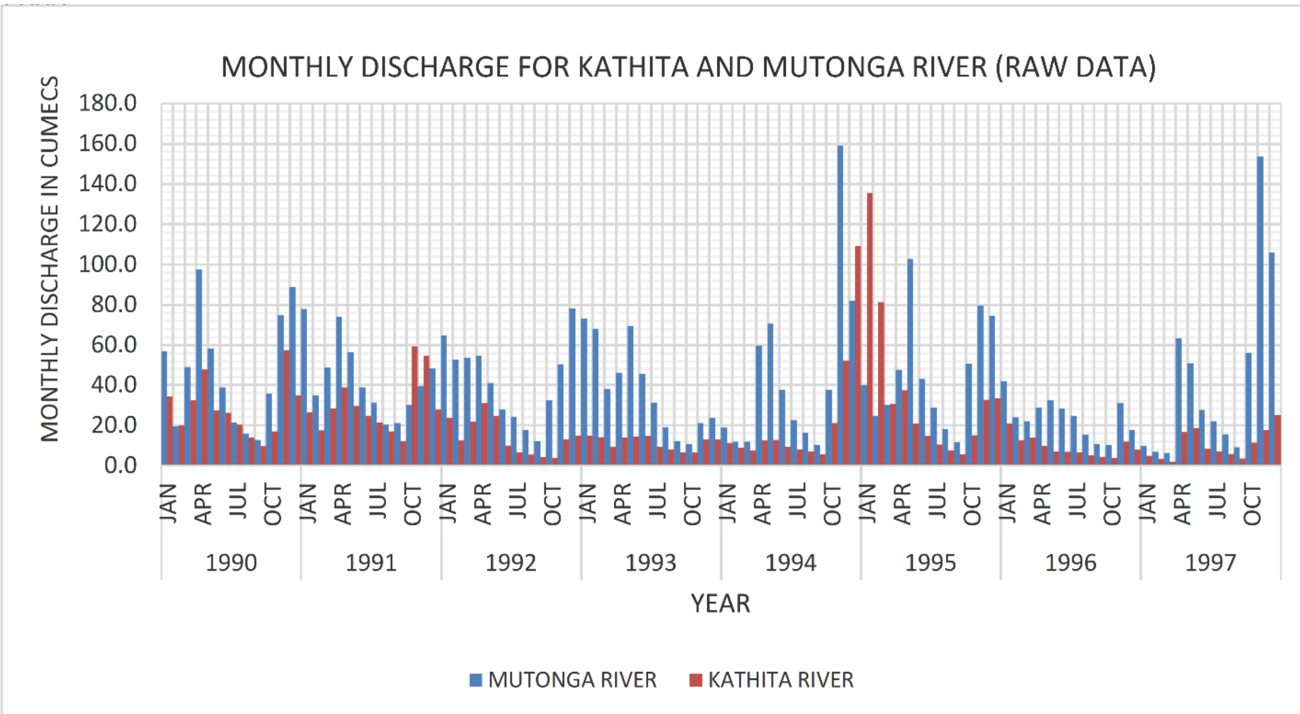


Figure 4.25: Mean monthly discharge (1990-1997)

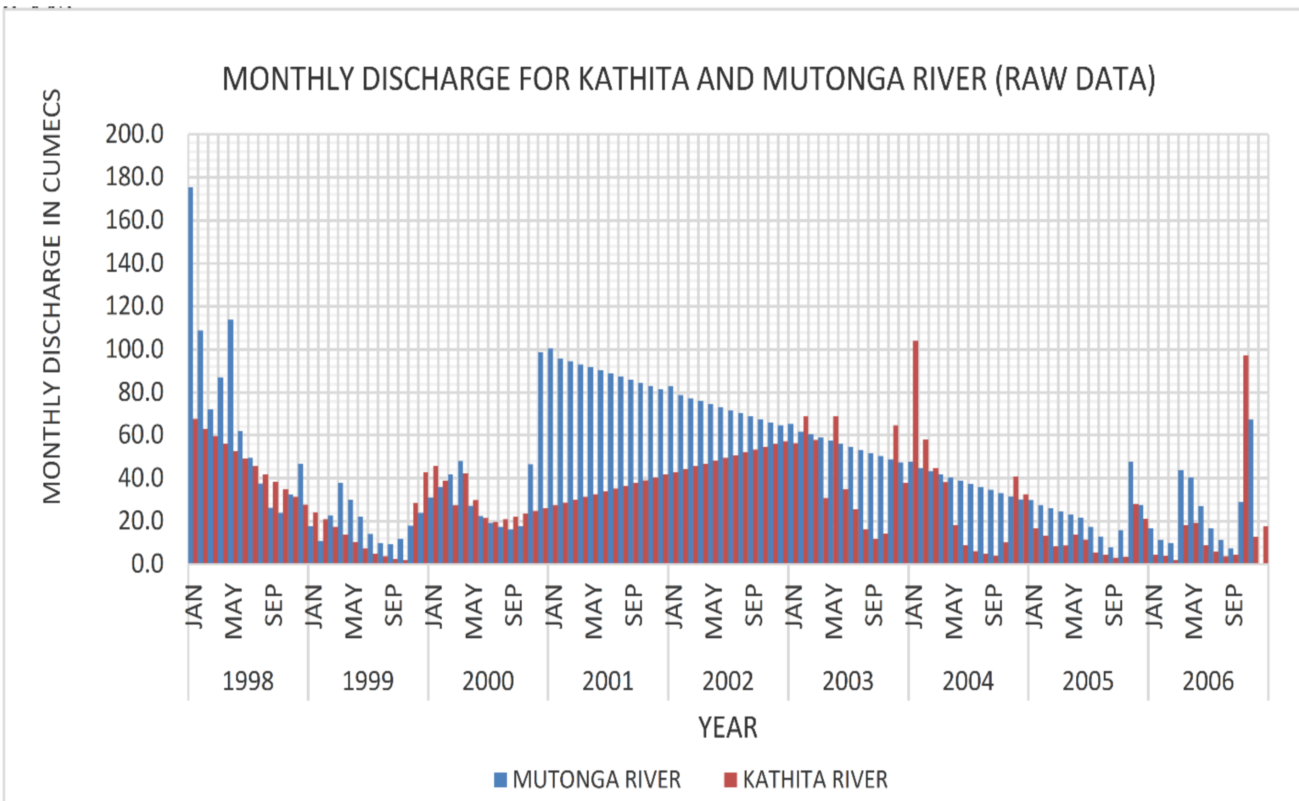


Figure 4.26: Mean monthly flow (1998-2006)

Further, as readings in Kathita river are steadily rising from the year 2000, reading of Mutonga river (which drains the same sub-catchment) begin with a peak flow that declines up to the year 2005. The root-cause of this phenomenon would be an interesting area of study to determine if a man-made intervention could have been responsible for this. A natural phenomenon is an unlikely cause of this.

From the data collected from these two rivers, an aggregate plot was made incorporating the two mean flows. Figures 4.27 to 4.31 show plots of mean monthly flows. The aggregated mean-flow data assumes a seasonal variation with the exception of the years 2001-2003 where flow is observed to be nearly steady for over thirty (30) months. Again, this is unusual but data gotten from WRA was re-checked for errors in processing and it was confirmed that processed data was in conformity with raw data collected.

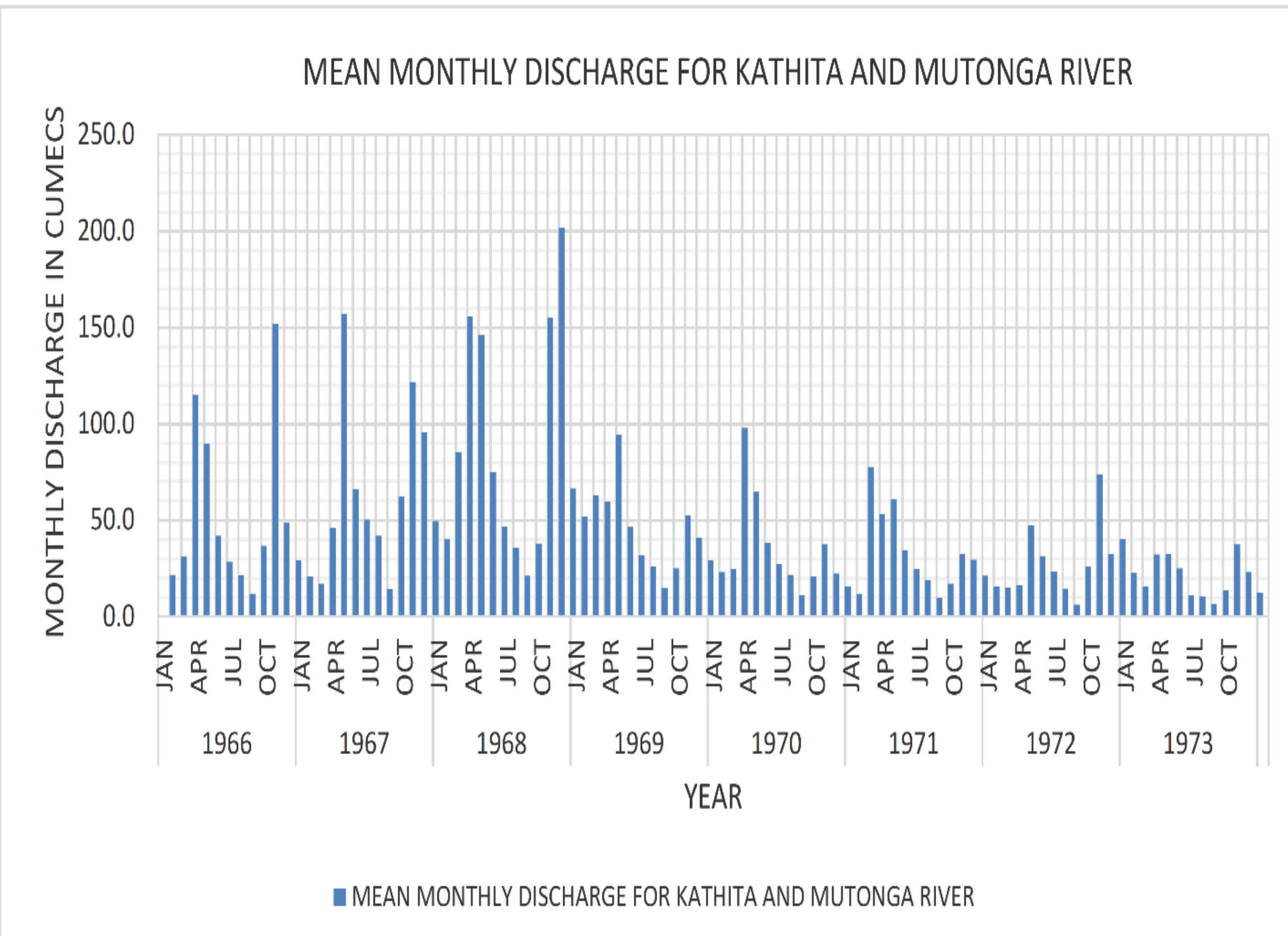


Figure 4.27: Mean aggregated flow (1966-1973)

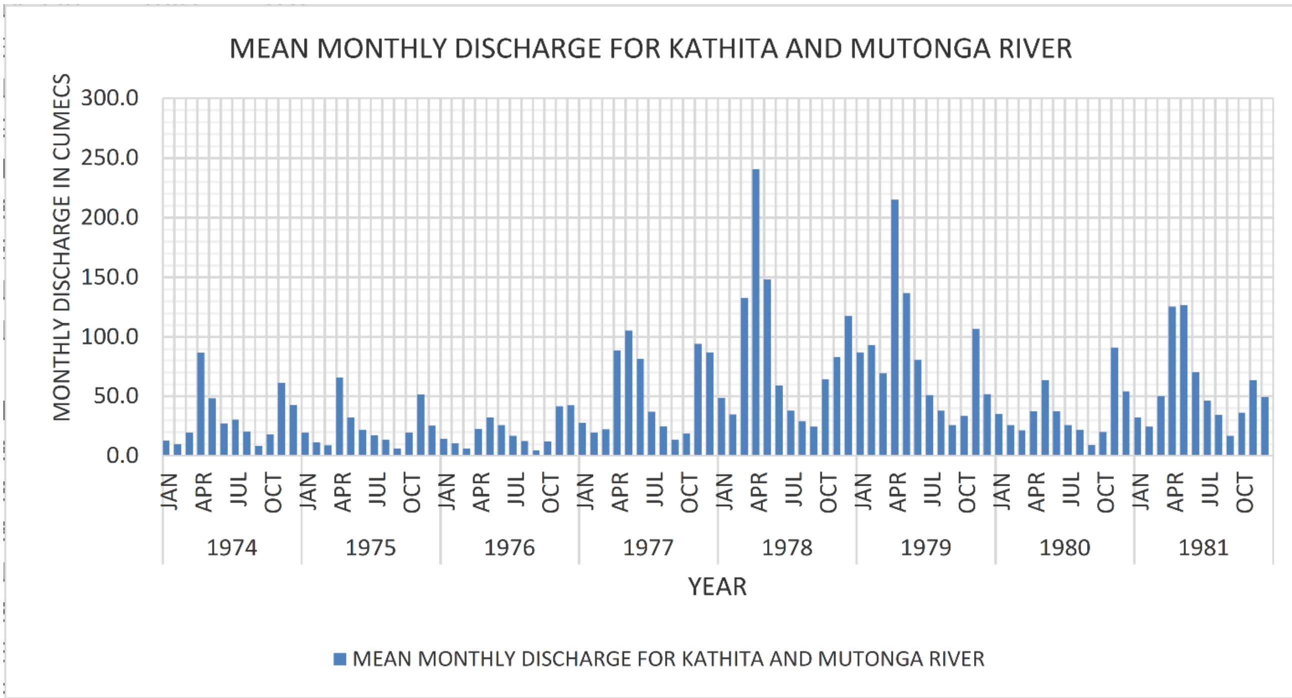


Figure 4.28: Mean aggregated flow (1974-1981)

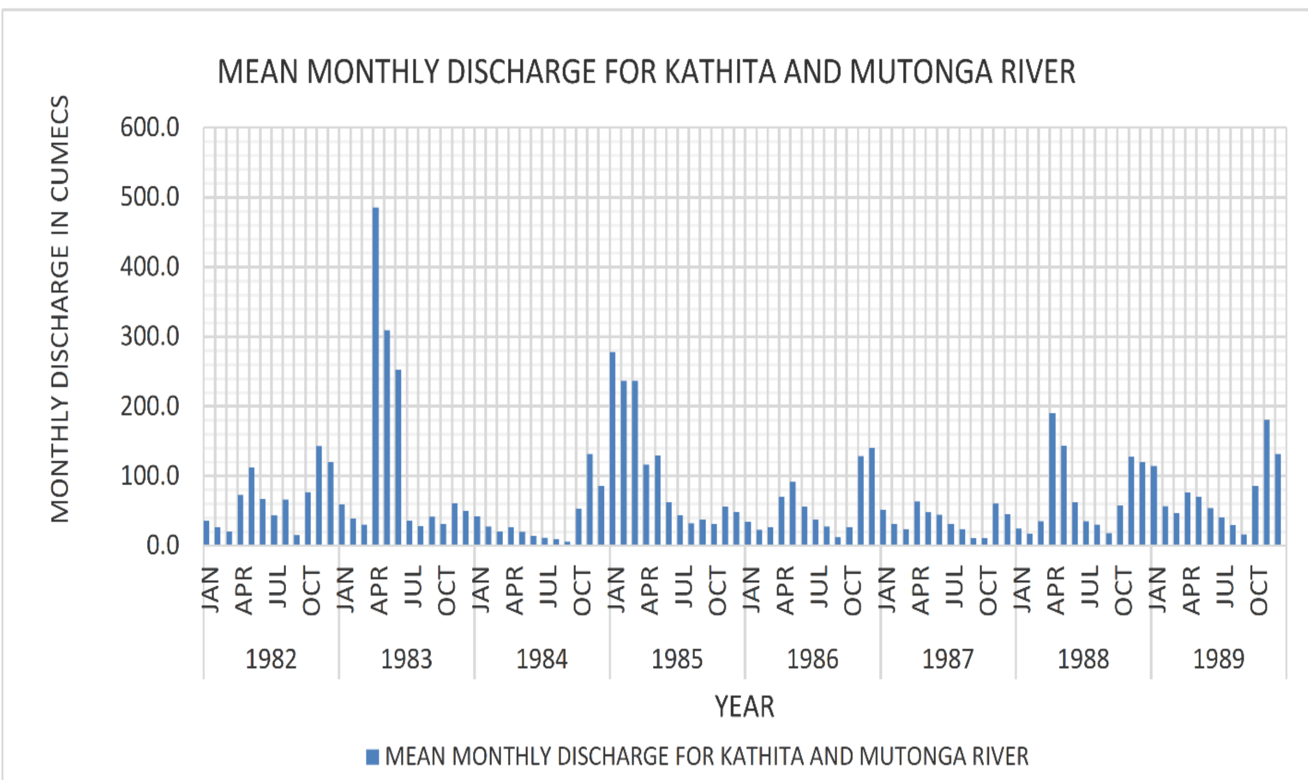


Figure 4.29: Mean aggregated flow (1982- 1989)

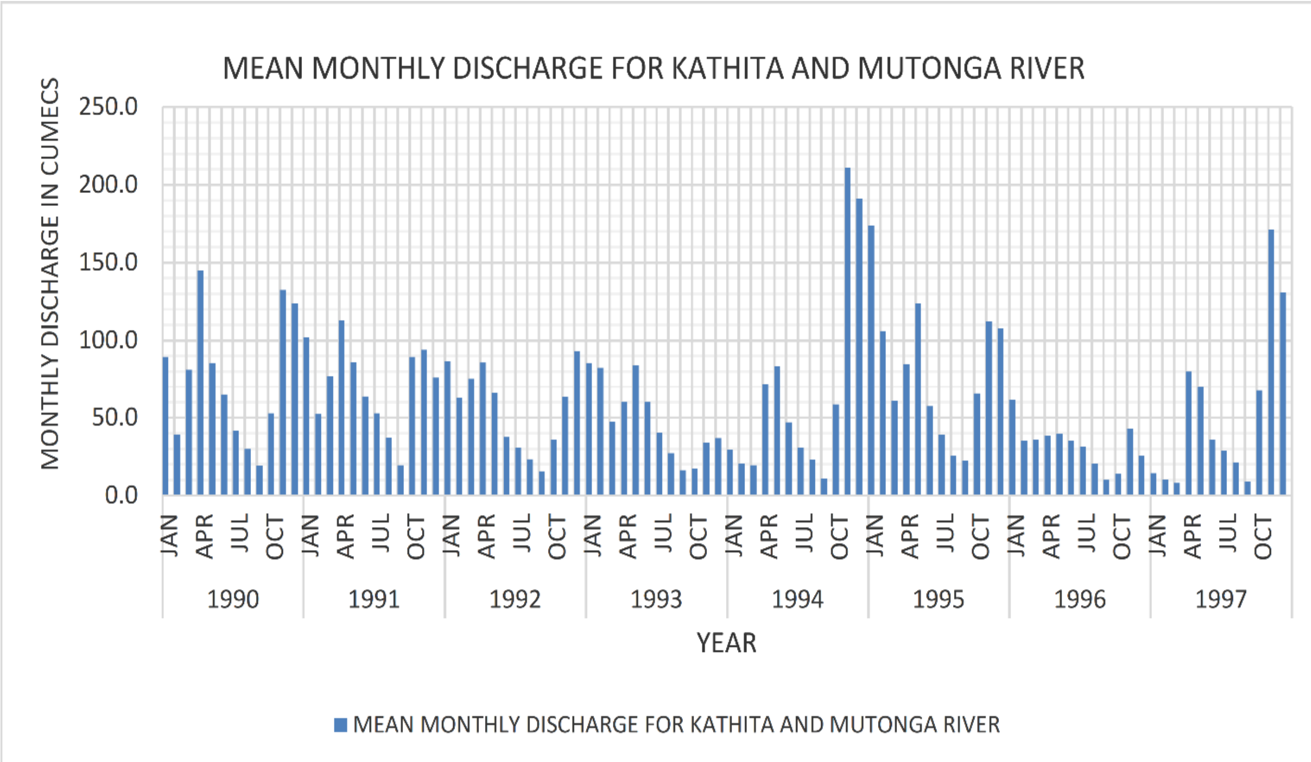


Figure4.30: Mean aggregated flow (1990-1997)

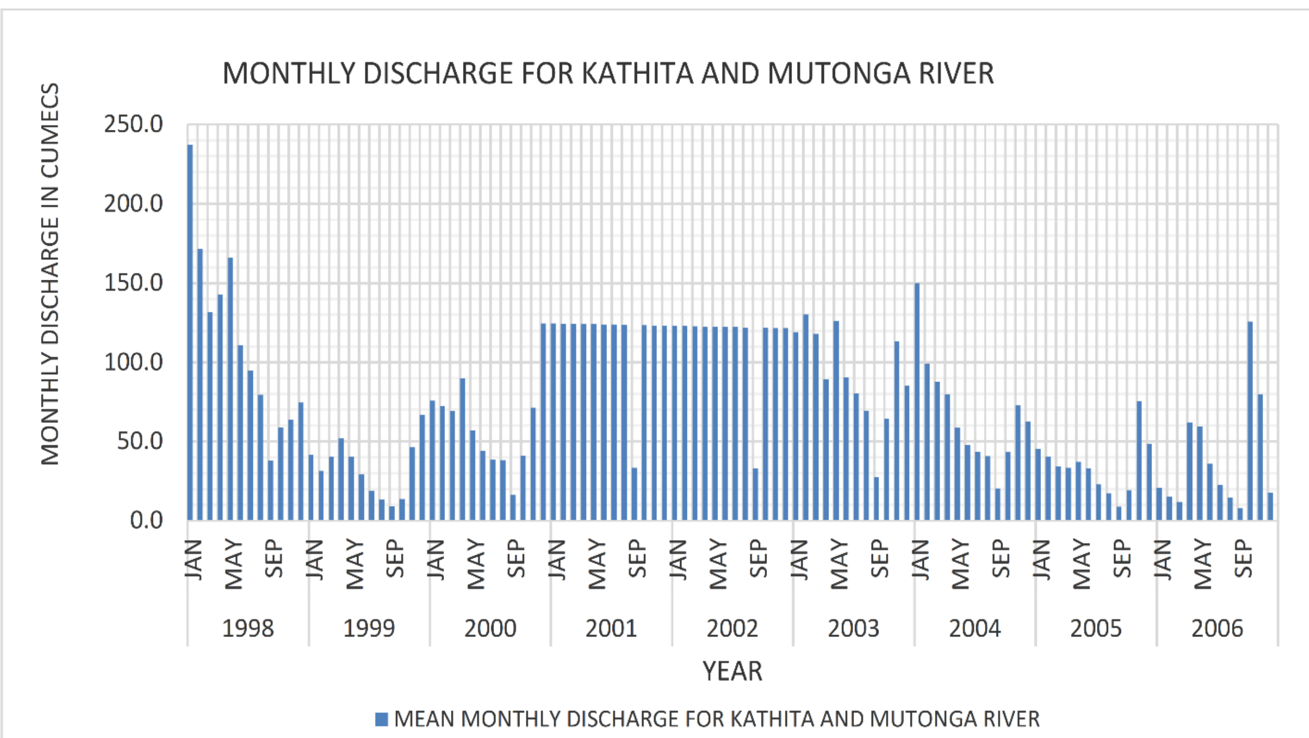


Figure 4.31: Mean aggregated flow (1998-2006)

A comparison of the average flow in each respective month was plotted. Figure 4.32 shows that peak flow occurs in the months of April and May, coinciding with the long-rains. The flow then declines gradually to reach the lowest ebb in October before rising again in November (in tandem with the short rains).

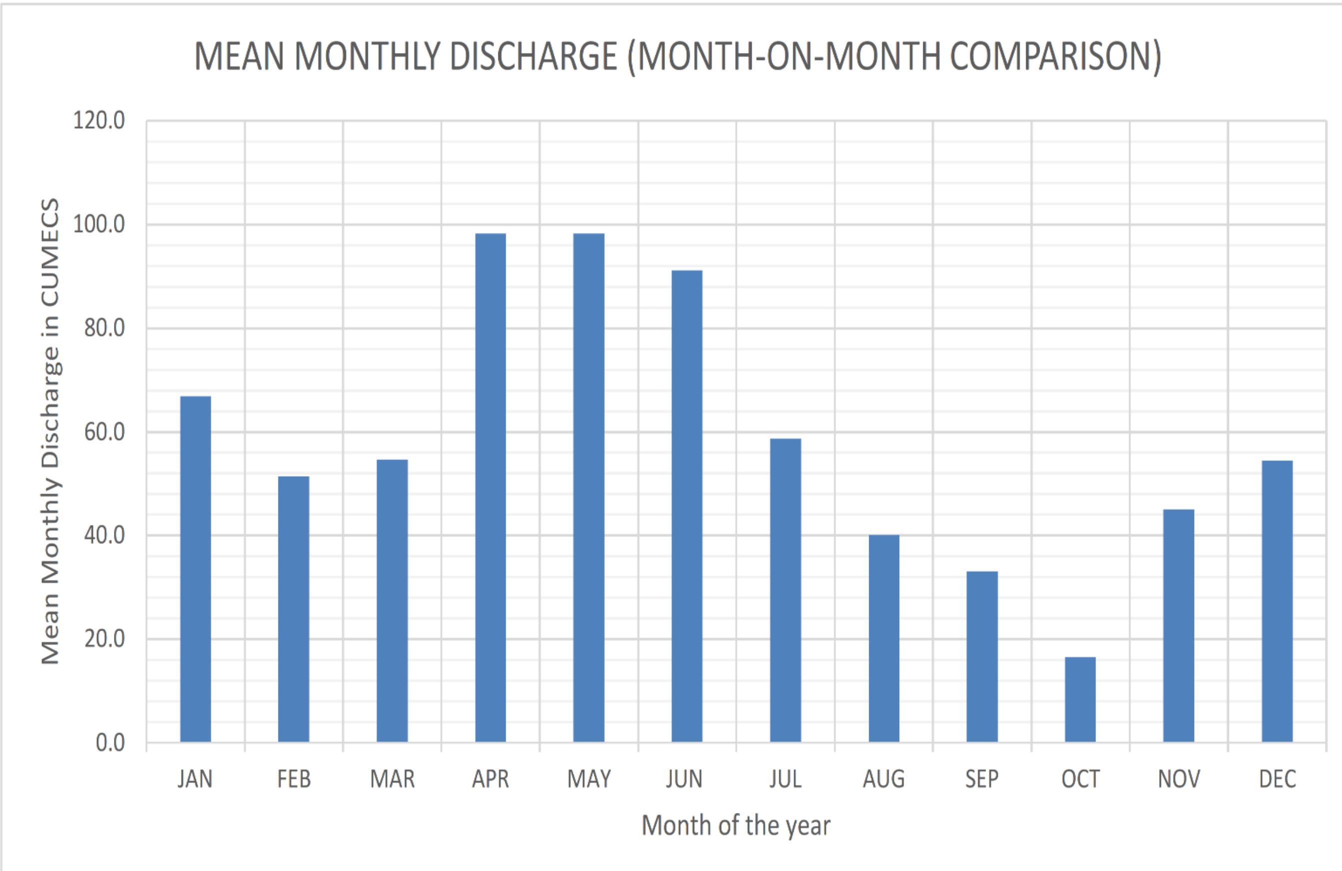


Figure 4.32: Month-on-month comparison of mean flow

Among the characteristics that can be deduced about the river-flow in the catchment is that the highest value of mean flow is slightly below 100 cumecs while base flow is at eighteen (18) cumecs in October. These values do not represent the maximas and minimas. A separate study could be conducted on these extreme discharge values.

4.5.1 Mann-Kendall two-tail test for Mean Monthly Discharge

The mean monthly discharge was evaluated using Mann-Kendall two-tailed trend test. A time-series graph was generated for each month of the year. Figure 4.33 shows a sample time series plot for mean monthly discharge for the month of January. Detailed time-series plots for other months are found in Appendix 4.7.

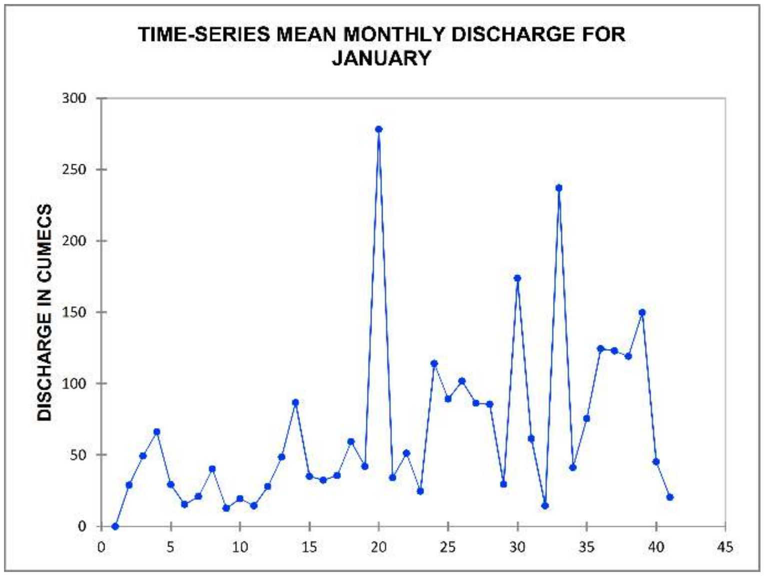


Figure 4.33: Time-series mean monthly discharge for January

A summary of the Mann-Kendall's two-tailed trend test is shown in Table 4.7 alongside the plot of p-values in Figure 4.34. The results suggest that there is a statistically significant trend in the mean monthly discharge in the months of January, February and November. Also noted was that the month of March was near the cut-off line. However, it was not immediately clear whether the trends detected were statistically significant positive or negative. A one-tailed trend test was needed to confirm this.

Table 4.7: Mann Kendall–
Two-tailed trend test

Two-tailed test		
Series	Kendall's tau	p-value
January	0.366	**0.001**
February	0.359	**0.001**
March	0.202	0.064
April	0.029	0.798
May	0.029	0.798
June	-0.068	0.539
July	0.059	0.600
August	0.154	0.161
September	0.149	0.175
October	0.149	0.175
November	0.266	**0.014**
December	0.149	0.175

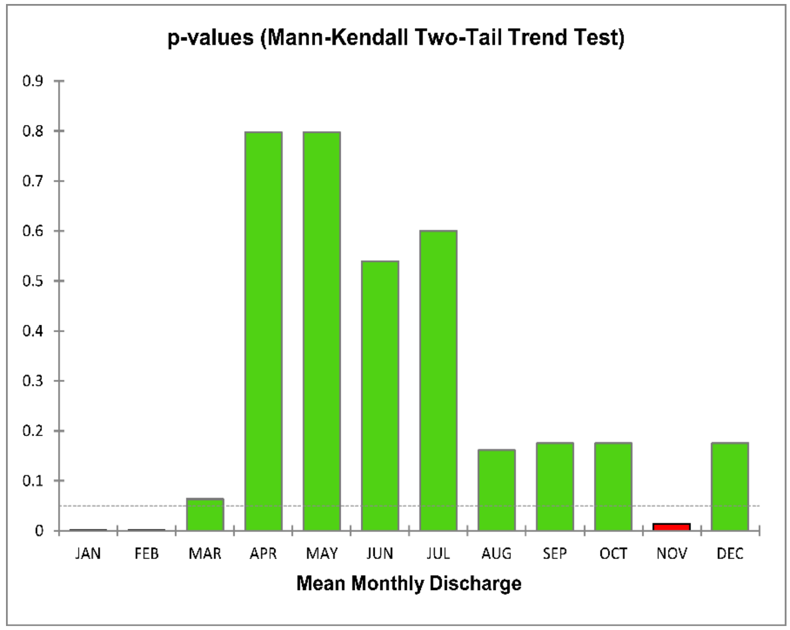


Figure 4.34: Mean monthly discharge Two-tailed trend test

4.5.2 Mann-Kendall One-tailed test on Mean Monthly Discharge

The results of this test are shown in Tables 4.8 and 4.9 and Figures 4.35 and 4.36.

Table 4.8: Summary-
upper-tailed trend test

Upper-tailed test		
Series	Kendall's tau	p-value
January	0.366	**0.000**
February	0.359	**0.000**
March	0.202	**0.032**
April	0.029	0.399
May	0.029	0.399
June	-0.068	0.738
July	0.059	0.300
August	0.154	0.081
September	0.149	0.088
October	0.149	0.088
November	0.266	**0.007**
December	0.149	0.088

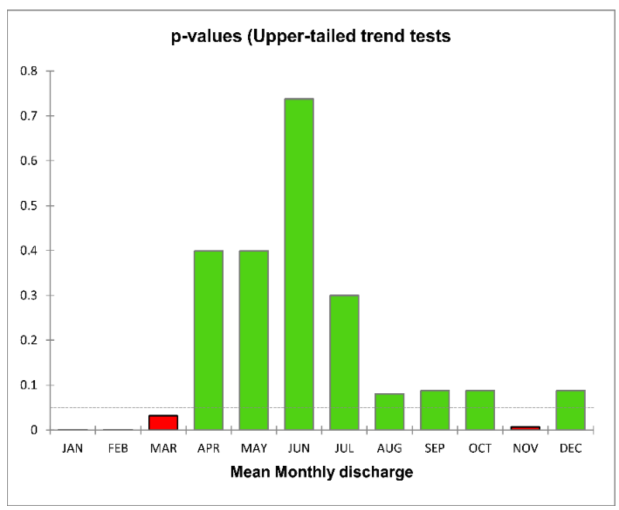


Figure 4.35: Mean monthly discharge (upper-bound trend test)

Table 4.9: Summary-
upper-tailed trend test

Lower-tailed test		
Series	Kendall's tau	p-value
January	0.366	1.000
February	0.359	1.000
March	0.202	0.970
April	0.029	0.610
May	0.029	0.610
June	-0.068	0.270
July	0.059	0.708
August	0.154	0.923
September	0.149	0.916
October	0.149	0.916
November	0.266	0.993
December	0.149	0.916

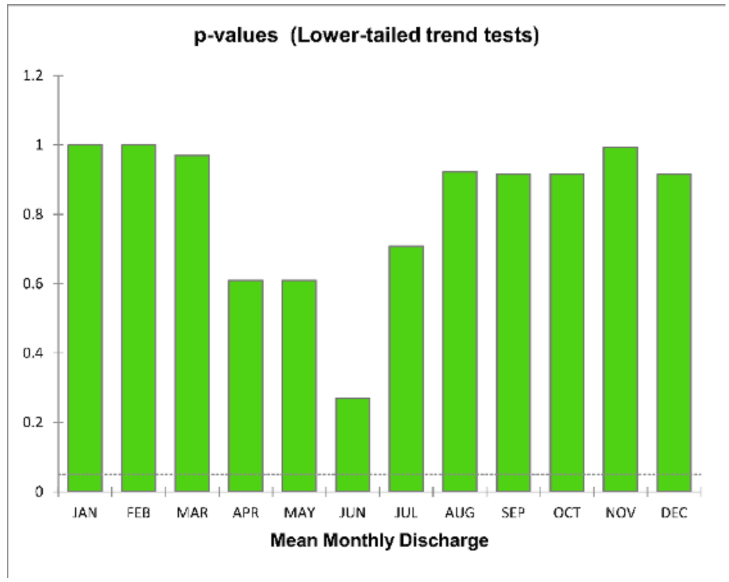


Figure 4.36: Mean monthly discharge lower-bound trend test

The results confirmed that there was a statistically significant increase in the men monthly discharge of the Mutonga and Kathita rivers. Detailed results can be found in appendices 4.8 and 4.9 for upper-bound and lower-bound tests respectively.

4.6 Evaluation of the Mean Annual Discharge using the Mann-Kendall tool

A plot of the mean annual discharge over the period 1966-2006 is shown in Figure 4.37. The lowest mean annual discharge was found to be in the year 1976 at 16.3m^3/s while the highest recording was in1983 at 162.0m^3/s. The mean for the period was 56.1m^3/s with a standard deviation on 32.0m^3/s as summarized in Table 4.10. During the 1997 – 1998 El-Nino rains, the mean annual discharge recorded was just slightly above 120m^3/s. This is comparable with the mean annual discharge recorded in the years 1983 and 1985. Further, the year 2001 and 2002 were relatively high compared with other years. These two years in particular will be looked into under sub-heading 4.7 of this report to investigate their effect on the Mann-Kendall trend tests.

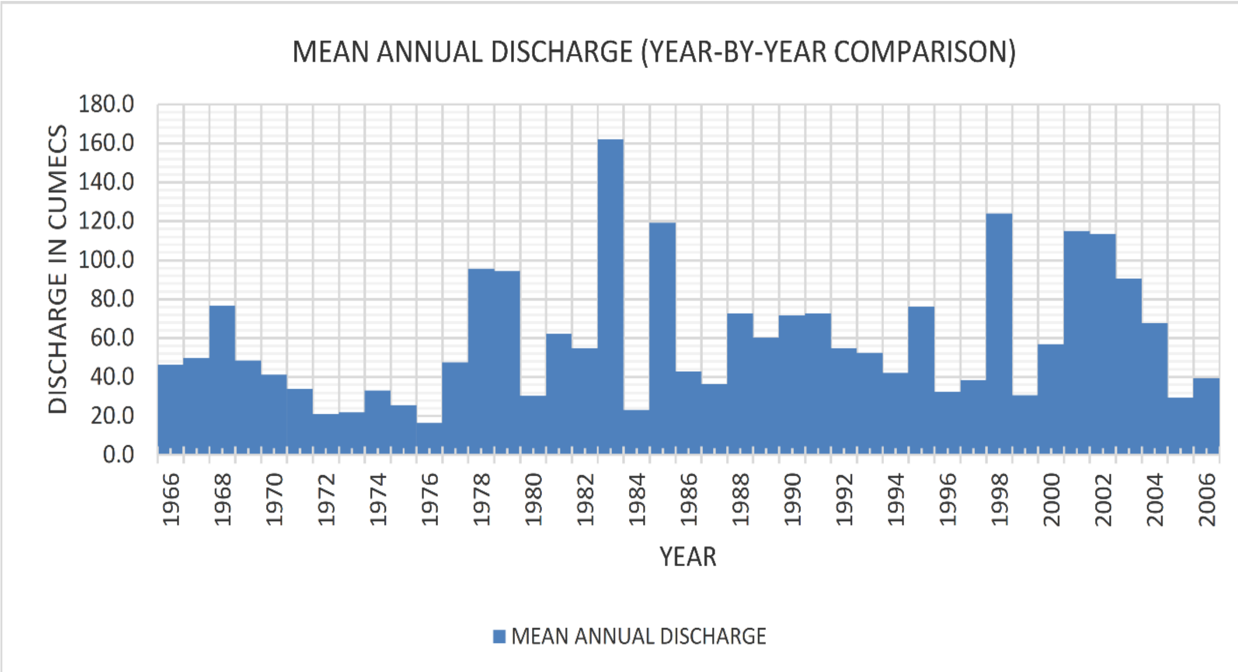


Figure 4.37: Year-on-year mean annual discharge

Table4.10: Summary - mean annual discharge

Minimum (m^3/s)	Maximum (m^3/s)	Mean (m^3/s)	Standard deviation (m^3/s)
16.307	162.060	56.166	32.081

4.6.1 Mann-Kendall's two-tailed trend test on mean annual discharge

When the Mann-Kendall's two-tail trend test was performed on the mean annual discharge, a sample time-series and p-values plot was yielded as shown in Figures 4.38 and 4.39. The two-tailed test did not detect any statistically significant trend, though the cut-off line was quite close to the p-value reading obtained. Detailed plots of p-values and time series for each month are found in Appendix 4.10.

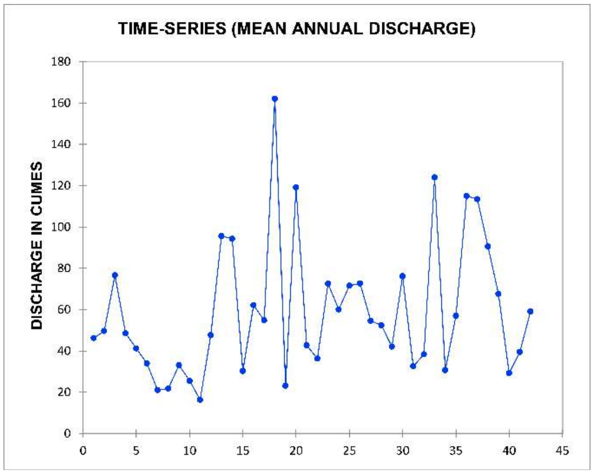


Figure 4.38: Time series-mean annual discharge

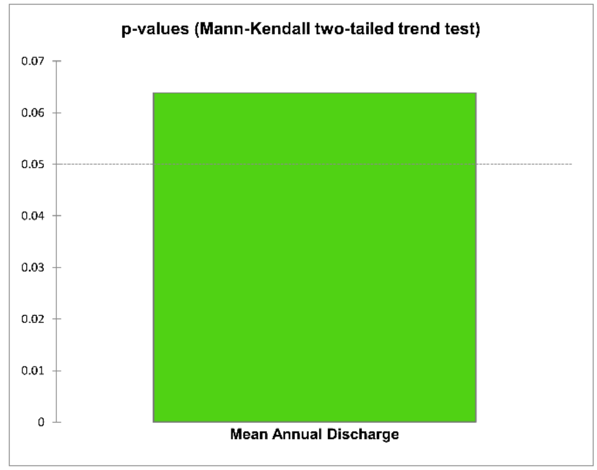


Figure 4.39: P-values two-tailed trend test

4.6.2 Mann-Kendall's one-tailed trend test on mean annual discharge

To confirm that indeed no statistically significant trend existed, a one-tailed trend test was performed on the same data. The one-tailed trend test suggested that there was an increasing statistically significant trend in the mean annual discharge. Figures 4.40 and 4.41 illustrate this. Detailed results of the upper-bound and lower bound tests can be found in Appendices 4.11 and 4.12.

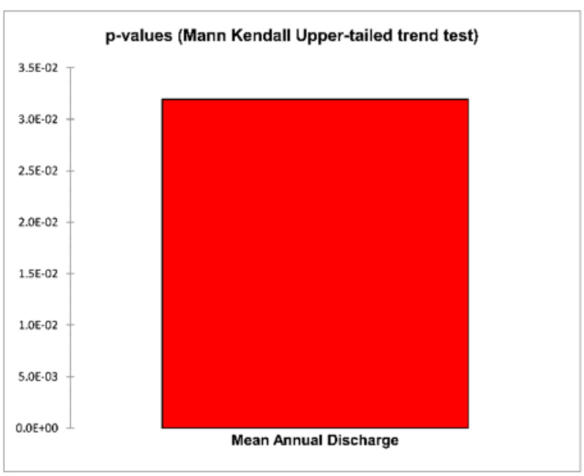


Figure 4.40: P-values: Upper-tailed trend test

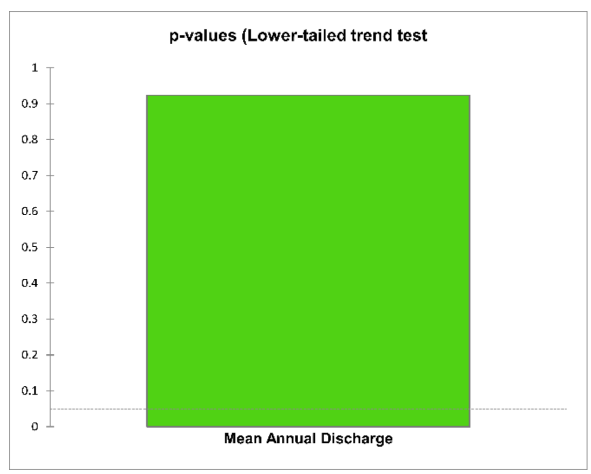


Figure 4.41: P-values: Lower-tailed trend test

4.7 In-depth Look into Discharge in the year 2001 – 2003

As noted previously, the mean monthly discharge data showed a peculiar pattern that did not conform with the seasonal variability observed in previous years. There were no rainfall records spanning 2001-2003 to check if indeed there had been consistent rainfall throughout the year to have caused the near-steady discharge (the rainfall records obtained in this study spanned between 1980-1994). As a recommendation, another study may be done to check river gauge records from a sub-catchment with similar characteristics to confirm discharge patterns in the three years. Table 4.11 and Figure 4.42 illustrate this.

Table 4.11: Mean monthly discharge (2001-2003)

	January	February	March	April	May	June	July	August	September	October	November	December
2001	124.5	124.4	124.3	124.1	124.1	124.0	123.9	123.7	123.6	33.1	123.3	106.1
2002	123.0	122.8	122.7	122.6	122.6	122.4	122.3	122.2	122.0	32.7	121.8	104.7
2003	119.1	130.1	117.9	89.4	89.4	126.0	90.5	80.0	69.2	27.4	64.2	83.6

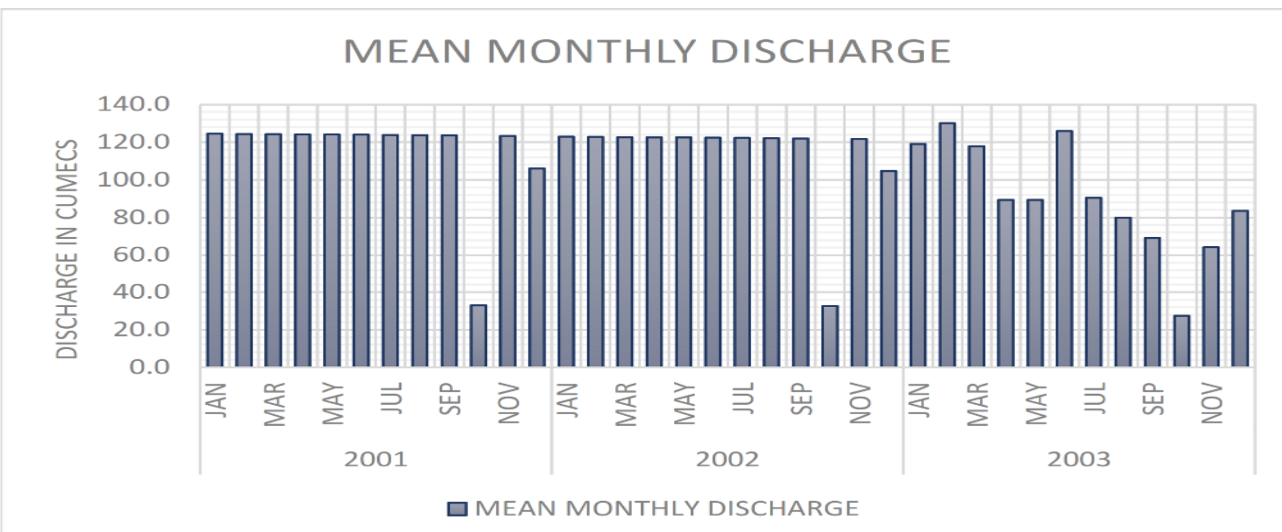


Figure 4.42: Mean monthly discharge (2001-2003)

The graphs show a near-uniform mean flow throughout the year with a sharp dip in the months of October (for all three years) and another slight decline in December (again for 2001-2002). This pattern ideally does not conform with the rest of the data set and could be viewed as an outlier. The cause of this behavior – whether due to human error in data collection, a systemic error in recording, errors in simulations to insert missing data or any other cause, may be confirmed in another study.

In view of this, mean annual discharge was checked for statistically significant trend once again, this time between 1966-2000 to find out if a statistically significant trend still existed in the absence of data from the years 2001-2006. A time-series plot was generated alongside plots of p-values for the two-tailed, upper-tailed and lower-tailed tests as shown in Figures 4.43 to 4.46 respectively.

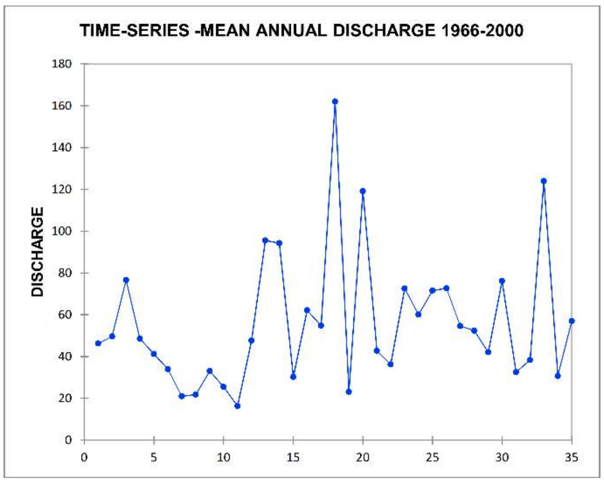


Figure 4.43: Time-series - Mean annual discharge (1966-2000)

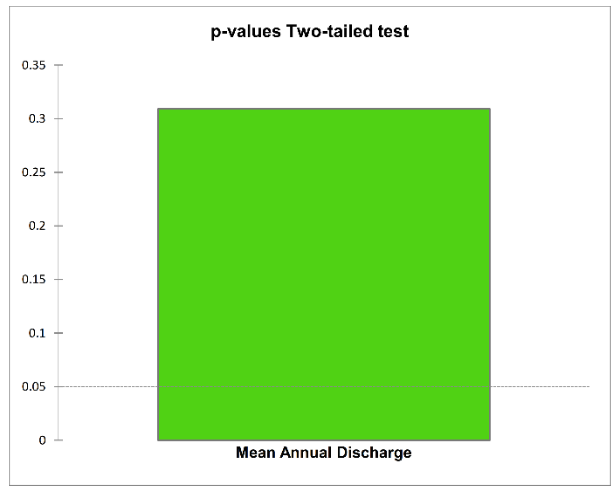


Figure 4.44: P-values plot (two-tail test)

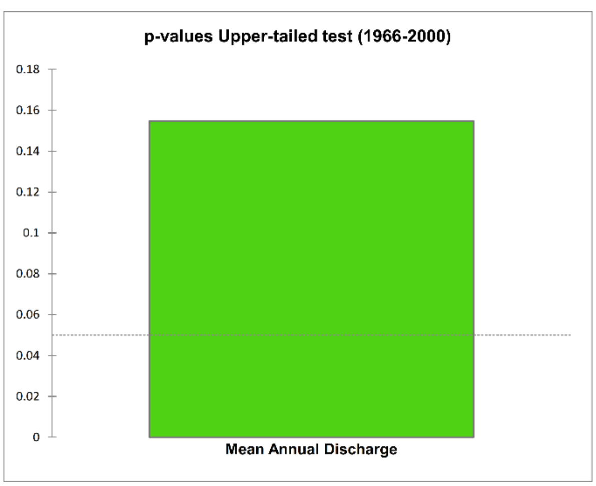


Figure4.45: P-values (Upper-tailed test)

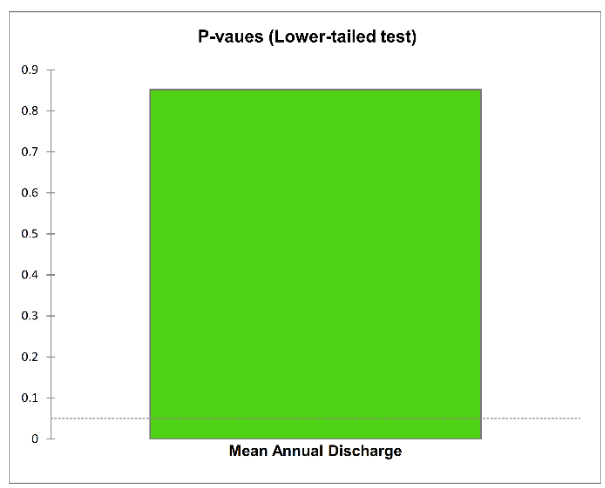


Figure 4.46: P-values (lower-tail test)

The tests did not detect any statistically significant trend. This suggested that the data collected in the years 2001-2003 may have had a significant contributory effect in causing occurrence of a statistically significant positive trend in mean annual discharge. Details of the results of these tests are found in appendix 4.13 to 4.15.

4.8 Summary of results and Interpretation

Table 4.12 summarizes the results of the study.

Table 4.12: Summary of results

Variable Tested	Two-Tailed Test	Upper-Tailed Test	Lower-Tailed Test
Mean monthly rainfall	Statistically significant trend detected in month of **August.**	No statistically significant trend detected.	Statistically significant trend detected in months of **August** and **September**.
Mean annual rainfall	No statistically significant trend detected.	No statistically significant trend detected.	No statistically significant trend detected.
Mean monthly discharge (1966-2006)	Statistically significant trend detected in months of **January, February** and **November.**	Statistically significant trend detected in months of **January, February, March** and **November.**	No statistically significant trend detected.
Mean annual discharge (1966-2006)	No statistically significant trend detected.	**statistically significant trend detected.**	No statistically significant trend detected.
Mean annual discharge (1966-2000)	No statistically significant trend detected.	No statistically significant trend detected.	No statistically significant trend detected.

With regard to rainfall, a statistically significant negative trend in the mean monthly rainfall was observed in the months of August and September. Traditionally, these two months are not in the two rainy seasons of the year. The proportion of months in a year that exhibited a statistically significant trend was (2 / 12) x 100% = 16.67%. There was no statistically significant trend in the mean annual rainfall over the period (1980-1994).

With respect to discharge between (1966-2006), a statistically significant increase in mean monthly discharge was observed in the months of January, February, March and November. This increase could be attributed to possible catchment degradation, resulting in increased run-off into the rivers. From the study, there is no statistically significant trend in the mean monthly rainfall in the four months that could be correlated to the increased discharge. the dataset for rainfall does not also span the entire period of discharge being studied and as a result, it may not be possible to correlate the two results. The proportion of months that suggested statistically significant trend were (4 / 12) x 100% = 33.33%. The mean annual discharge also had a statistically significant positive trend suggesting that the mean flow had been increasing over the period under study.

A third analysis was performed, ignoring data from the years 2001-2006 which had an abnormal pattern that did not conform with the seasonal variability in previous years. When trend tests were performed, it was observed that no statistically significant trend existed between 1966-2000. This suggests that the data in the years 2001-2003 had a significant effect on the trend tests.

The results of this study seemed to agree with a similar study by Kristian (2013) which was funded by the Nordic Climate Facility titled "Building Adaptive Capacity to Climate Change in Kenya". That particular study had used historical data from 1960 – 2009 and had concluded that there would be a general increase in the mean monthly runoff in the eight catchments on the western side of Mount Kenya midway through the beginning of the short rains seasons and going all the way to the middle of the long rains season (November to May). This research report on the upper Tana sub-catchment found that there was a statistically significant increasing trend in river discharge in the months of November, January, February and March over the period of study (1966-2006). This was not a major deviation, bearing in mind that the Tana Sub-catchment is found on the windward side of Mount Kenya while the eight catchments that were under study in the Nordic Climate Facility were all located on the Lee-ward side of Mount Kenya in Laikipia County.

With regard to mean annual discharge, the Nordic Climate Facility report predicted that there would be an increase in annual runoff by between 5-30 % in the "near future" and a much more significant increase in the "far future" by between 25 – 60%. In the NCF study, the near future was taken to be between the years 2020 – 2049 while the far future was taken to be between 2070 – 2099. The study concluded that as much as Climate Change would be largely responsible for the increased runoff, this effect of having increased runoff would not be an entirely negative phenomenon in the light of the water insecurity in Kenya.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

With regard to the first objective that sought to detect existence of a statistically significant trend in the mean monthly and mean annual rainfall, the results of the trend test showed that only two months (August and September) had a negative, statistically significant trend, representing 16.67%. As a result, for those two months, the null hypothesis (H_0) was rejected and the alternative hypothesis (H_a) accepted. Trend tests on mean annual rainfall did not suggest the presence of a statistically significant trend. This meant that the null hypothesis (H_0) could not be rejected. Therefore, with respect to the first objective, it can be reasonably concluded that the evidence obtained is not sufficient to imply the presence of climate change since less than half (50%) of the twelve months detected a statistically significant trend.

The second objective sought to detect the presence of a statistically significant trend in the mean monthly and mean annual discharge. The results suggested the presence of a positive statistically significant trend in the mean monthly discharge in the months of January, February, March and November (representing 33.33%). This meant that the null hypothesis (H_0) was rejected and the alternative hypothesis (H_a) accepted for four months out of twelve. With regard to mean annual discharge, an overall positive statistically significant trend was detected implying that the null hypothesis (H_0) was rejected and the alternative hypothesis (H_a). Ideally, the results of the mean annual discharge data would have been enough to draw conclusions, however, other important factors needed to be quantified and taken into account such as the presence of perceived data outliers between 2001-2003 and also the likelihood of increased run-off coefficient in the sub-catchment as a result of catchment degradation.

In conclusion, the results obtained from this study cannot conclusively imply climate change. The rainfall data obtained had a relatively short span (1980-1994) and only six rainfall stations were analyzed in the vast upper Tana sub-catchment. This dataset may have been inadequate to give a sufficient representation of the catchment characteristics. The river gauge data also had a period that generally did not appear to conform with the pattern observed in previous years (2001-2003) suggesting that there could have been some errors either in recording data. In addition, the possibility of catchment degradation in the upper reaches could have resulted in the increase in the overall run-off coefficient and this has a likelihood of increasing discharge in stream flows.

5.2 Recommendations

To enrich the study further, the following are recommended:

a) Another study on statistically significant trend test detection be conducted on a sub-catchment in the upper Tana that has comparable rainfall patterns and with rainfall records spanning a longer period (preferably spanning to 2006) to confirm the presence (or otherwise) of a statistically significant trend.

b) Advanced methods of checking the accuracy of discharge data be employed to validate discharge data collected between 2001-2003. This may rule out the presence of human error during data collection, systemic errors during recording or the likelihood of using wrong simulation methods to impute missing data.

c) A study of the nature and extent of catchment degradation in the upper Tana catchment be done to determine parameters such as catchment run-off coefficient to help in apportioning of the contribution of catchment degradation to the increased stream flows and the portion attributable to Climate change.

d) A study to detect the presence of a statistically significant trend be performed on extreme values.

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APPENDICES

Appendix 4.1: Mean Monthly Precipitation (Mann-Kendall's Two-tail Trend Test)

XLSTAT 2018.1.49205 - Mann-Kendall trend tests - Start time: 1/24/2018 at 9:47:33 PM / End time: 1/24/2018 at 9:47:35 PM

Time series: Workbook = mean monthly precipitation.xlsx / Sheet = Sheet1 / Range = Sheet1!$B$1:$M$16 / 15 rows and 12 columns

Significance level (%): 5

Confidence interval (%)(Sen's slope): 95

Summary statistics

Summary statistics:

Variable	No. of observa-tions	Entries with missing data	Entries without missing data	Mean rainfall	Maximum rainfall	Minimum rainfall	Standard Deviation
JANUARY	1	0	15	3.333	281.050	48.556	68.714
FEBRUARY	1	0	15	2.100	122.500	23.861	35.150
MARCH	1	0	15	15.517	349.267	97.328	97.326
APRIL	1	0	15	128.683	612.833	336.484	140.772
MAY	1	0	15	51.083	331.433	154.827	91.813
JUNE	1	0	15	0.000	46.767	15.228	15.861
JULY	1	0	15	0.000	29.550	14.593	8.691
AUGUST	1	0	15	0.000	56.783	17.733	16.992
SEPTEMBER	1	0	15	0.000	56.575	23.343	19.963
OCTOBER	1	0	15	14.333	591.133	236.131	158.889
NOVEMBER	1	0	15	120.200	599.000	288.712	139.697
DECEMBER	1	0	15	27.850	301.000	127.013	80.229

4.1.1 Mann-Kendall trend test / Two-tailed test (JANUARY):

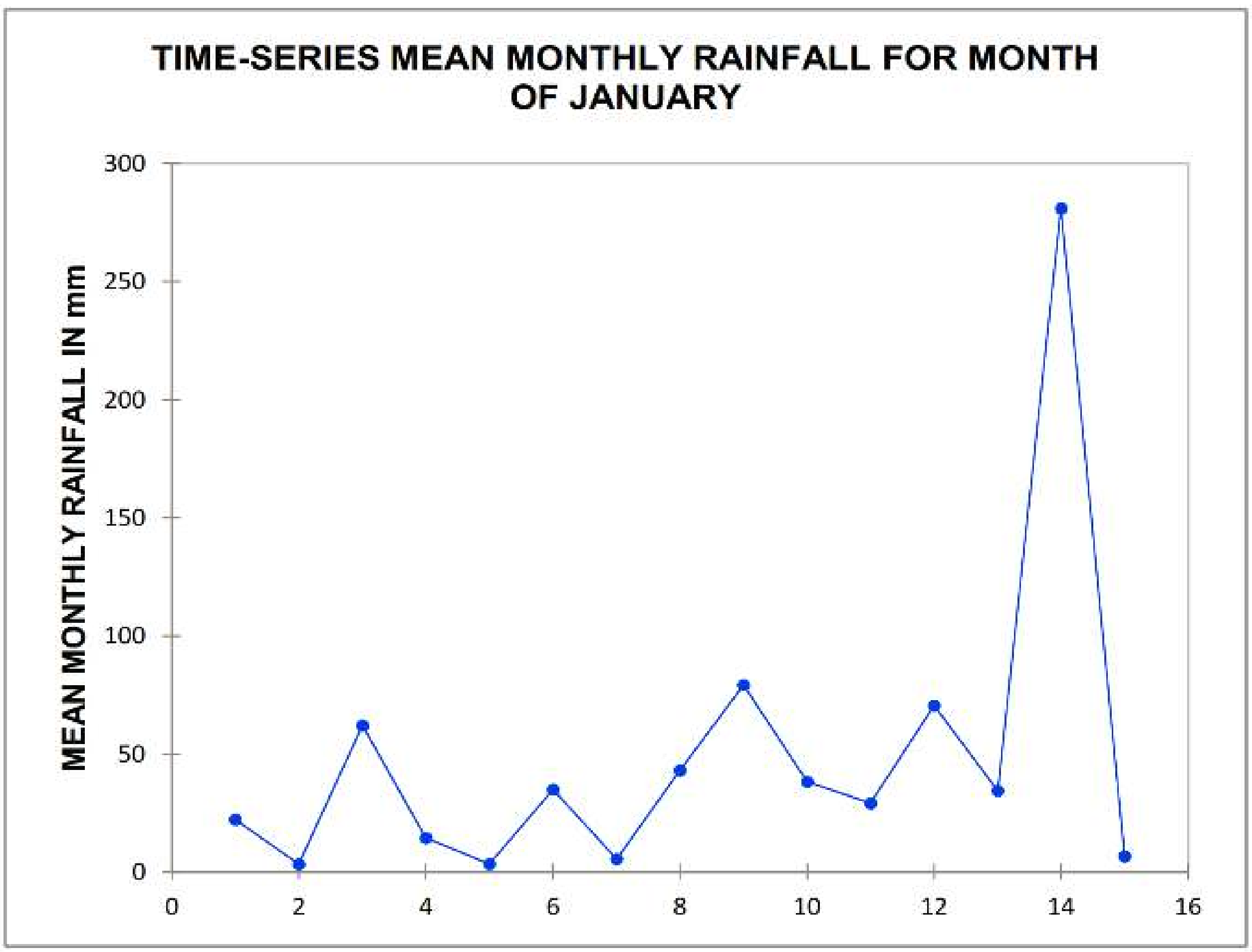
Kendall's tau	0.276
S	29.000
Var(S)	408.333
p-value	0.169
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 16.86%.

Sen's slope: 2.658

Confidence interval:] 2.147,2.870 [



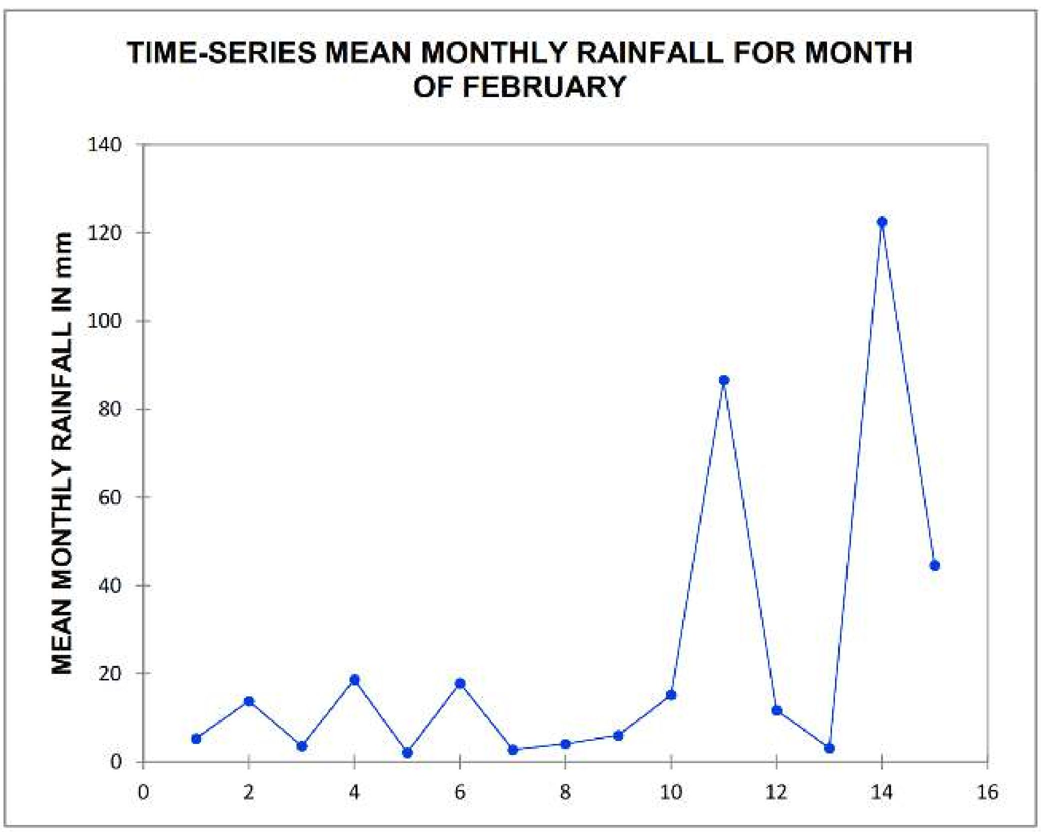
4.1.2 Mann-Kendall trend test / Two-tailed test (FEBRUARY):

Kendall's ta	0.276
S	29.000
Var(S)	408.333
p-value (Tw	0.169
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 16.86%.

Sen's slope: 1.379
Confidence interval:] 1.047,1.742 [



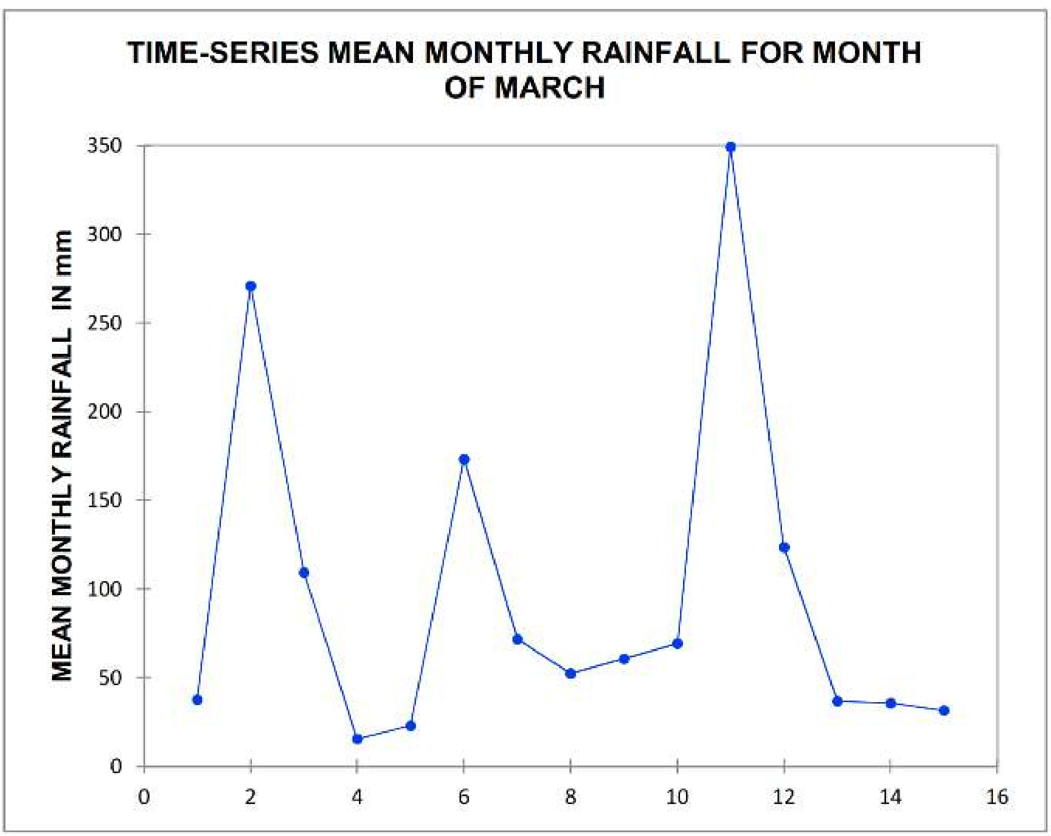
4.1.3 Mann-Kendall trend test / Two-tailed test (MARCH):

Kendall's ta	-0.124
S	-13.000
Var(S)	408.333
p-value (Tw	0.559
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 55.90%.

Sen's slope: -2.792
Confidence interval:] -3.458 ,-0.933 [



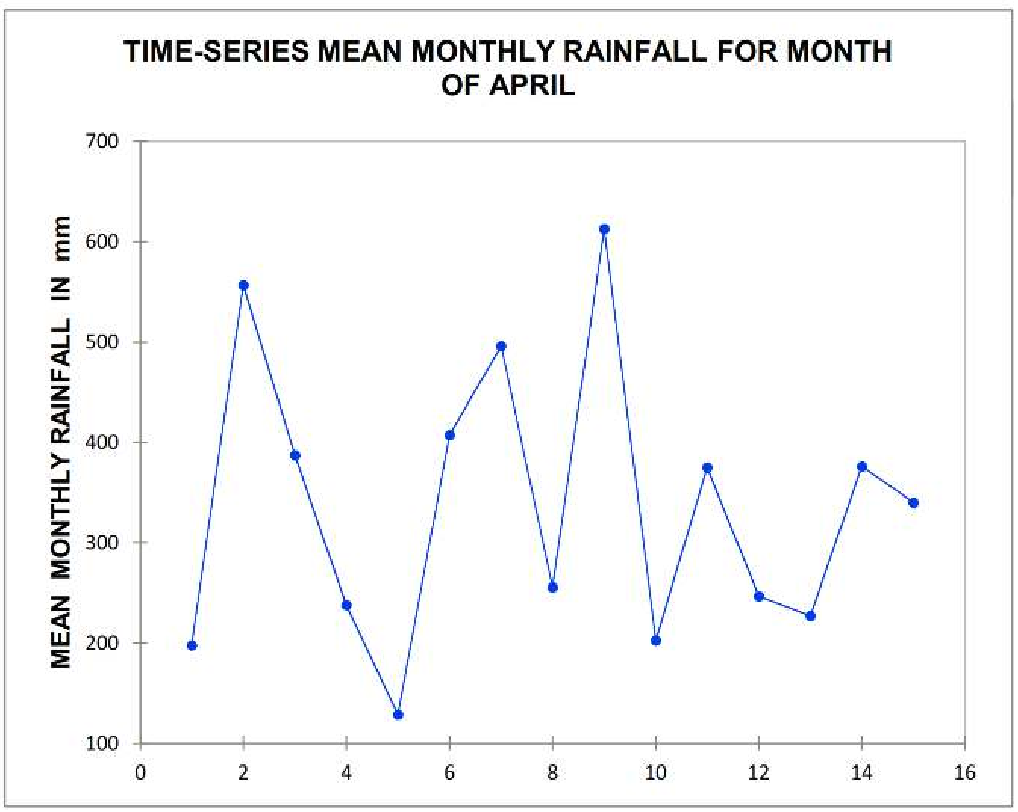
4.1.4 Mann-Kendall trend test / Two-tailed test (APRIL):

Kendall's ta	-0.010
S	-1.000
Var(S)	408.333
p-value (Tw	1.000
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 100.00%.

Sen's slope: -1.018
Confidence interval:] -1.936 ,0.878 [



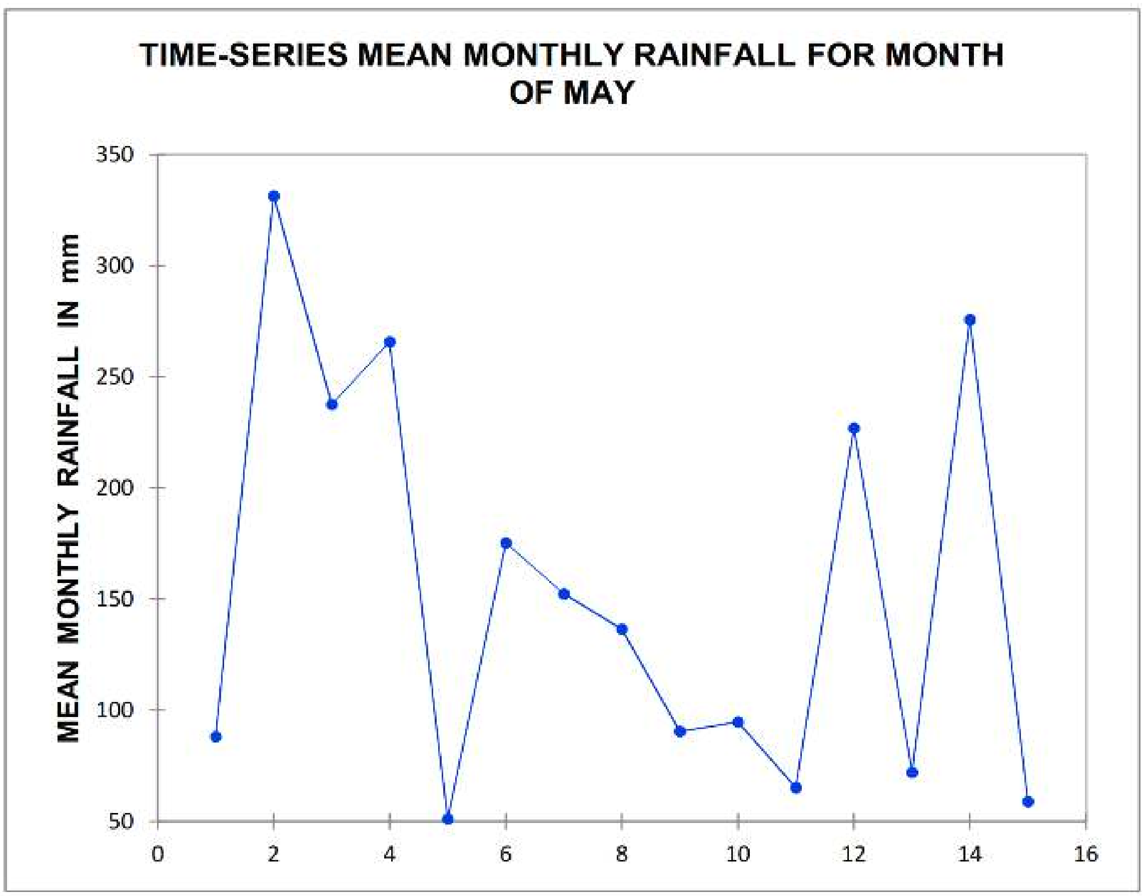
4.1.5 Mann-Kendall trend test / Two-tailed test (MAY):

Kendall's ta	-0.257
S	-27.000
Var(S)	408.333
p-value (Tw	0.202
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 20.18%.

Sen's slope: -10.441
Confidence interval:] -12.268 ,-7.328 [



4.1.6 Mann-Kendall trend test / Two-tailed test (JUNE):

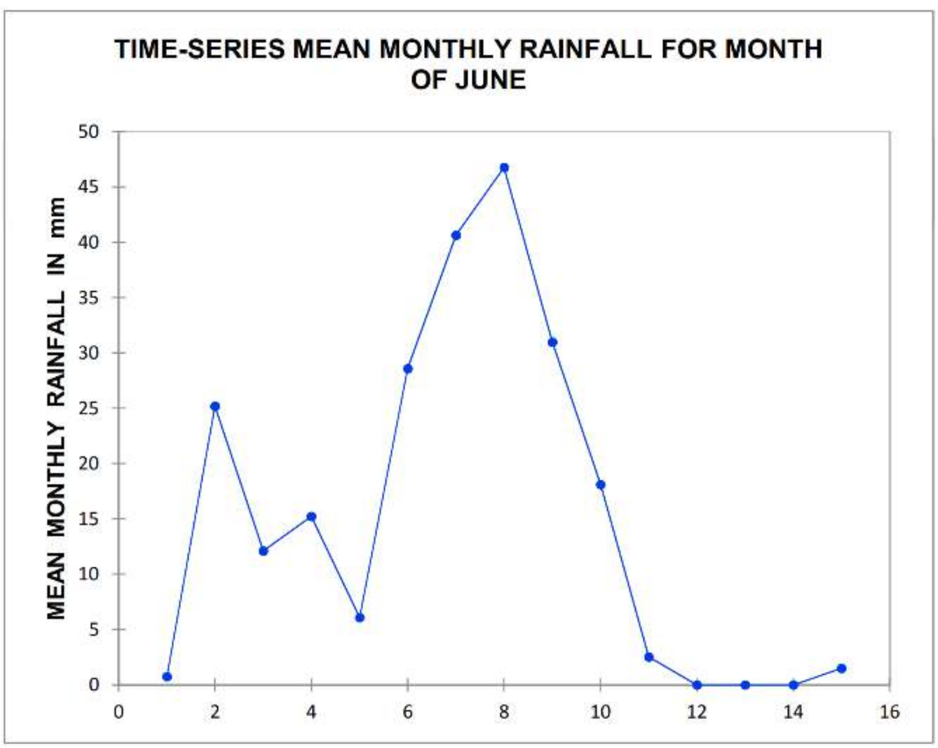
Kendall's ta	-0.251
S	-26.000
Var(S)	404.667
p-value (Tw	0.196
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 19.62%.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope: -0.885
Confidence interval:] -1.204 ,-0.854 [



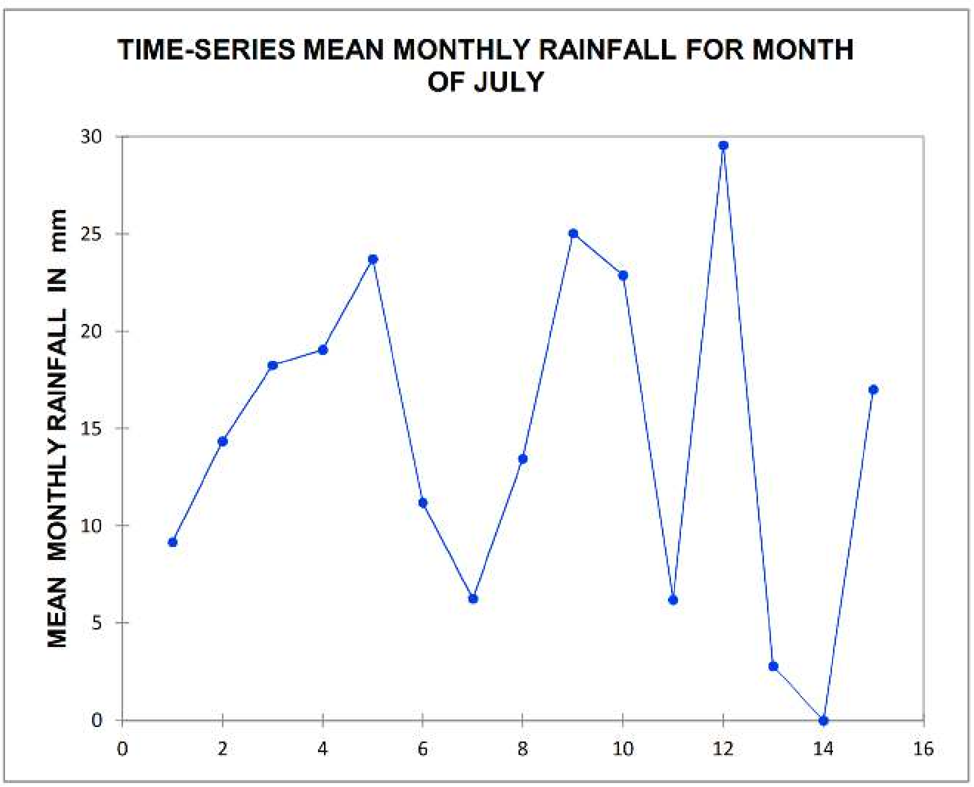
4.1.7 Mann-Kendall trend test / Two-tailed test (JULY):

Kendall's ta	-0.086
S	-9.000
Var(S)	408.333
p-value (Tw	0.697
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 69.72%.

Sen's slope: -0.186
Confidence interval:] -0.512 ,-0.123 [



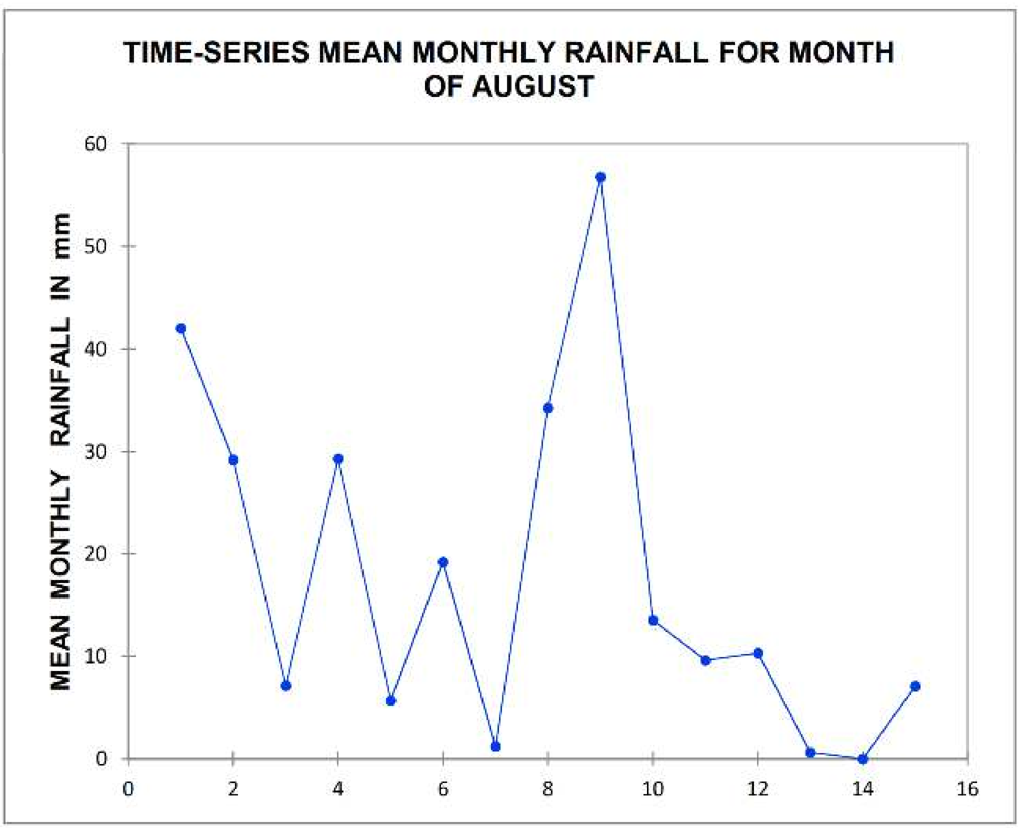
4.1.8 Mann-Kendall trend test / Two-tailed test (AUGUST):

Kendall's ta	-0.390
S	-41.000
Var(S)	408.333
p-value (Tw	0.046
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
The risk to reject the null hypothesis H0 while it is true is lower than 4.63%.

Sen's slope: -1.92
Confidence interval:] -2.112 ,-1.642 [



4.1.9 Mann-Kendall trend test / Two-tailed test (SEPTEMBER):

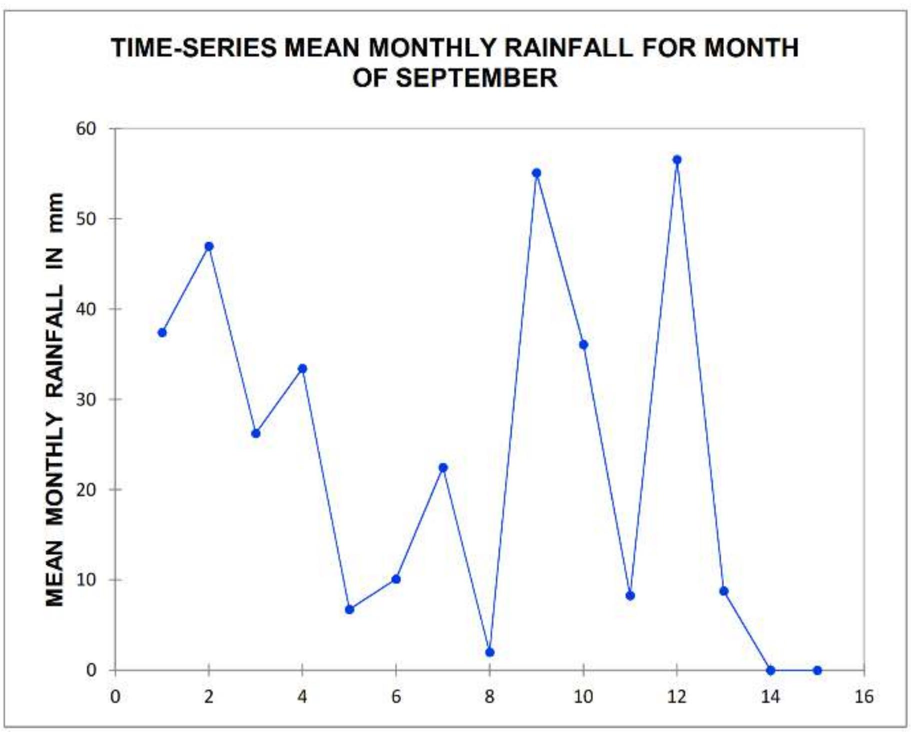
Kendall's ta	-0.325
S	-34.000
Var(S)	407.333
p-value (Tw	0.092
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 9.21%.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope: -2.244
Confidence interval:] -2.386 ,-1.876 [



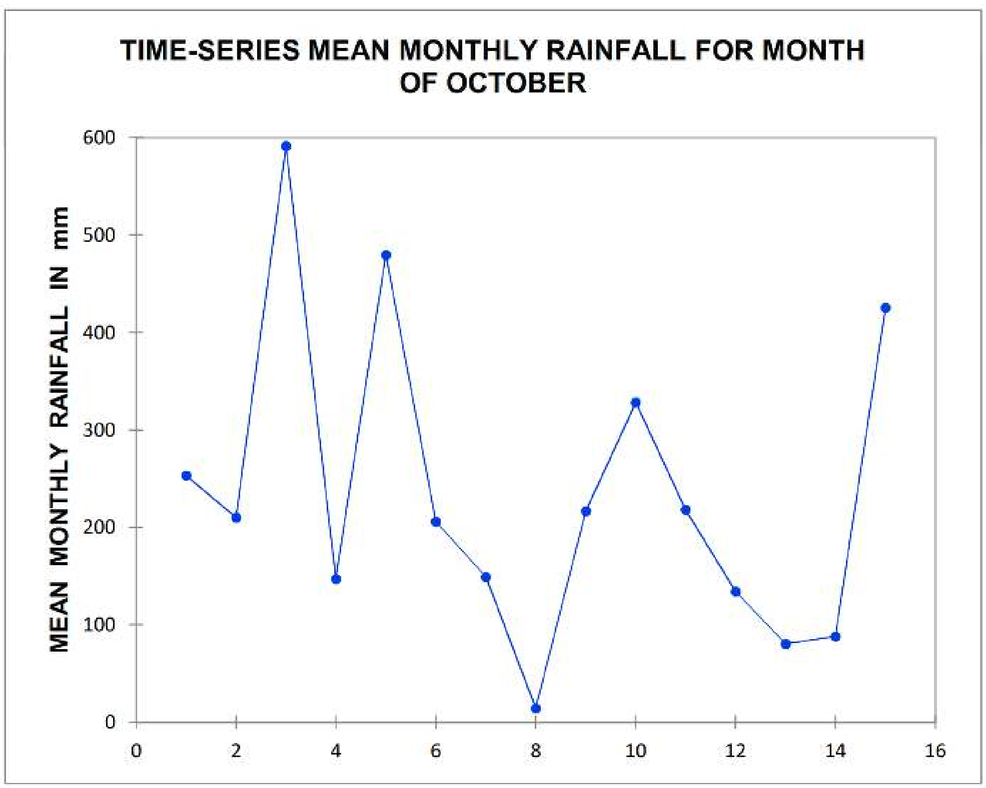
4.1.10 Mann-Kendall trend test / Two-tailed test (OCTOBER):

Kendall's ta	-0.219
S	-23.000
Var(S)	408.333
p-value (Tw	0.282
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 28.16%.

Sen's slope: -10.161
Confidence interval:] -11.644 ,-8.041 [



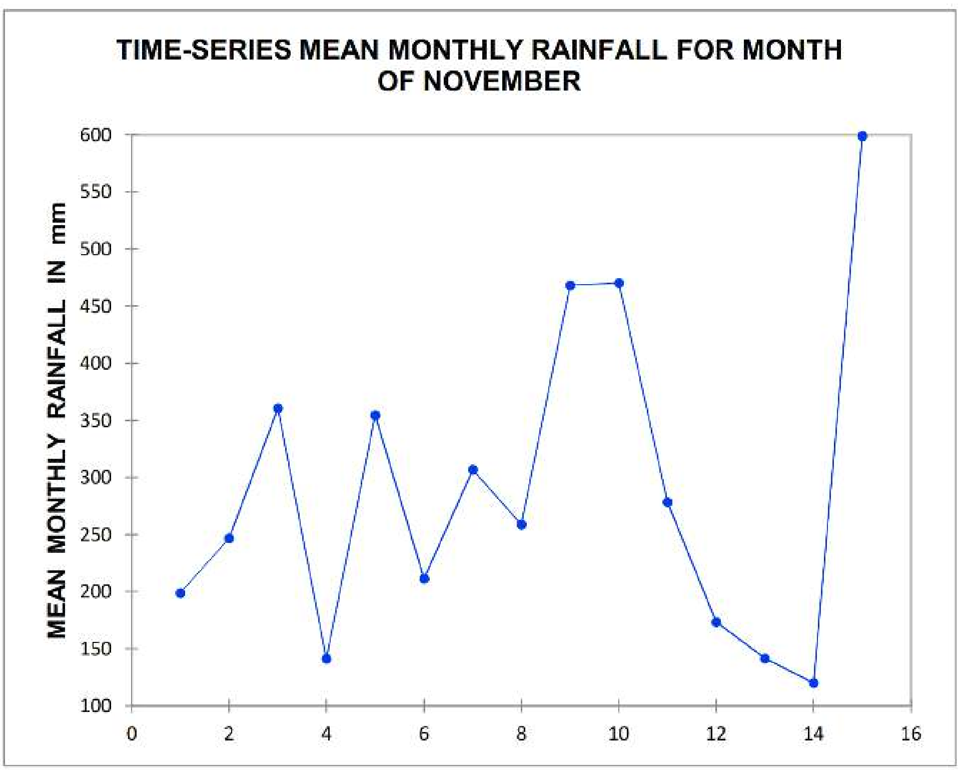
4.1.11 Mann-Kendall trend test / Two-tailed test (NOVEMBER):

Kendall's ta	0.029
S	3.000
Var(S)	408.333
p-value (Tw	0.923
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 92.26%.

Sen's slope: 2
Confidence interval:] -2.239 ,3.104 [



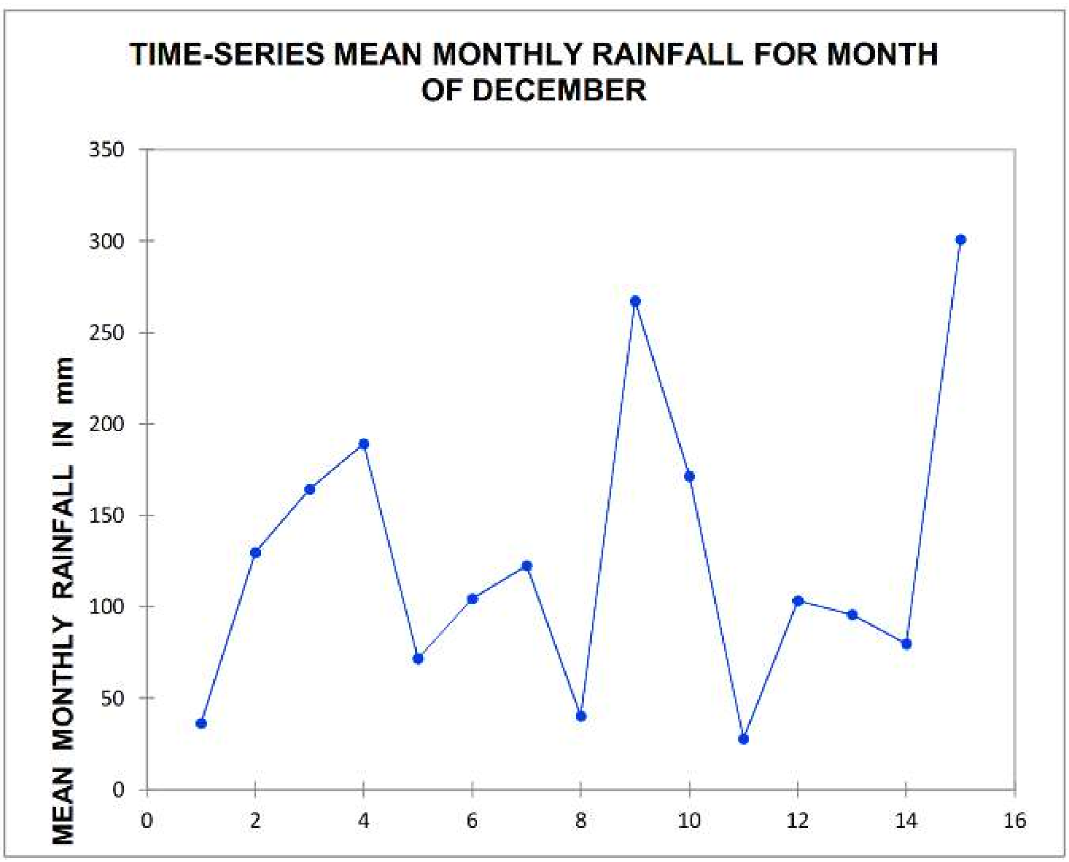
4.1.12 Mann-Kendall trend test / Two-tailed test (DECEMBER):

Kendall's ta	0.029
S	3.000
Var(S)	408.333
p-value (Tw	0.923
alpha	0.05

An approximation has been used to compute the p-value.

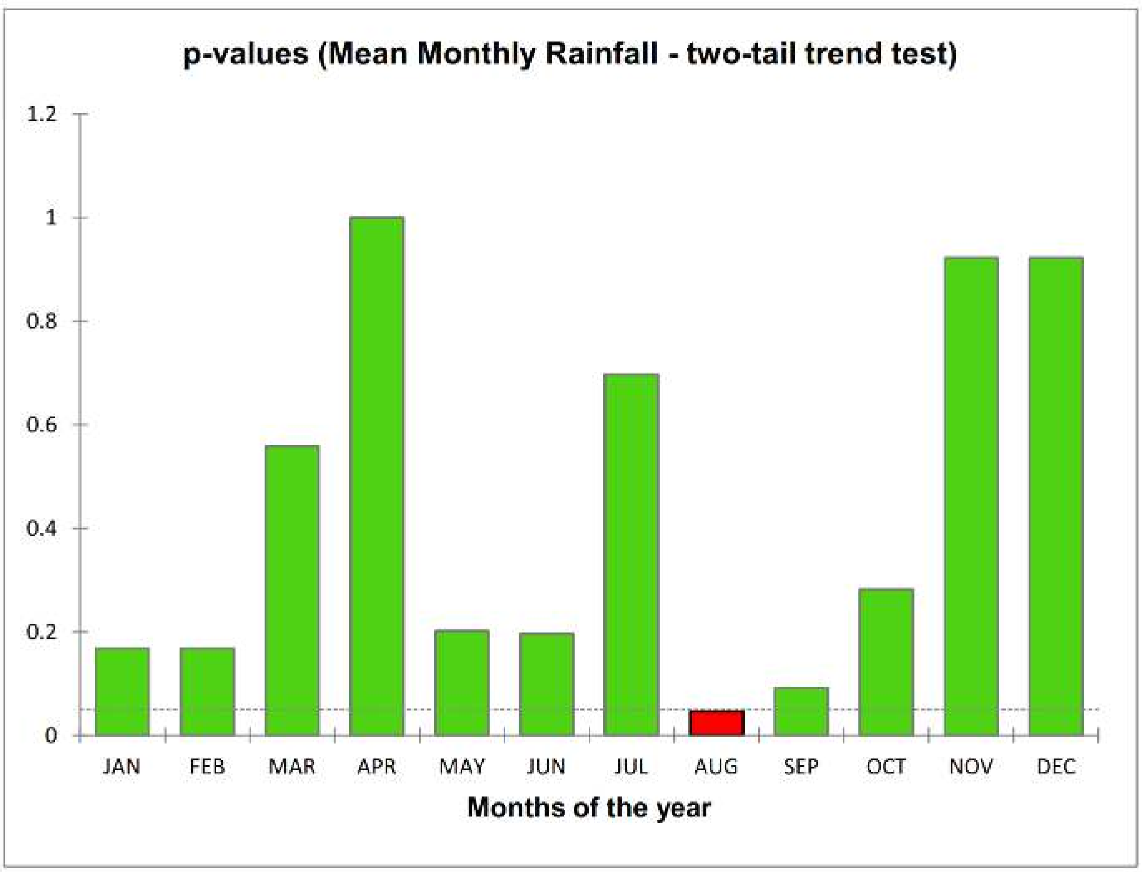
Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 92.26%.

Sen's slope: 0.898
Confidence interval:] -0.574 ,3.216 [



Summary:

Series\Test	Kendall's tau	p-value	Sen's slope
JANUARY	0.276	0.169	2.658
FEBRUARY	0.276	0.169	1.379
MARCH	-0.124	0.559	-2.792
APRIL	-0.010	1.000	-1.018
MAY	-0.257	0.202	-10.441
JUNE	-0.251	0.196	-0.885
JULY	-0.086	0.697	-0.186
AUGUST	-0.390	**0.046**	-1.920
SEPTEMBER	-0.325	0.092	-2.244
OCTOBER	-0.219	0.282	-10.161
NOVEMBER	0.029	0.923	2.000
DECEMBER	0.029	0.923	0.898



Appendix 4.2: Mean Monthly Precipitation (Mann-Kendall's Upper-Bound Trend Test)

XLSTAT 2018.1.49205 - Mann-Kendall trend tests - Start time: 1/24/2018 at 9:49:08 PM / End time: 1/24/2018 at 9:49:09 PM

Time series: Workbook = mean monthly precipitation.xlsx / Sheet = Sheet1 / Range = Sheet1!$B$1:$M$16 / 15 rows and 12 columns

Significance level (%): 5
Confidence interval (%)(Sen's slope): 95

Summary statistics

Summary statistics:

Variable	No. of observations	Entries with missing data	Entries without missing data	Mean rainfall	Maximum rainfall	Minimum rainfall	Standard Deviation
JANUARY	15	0	15	3.333	281.050	48.556	68.714
FEBRUARY	15	0	15	2.100	122.500	23.861	35.150
MARCH	15	0	15	15.517	349.267	97.328	97.326
APRIL	15	0	15	128.683	612.833	336.484	140.772
MAY	15	0	15	51.083	331.433	154.827	91.813
JUNE	15	0	15	0.000	46.767	15.228	15.861
JULY	15	0	15	0.000	29.550	14.593	8.691
AUGUST	15	0	15	0.000	56.783	17.733	16.992
SEPTEMBER	15	0	15	0.000	56.575	23.343	19.963
OCTOBER	15	0	15	14.333	591.133	236.131	158.889
NOVEMBER	15	0	15	120.200	599.000	288.712	139.697
DECEMBER	15	0	15	27.850	301.000	127.013	80.229

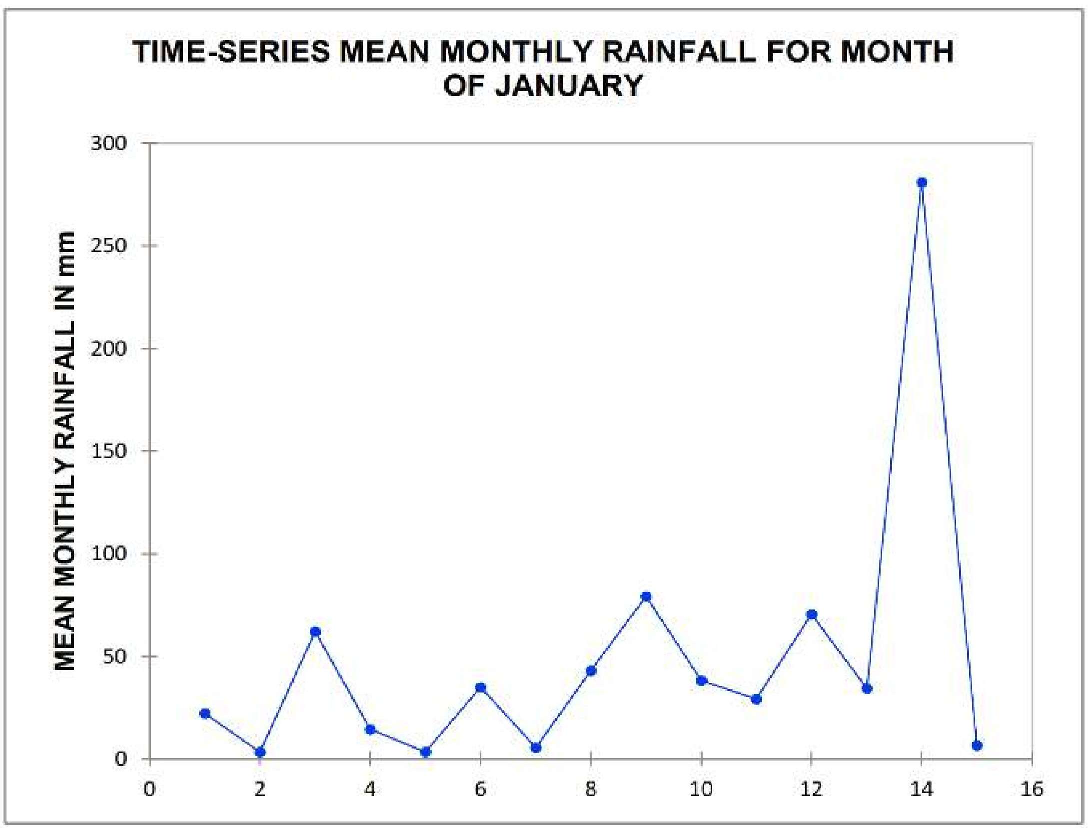
4.2.1 Mann-Kendall trend test / Upper-tailed test (JANUARY):

Kendall's ta	0.276
S	29.000
Var(S)	408.333
p-value (on	0.084
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 8.43%.

Sen's slope: 2.658
Confidence interval:] 2.147,2.870 [



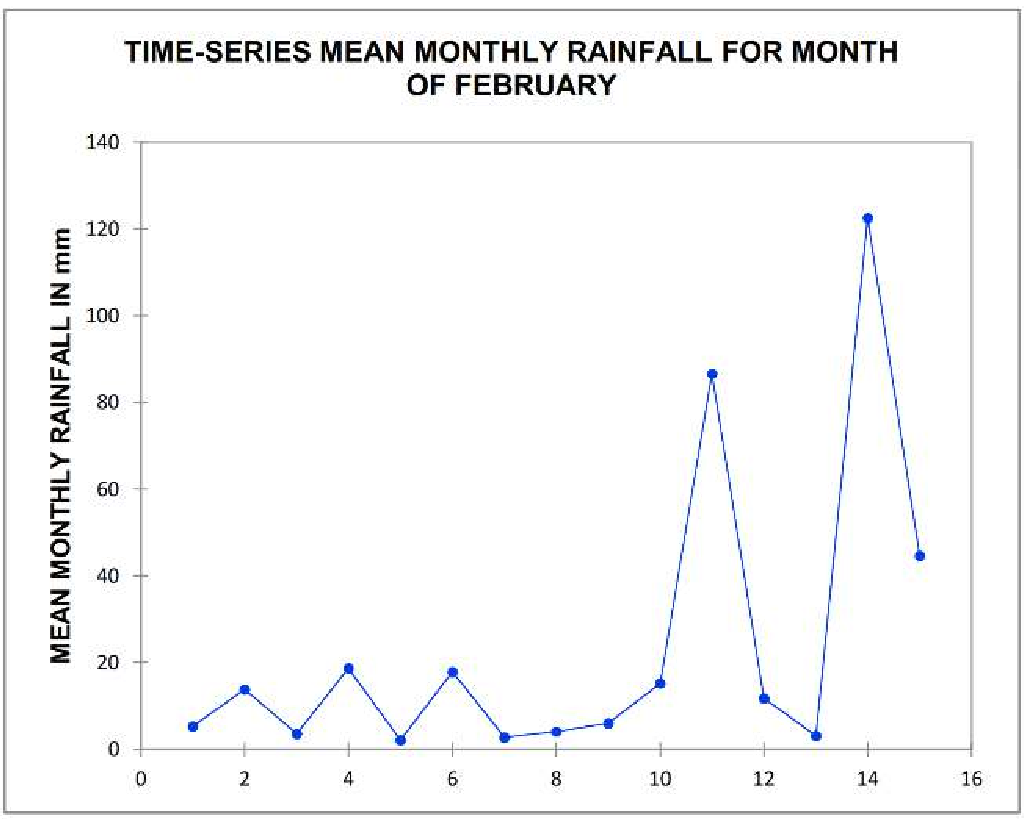
4.2.2 Mann-Kendall trend test / Upper-tailed test (FEBRUARY):

Kendall's ta	0.276
S	29.000
Var(S)	408.333
p-value (on	0.084
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 8.43%.

Sen's slope: 1.379
Confidence interval:] 1.047,1.742 [



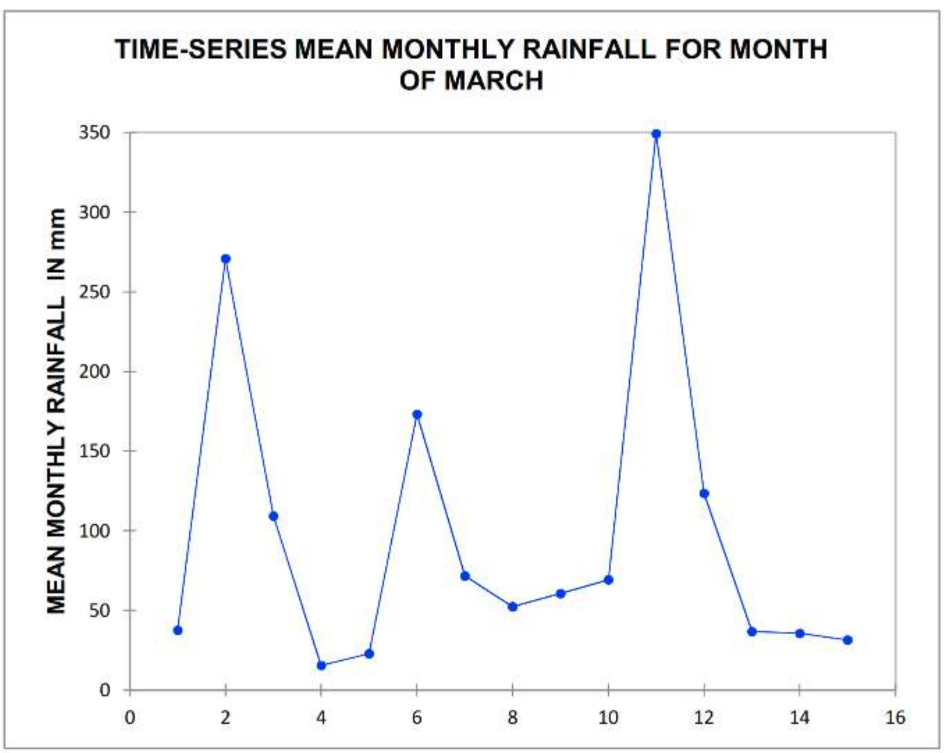
4.2.3 Mann-Kendall trend test / Upper-tailed test (MARCH):

Kendall's ta	-0.124
S	-13.000
Var(S)	408.333
p-value (on	0.752
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 75.25%.

Sen's slope: -2.792
Confidence interval:] -3.458 ,-0.933 [



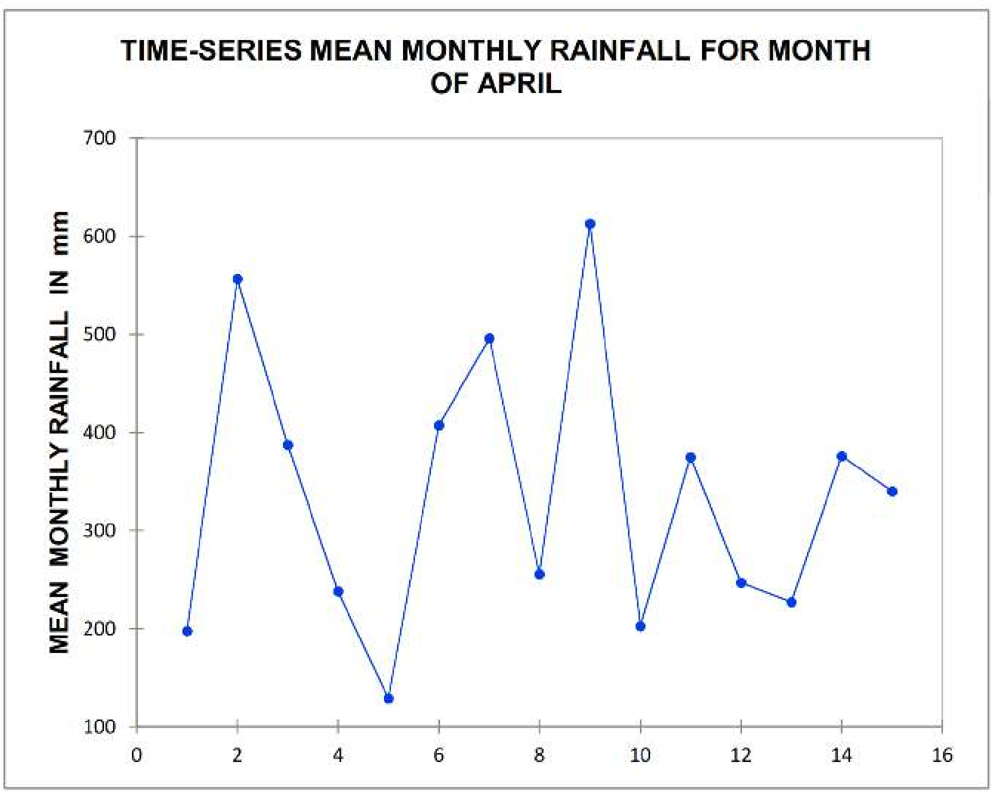
4.2.4 Mann-Kendall trend test / Upper-tailed test (APRIL):

Kendall's ta	-0.010
S	-1.000
Var(S)	408.333
p-value (on	0.539
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 53.87%.

Sen's slope: -1.018
Confidence interval:] -1.936 ,0.878 [



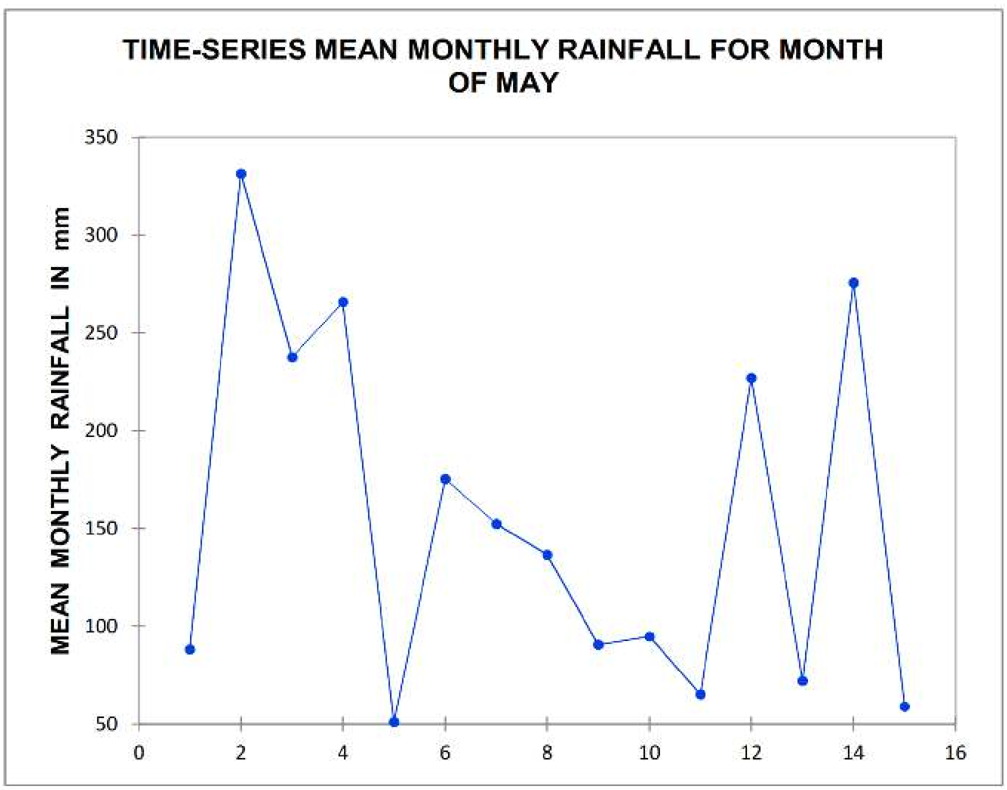
4.2.5 Mann-Kendall trend test / Upper-tailed test (MAY):

Kendall's ta	-0.257
S	-27.000
Var(S)	408.333
p-value (on	0.916
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 91.57%.

Sen's slope: -10.441
Confidence interval:] -12.268 ,-7.328 [



4.2.6 Mann-Kendall trend test / Upper-tailed test (JUNE):

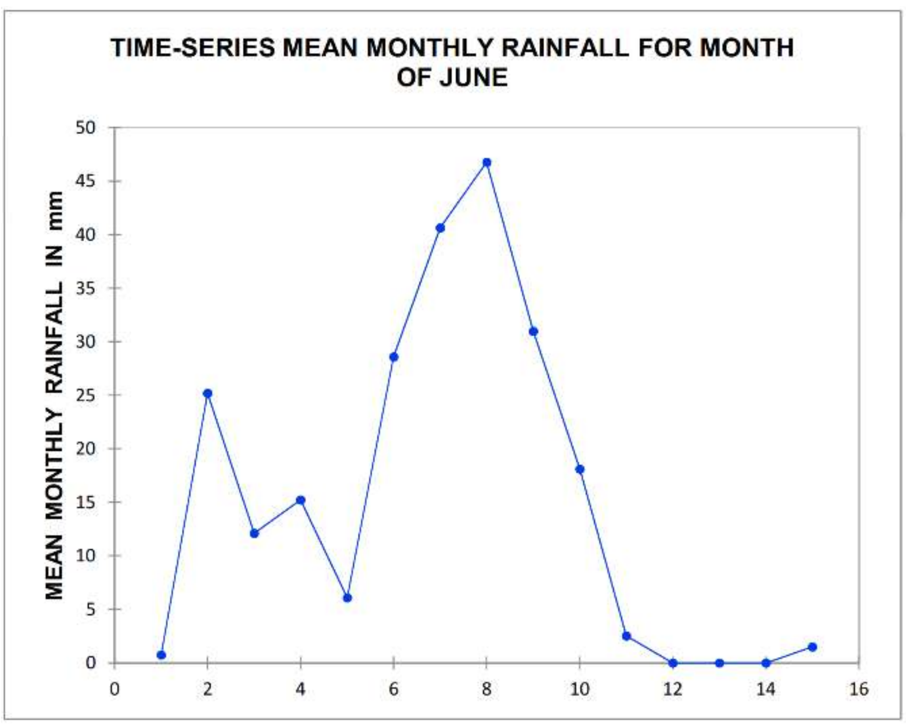
Kendall's ta	-0.251
S	-26.000
Var(S)	404.667
p-value (on	0.902
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 90.19%.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope: -0.885
Confidence interval:] -1.204 ,-0.854 [



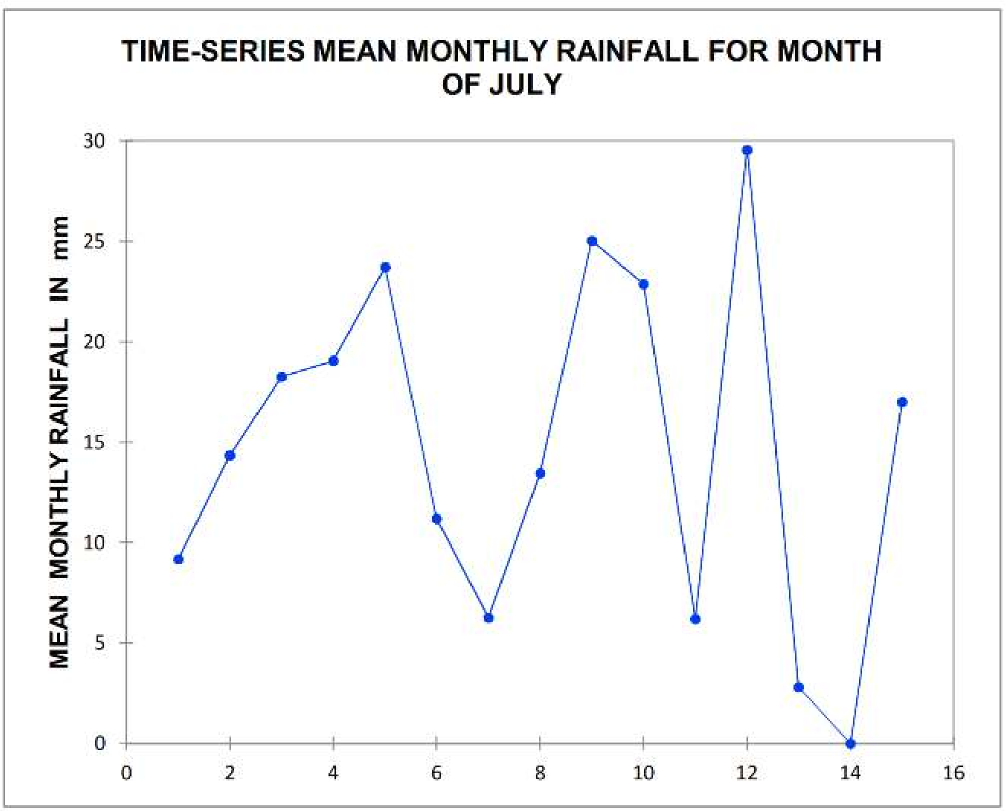
4.2.7 Mann-Kendall trend test / Upper-tailed test (JULY):

Kendall's ta	-0.086
S	-9.000
Var(S)	408.333
p-value (on	0.687
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 68.68%.

Sen's slope: -0.186
Confidence interval:] -0.512 ,-0.123 [



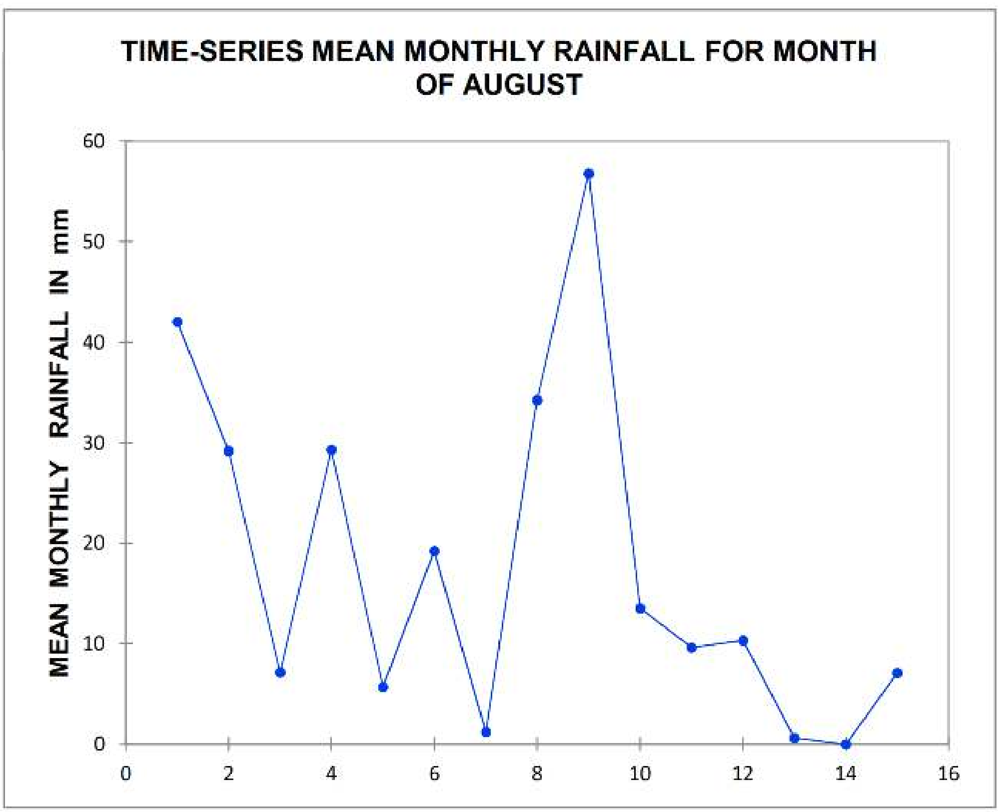
4.2.8 Mann-Kendall trend test / Upper-tailed test (AUGUST):

Kendall's ta	-0.390
S	-41.000
Var(S)	408.333
p-value (on	0.982
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 98.21%.

Sen's slope: -1.92
Confidence interval:] -2.112 ,-1.642 [



4.2.9 Mann-Kendall trend test / Upper-tailed test (SEPTEMBER):

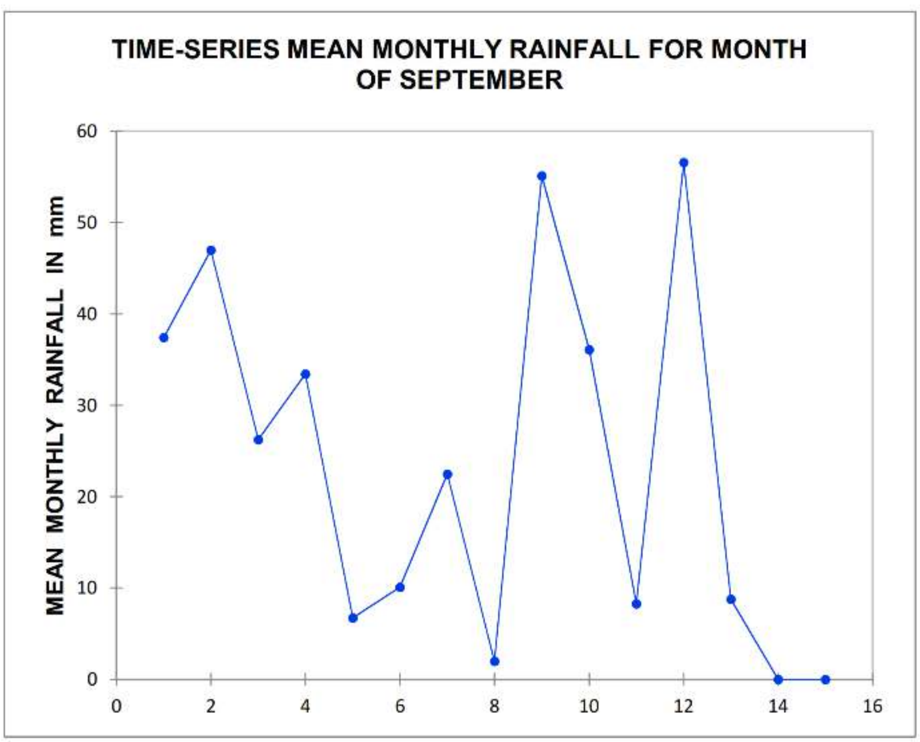
Kendall's ta	-0.325
S	-34.000
Var(S)	407.333
p-value (on	0.954
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 95.40%.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope: -2.244
Confidence interval:] -2.386 ,-1.876 [



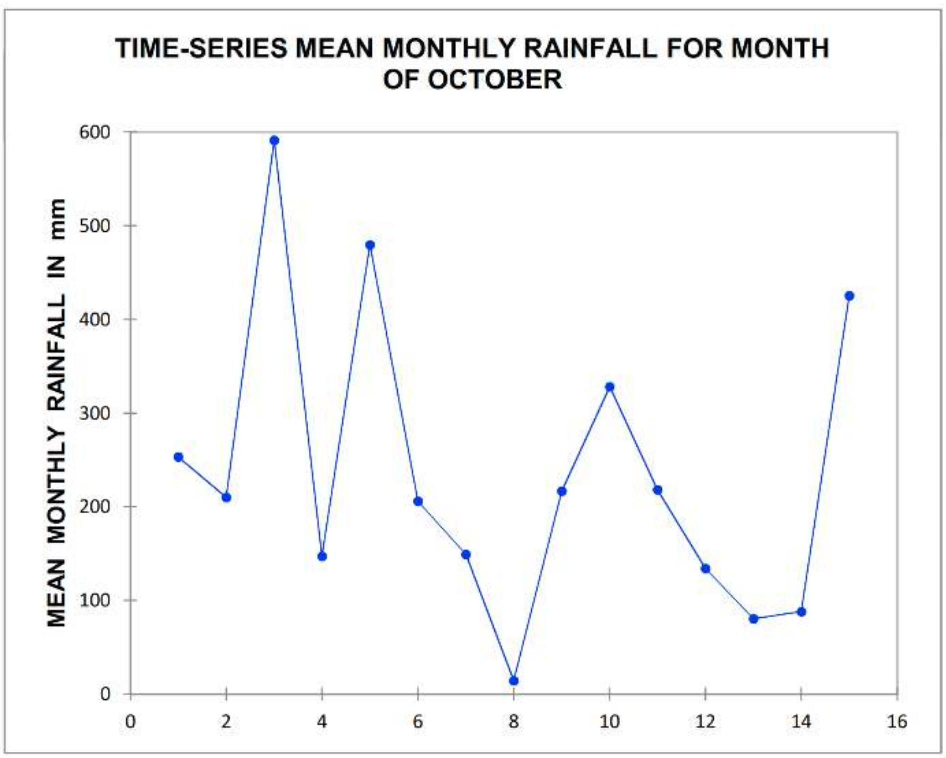
4.2.10 Mann-Kendall trend test / Upper-tailed test (OCTOBER):

Kendall's ta	-0.219
S	-23.000
Var(S)	408.333
p-value (on	0.880
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 88.03%.

Sen's slope: -10.161
Confidence interval:] -11.644 ,-8.041 [



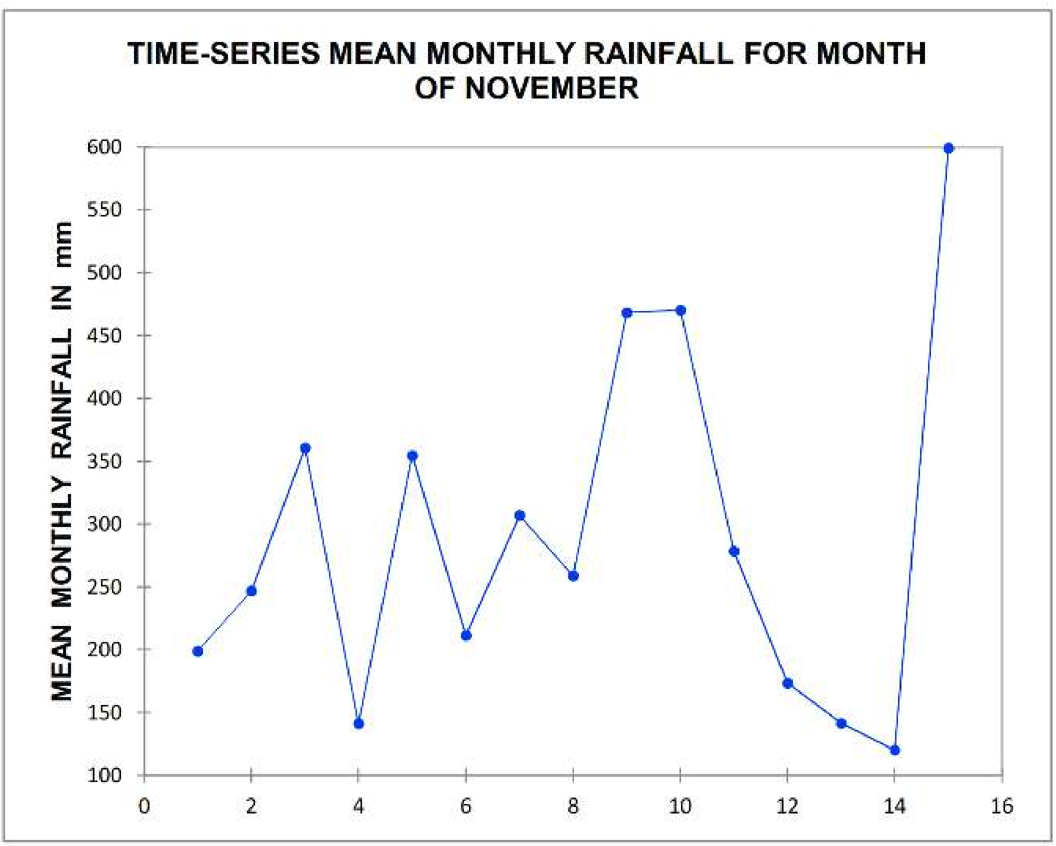
4.2.11 Mann-Kendall trend test / Upper-tailed test (NOVEMBER):

Kendall's ta	0.029
S	3.000
Var(S)	408.333
p-value (on	0.461
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 46.13%.

Sen's slope: 2
Confidence interval:] -2.239 ,3.104 [



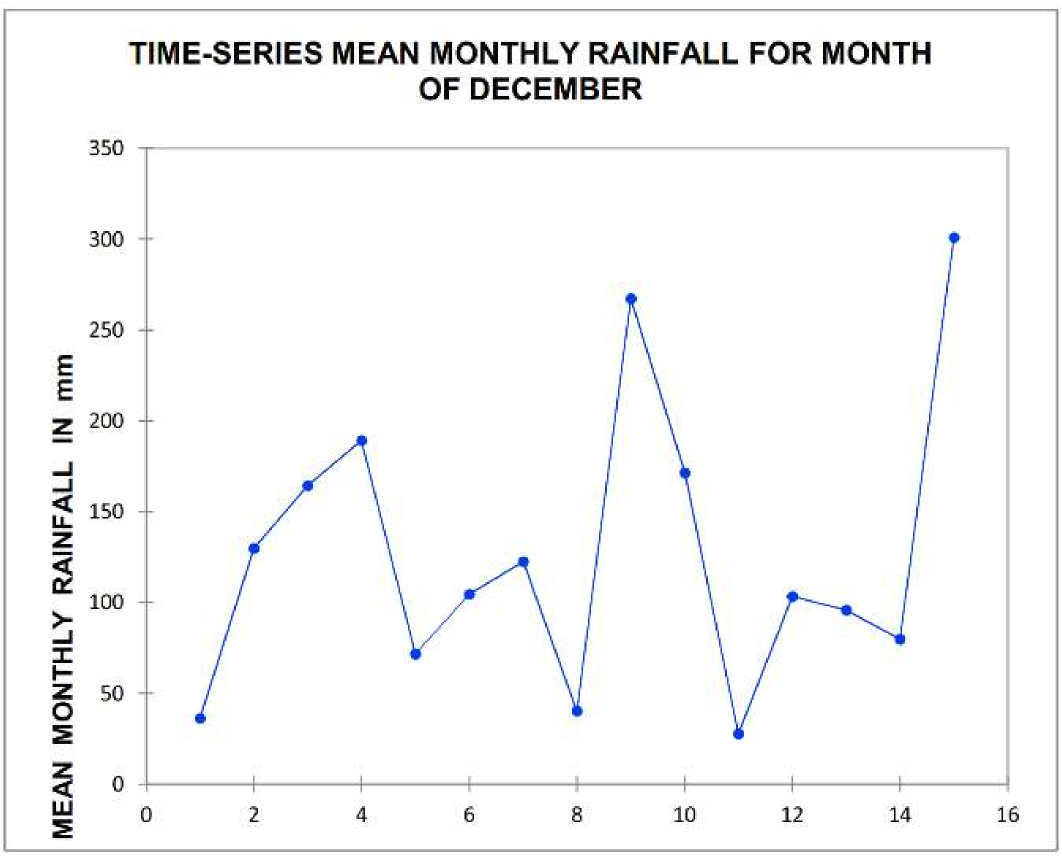
4.2.12 Mann-Kendall trend test / Upper-tailed test (DECEMBER):

Kendall's ta	0.029
S	3.000
Var(S)	408.333
p-value (on	0.461
alpha	0.05

An approximation has been used to compute the p-value.

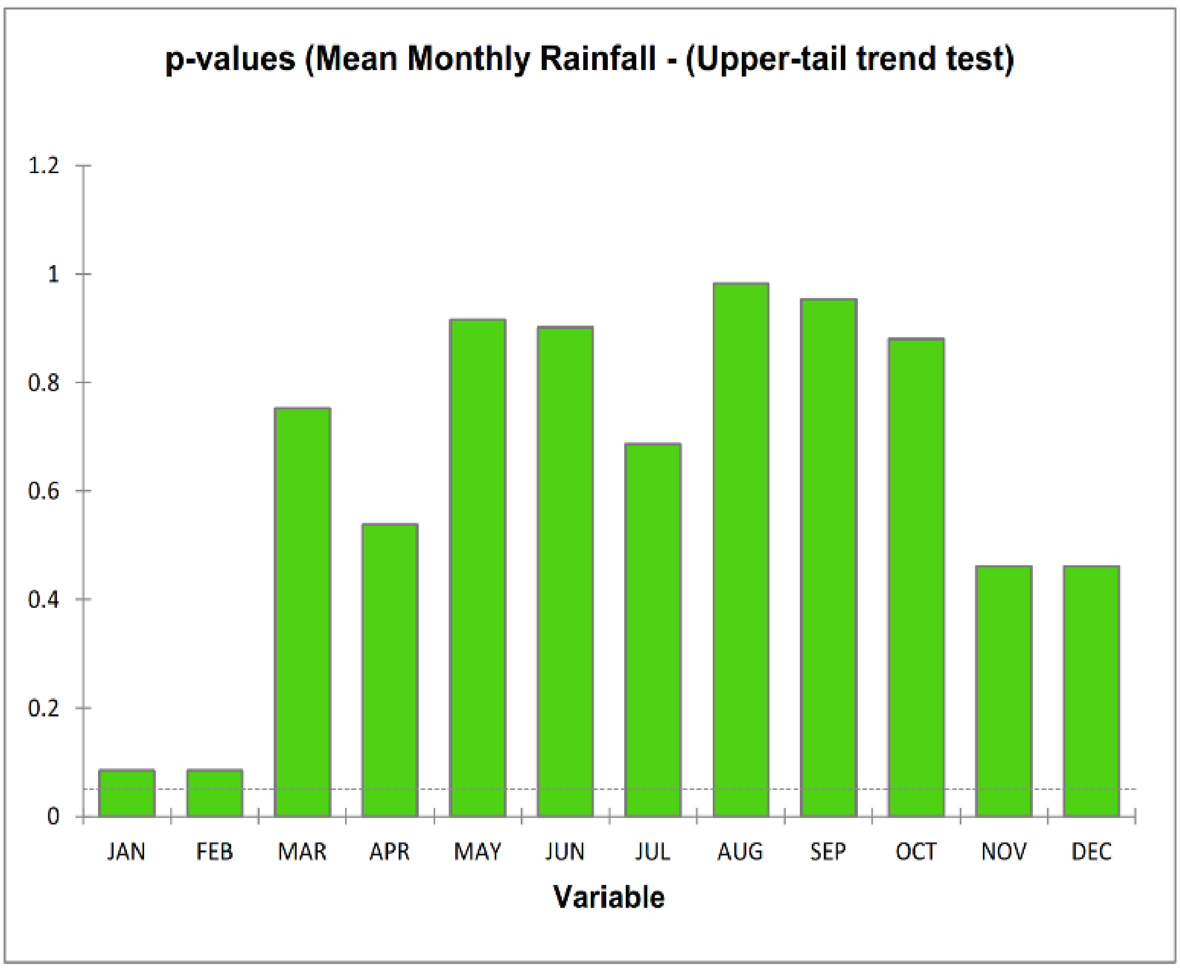
Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 46.13%.

Sen's slope: 0.898
Confidence interval:] -0.574 ,3.216 [



Summary:

Series\Test	Kendall's tau	p-value	Sen's slope
JANUARY	0.276	0.084	2.658
FEBRUARY	0.276	0.084	1.379
MARCH	-0.124	0.752	-2.792
APRIL	-0.010	0.539	-1.018
MAY	-0.257	0.916	-10.441
JUNE	-0.251	0.902	-0.885
JULY	-0.086	0.687	-0.186
AUGUST	-0.390	0.982	-1.920
SEPTEMBER	-0.325	0.954	-2.244
OCTOBER	-0.219	0.880	-10.161
NOVEMBER	0.029	0.461	2.000
DECEMBER	0.029	0.461	0.898



Appendix 4.3: Mean Monthly Precipitation (Mann-Kendall's Lower-Bound Trend Test)

XLSTAT 2018.1.49205 - Mann-Kendall trend tests - Start time: 1/24/2018 at 9:48:04 PM / End time: 1/24/2018 at 9:48:05 PM

Time series: Workbook = mean monthly precipitation.xlsx / Sheet = Sheet1 / Range = Sheet1!$B$1:$M$16 / 15 rows and 12 columns

Significance level (%): 5

Confidence interval (%)(Sen's slope): 95

Summary statistics

Summary statistics:

Variable	No. of observations	Entries with missing data	Entries without missing data	Mean rainfall	Maximum rainfall	Minimum rainfall	Standard Deviation
JANUARY	15	0	15	3.333	281.050	48.556	68.714
FEBRUARY	15	0	15	2.100	122.500	23.861	35.150
MARCH	15	0	15	15.517	349.267	97.328	97.326
APRIL	15	0	15	128.683	612.833	336.484	140.772
MAY	15	0	15	51.083	331.433	154.827	91.813
JUNE	15	0	15	0.000	46.767	15.228	15.861
JULY	15	0	15	0.000	29.550	14.593	8.691
AUGUST	15	0	15	0.000	56.783	17.733	16.992
SEPTEMBER	15	0	15	0.000	56.575	23.343	19.963
OCTOBER	15	0	15	14.333	591.133	236.131	158.889
NOVEMBER	15	0	15	120.200	599.000	288.712	139.697
DECEMBER	15	0	15	27.850	301.000	127.013	80.229

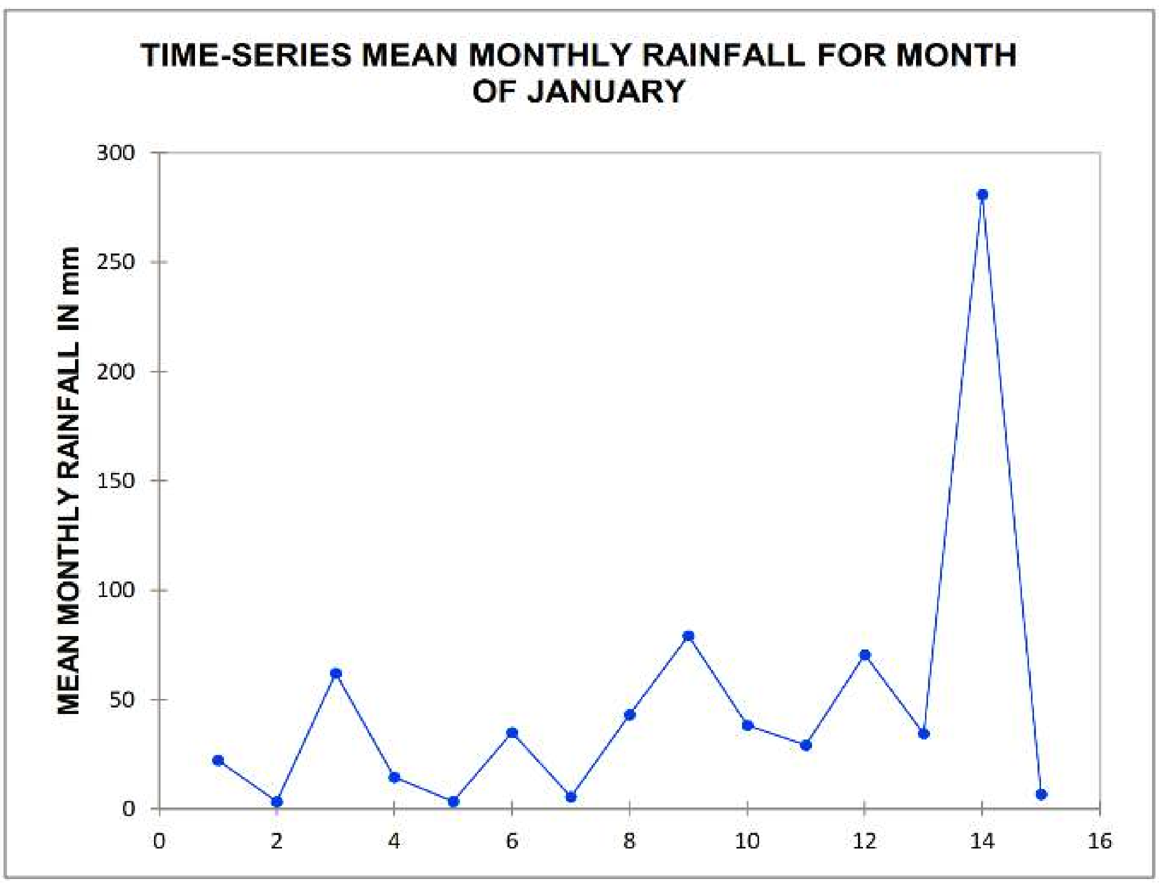
4.3.1 Mann-Kendall trend test / Lower-tailed test (JANUARY):

Kendall's tau	0.276
S	29.000
Var(S)	408.333
p-value (on	0.930
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 93.03%.

Sen's slope: 2.658
Confidence interval:] 2.147,2.870 [



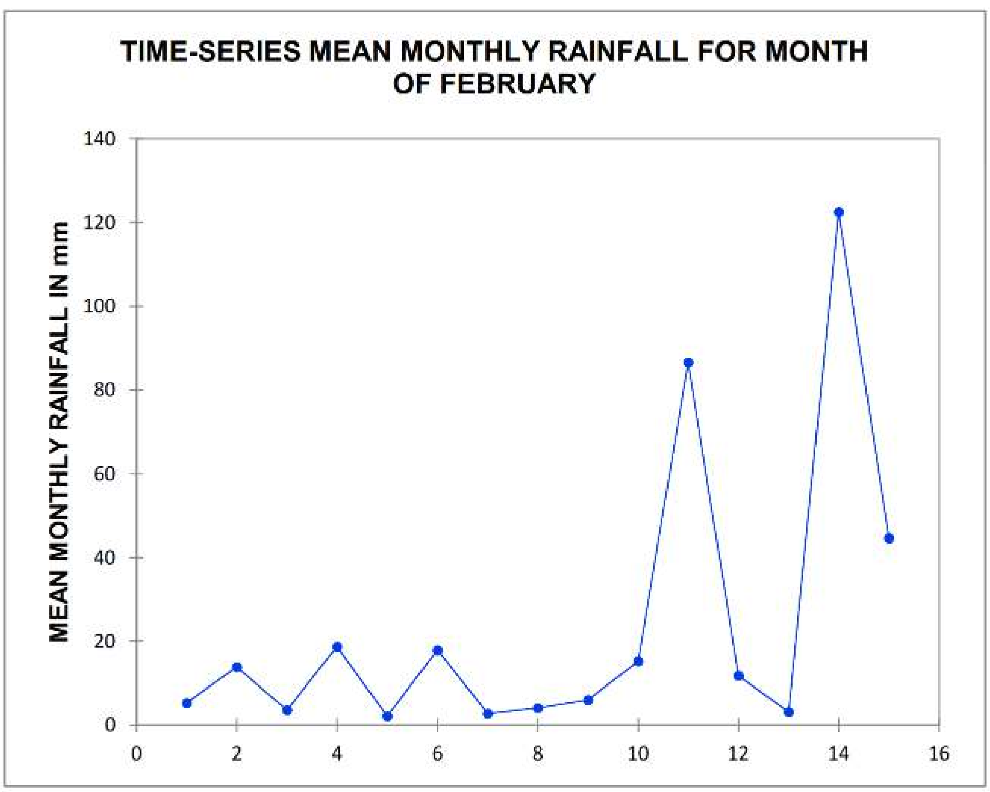
4.3.2 Mann-Kendall trend test / Lower-tailed test (FEB):

Kendall's ta	0.276
S	29.000
Var(S)	408.333
p-value (on	0.930
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 93.03%.

Sen's slope: 1.379
Confidence interval:] 1.047,1.742 [



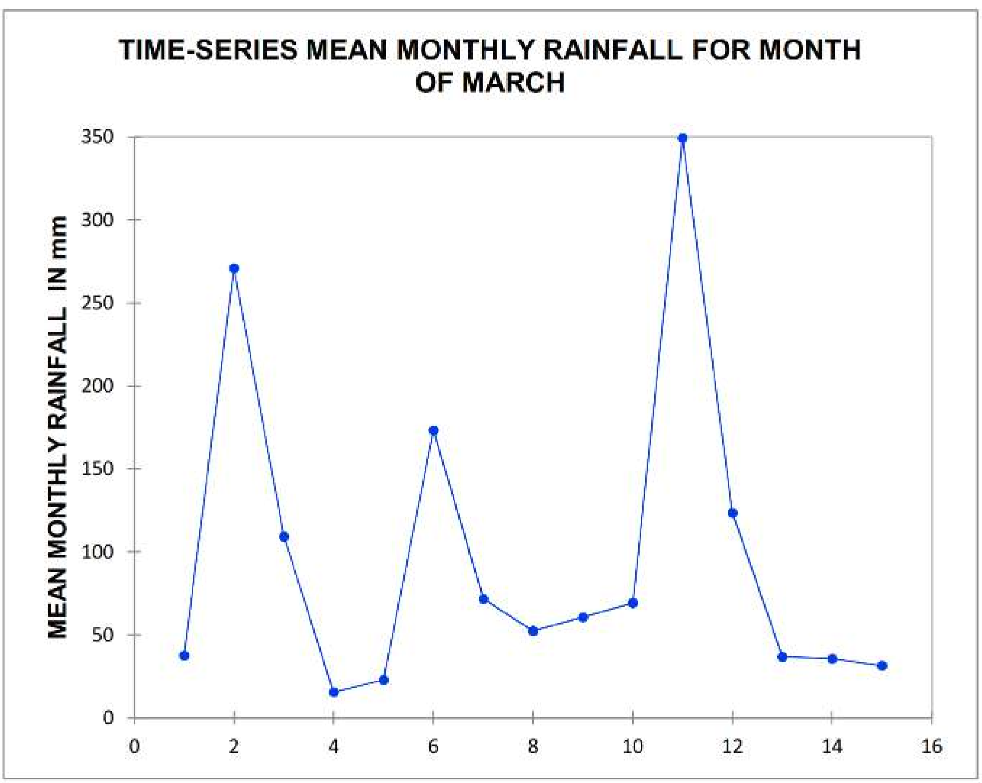
4.3.3 Mann-Kendall trend test / Lower-tailed test (MARCH):

Kendall's ta	-0.124
S	-13.000
Var(S)	408.333
p-value (on	0.279
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 27.95%.

Sen's slope: -2.792
Confidence interval:] -3.458 ,-0.933 [



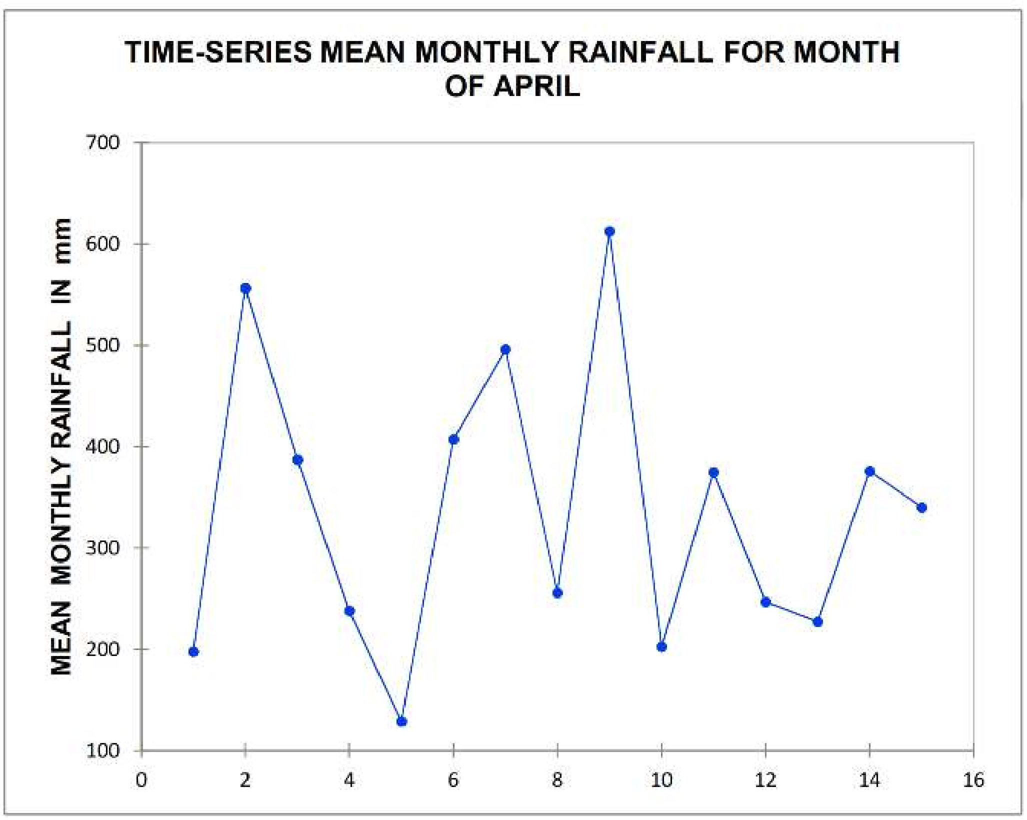
4.3.4 Mann-Kendall trend test / Lower-tailed test (APRIL):

Kendall's ta	-0.010
S	-1.000
Var(S)	408.333
p-value (on	0.500
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 50.00%.

Sen's slope: -1.018
Confidence interval:] -1.936 ,0.878 [



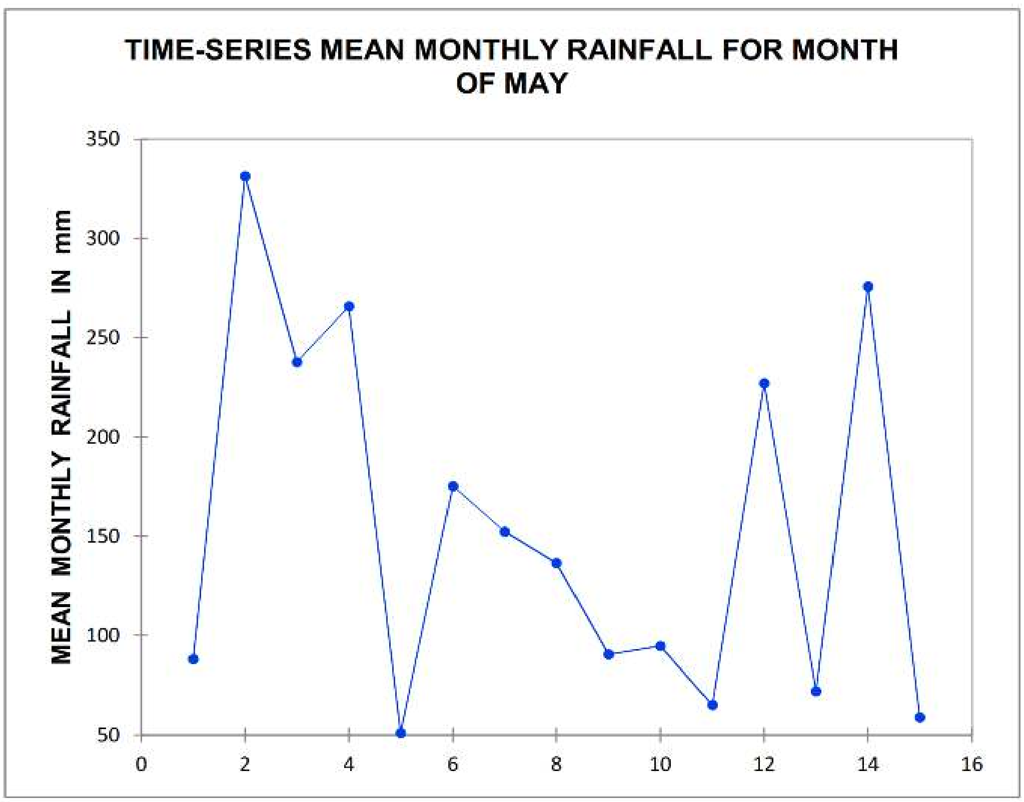
4.3.5 Mann-Kendall trend test / Lower-tailed test (MAY):

Kendall's ta	-0.257
S	-27.000
Var(S)	408.333
p-value (on	0.101
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 10.09%.

Sen's slope: -10.441
Confidence interval:] -12.268 ,-7.328 [



4.3.6 Mann-Kendall trend test / Lower-tailed test (JUNE):

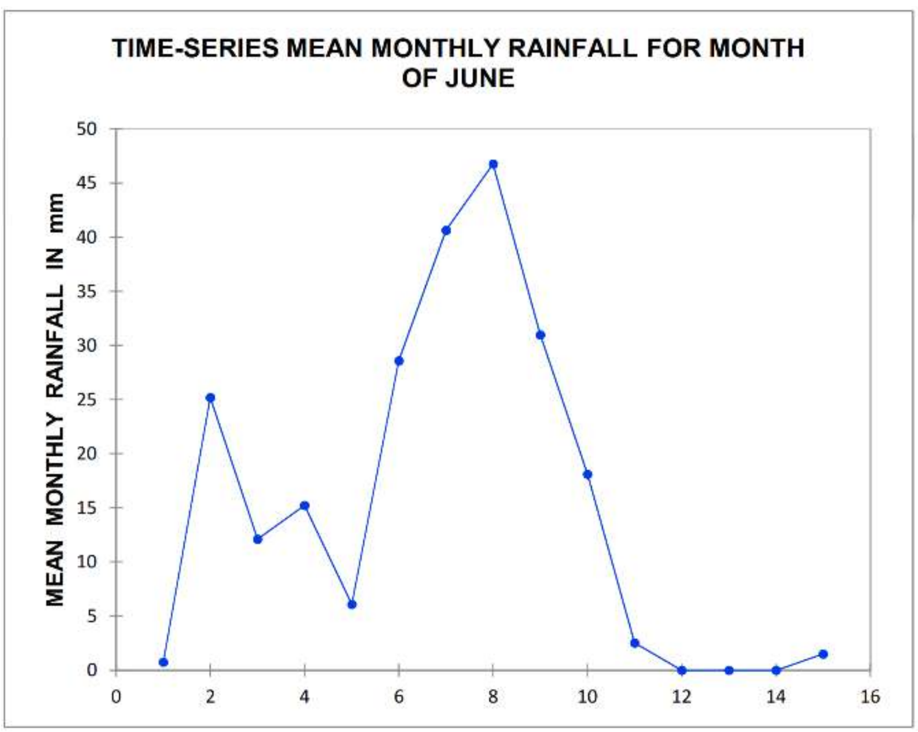
Kendall's ta	-0.251
S	-26.000
Var(S)	404.667
p-value (on	0.098
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 9.81%.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope: -0.885
Confidence interval:] -1.204 ,-0.854 [



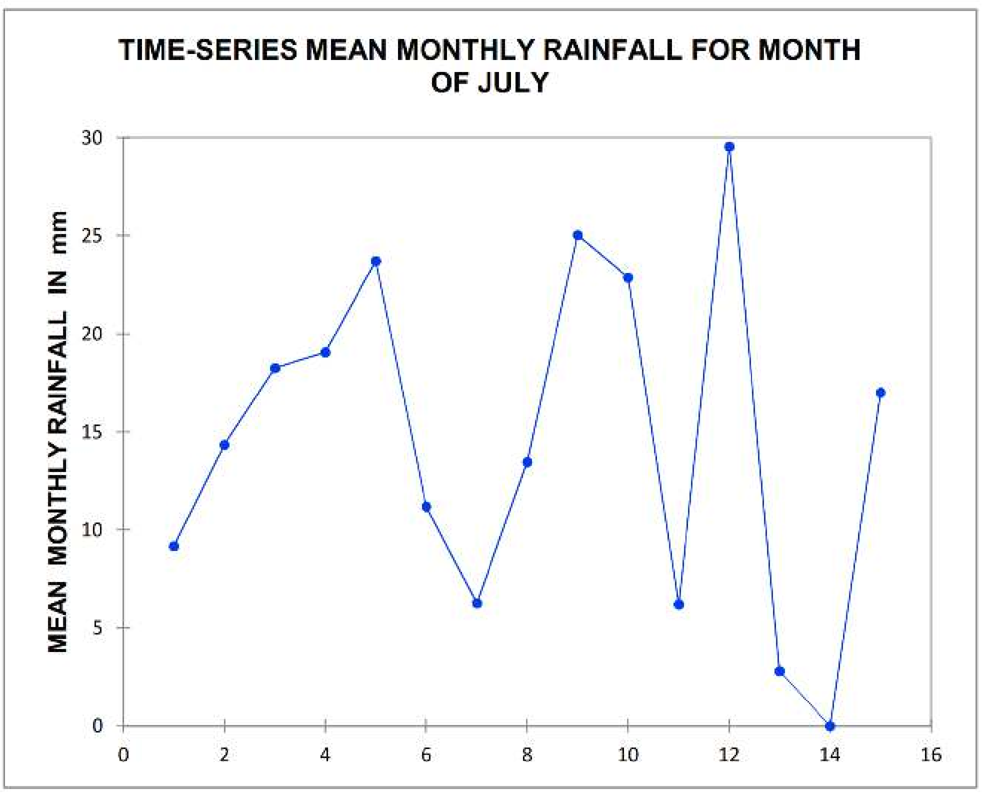
4.3.7 Mann-Kendall trend test / Lower-tailed test (JULY):

Kendall's ta	-0.086
S	-9.000
Var(S)	408.333
p-value (on	0.349
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 34.86%.

Sen's slope: -0.186
Confidence interval:] -0.512 ,-0.123 [



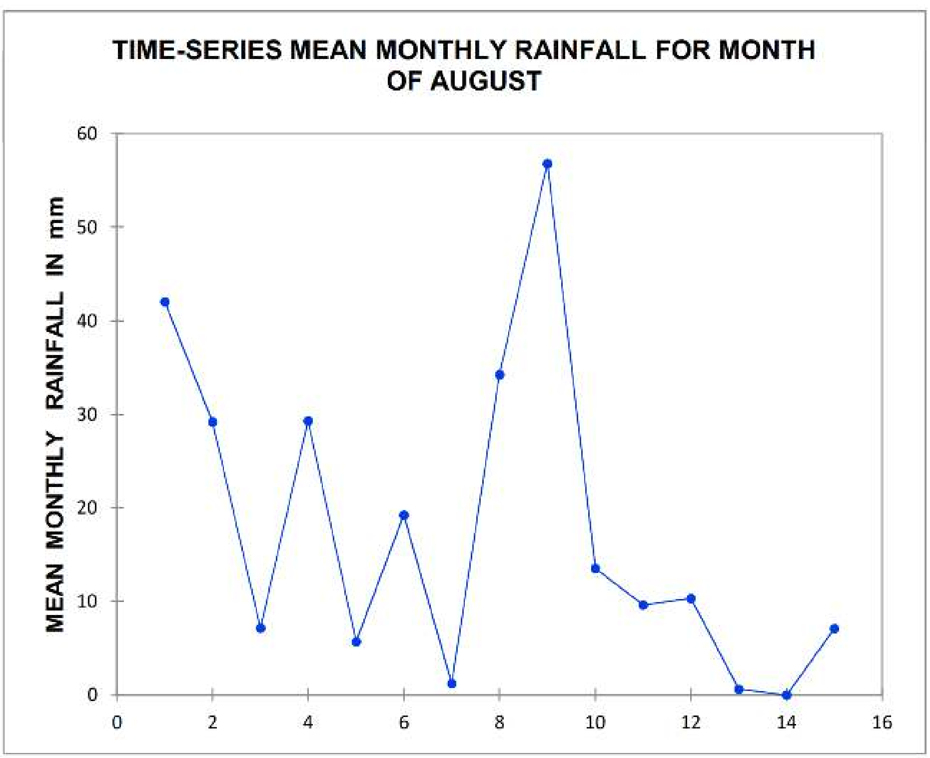
4.3.8 Mann-Kendall trend test / Lower-tailed test (AUGUST):

Kendall's ta	-0.390
S	-41.000
Var(S)	408.333
p-value (on	0.023
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
The risk to reject the null hypothesis H0 while it is true is lower than 2.31%.

Sen's slope: -1.92
Confidence interval:] -2.112 ,-1.642 [



4.3.9 Mann-Kendall trend test / Lower-tailed test (SEPTEMBER):

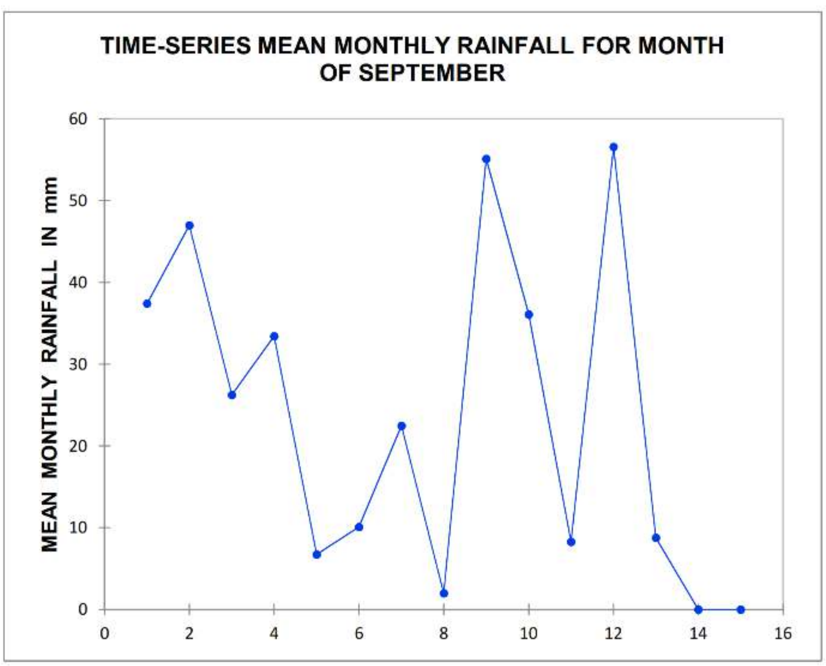
Kendall's ta	-0.325
S	-34.000
Var(S)	407.333
p-value (on	0.046
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
The risk to reject the null hypothesis H0 while it is true is lower than 4.60%.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope: -2.244
Confidence interval:] -2.386 ,-1.876 [



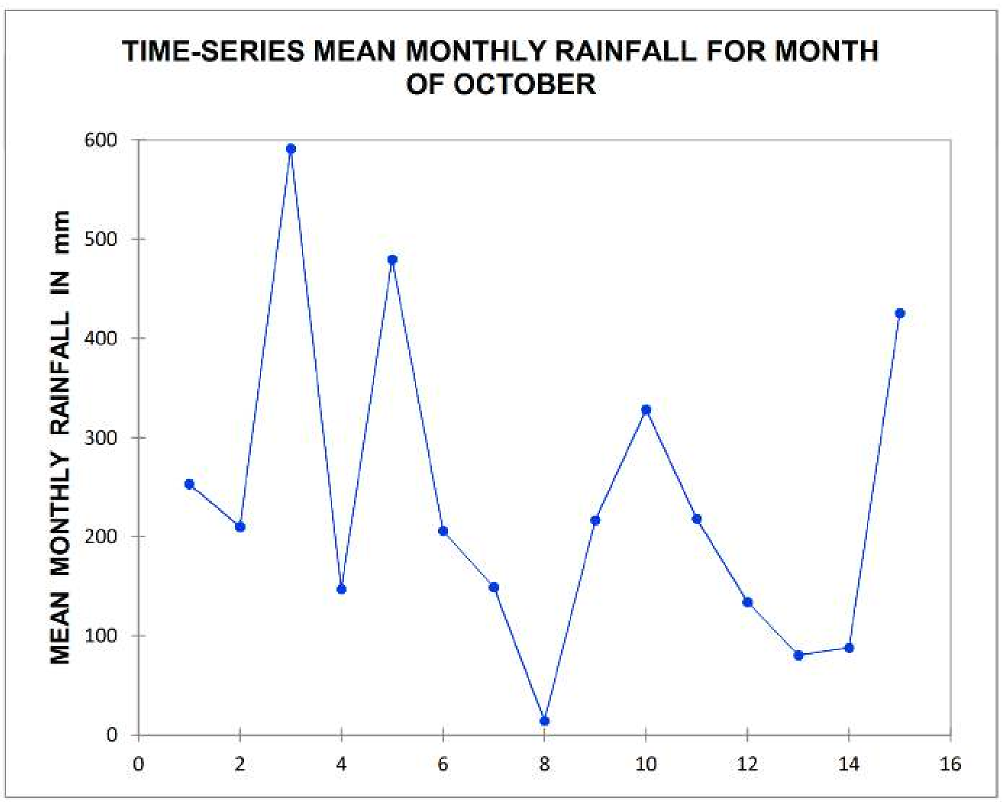
4.3.10 Mann-Kendall trend test / Lower-tailed test (OCTOBER):

Kendall's ta	-0.219
S	-23.000
Var(S)	408.333
p-value (on	0.141
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 14.08%.

Sen's slope: -10.161
Confidence interval:] -11.644 ,-8.041 [



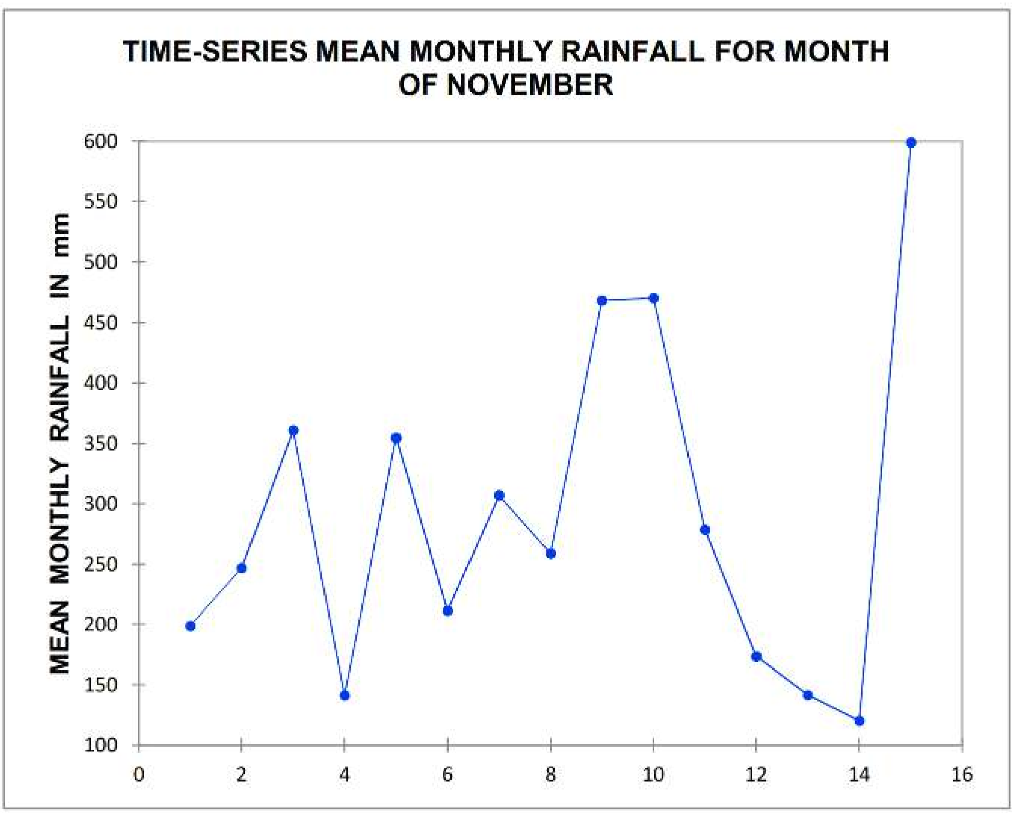
4.3.11 Mann-Kendall trend test / Lower-tailed test (NOVEMBER):

Kendall's ta	0.029
S	3.000
Var(S)	408.333
p-value (on	0.577
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 57.71%.

Sen's slope: 2
Confidence interval:] -2.239 ,3.104 [



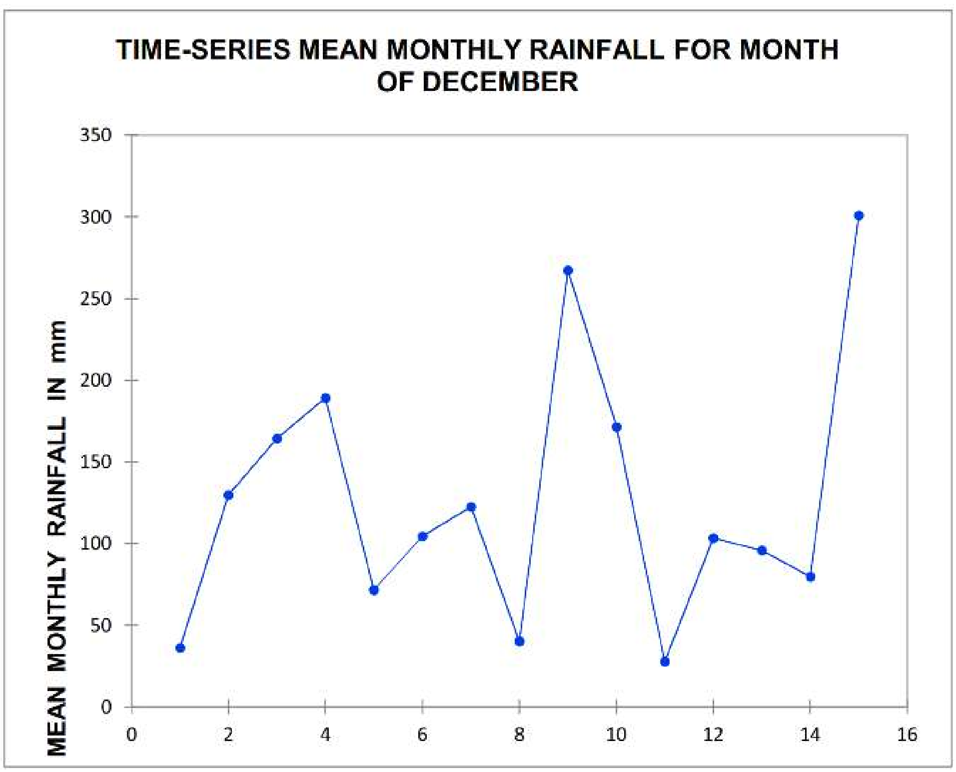
4.3.12 Mann-Kendall trend test / Lower-tailed test (DECEMBER):

Kendall's ta	0.029
S	3.000
Var(S)	408.333
p-value (on	0.577
alpha	0.05

An approximation has been used to compute the p-value.

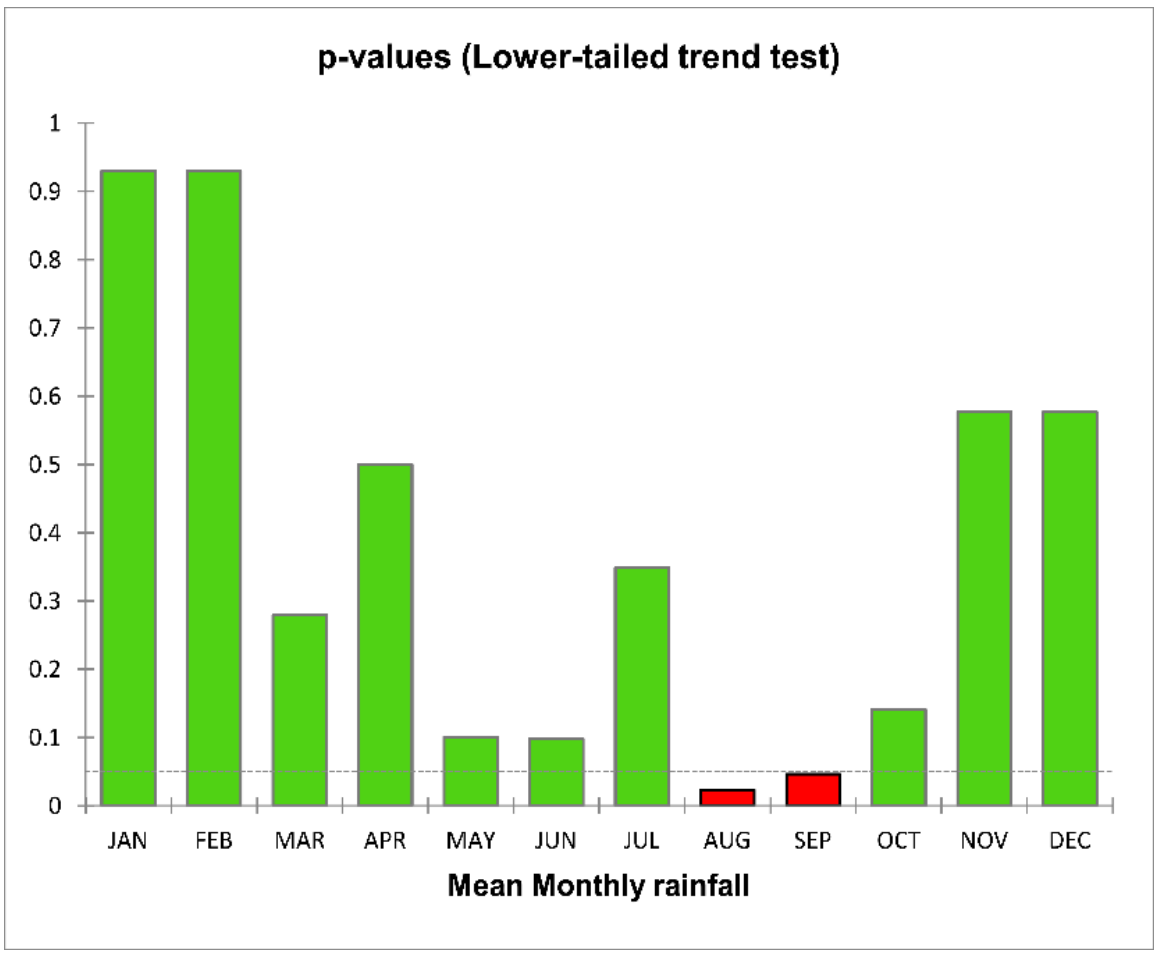
Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 57.71%.

Sen's slope: 0.898
Confidence interval:] -0.574 ,3.216 [



Summary:

Series\Test	Kendall's	p-value	Sen's slope
JANUARY	0.276	0.930	2.658
FEBRUARY	0.276	0.930	1.379
MARCH	-0.124	0.279	-2.792
APRIL	-0.010	0.500	-1.018
MAY	-0.257	0.101	-10.441
JUNE	-0.251	0.098	-0.885
JULY	-0.086	0.349	-0.186
AUGUST	-0.390	**0.023**	-1.920
SEPTEMBER	-0.325	**0.046**	-2.244
OCTOBER	-0.219	0.141	-10.161
NOVEMBER	0.029	0.577	2.000
DECEMBER	0.029	0.577	0.898



Appendix 4.4: Mean Annual Precipitation (Mann-Kendall's Two-tail Trend Test)

XLSTAT2018.1.49205-Mann-Kendalltrendtests-
Starttime:1/24/2018at8:51:27PM/Endtime:1/24/2018at8:51:30PM

Timeseries:Workbook=meanannualprecipitation.xlsx/Sheet=Sheet1/Range=
Sheet1!$N$1:$N$16/15rowsand1column

Significance level(%):5
Confidence interval(%)(Sen's slope):95

Summary statistics

Summary statistics:

Variable	No. of observations	Entries with missing data	Entries without missing data	Mean rainfall	Maximum rainfall	Minimum rainfall	Standard Deviation
Mean Ann	15	0	15	58.621	164.961	115.317	33.167

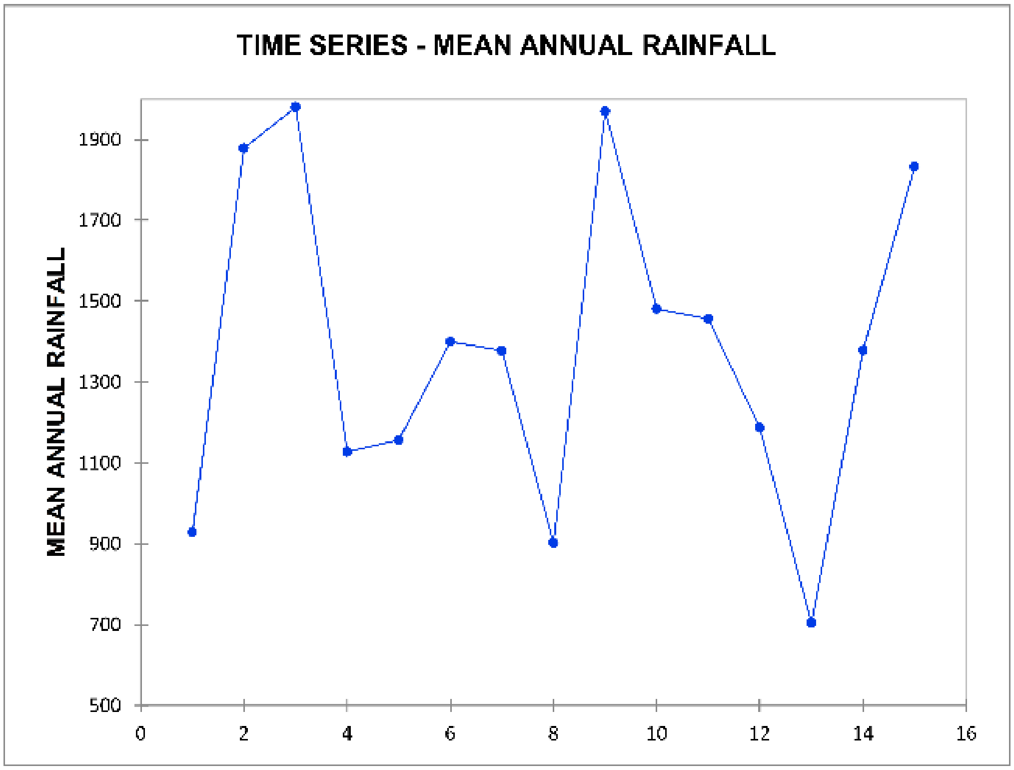
4.4.1 Mann-Kendall trend test/Two-tailed test (ANNUAL AVERAGE RAINFALL):

Kendall's tau	0.010
S	1.000
Var(S)	408.333
p-value(Tw	1.000
alpha	0.05

An approximation has been used to compute the p-value.

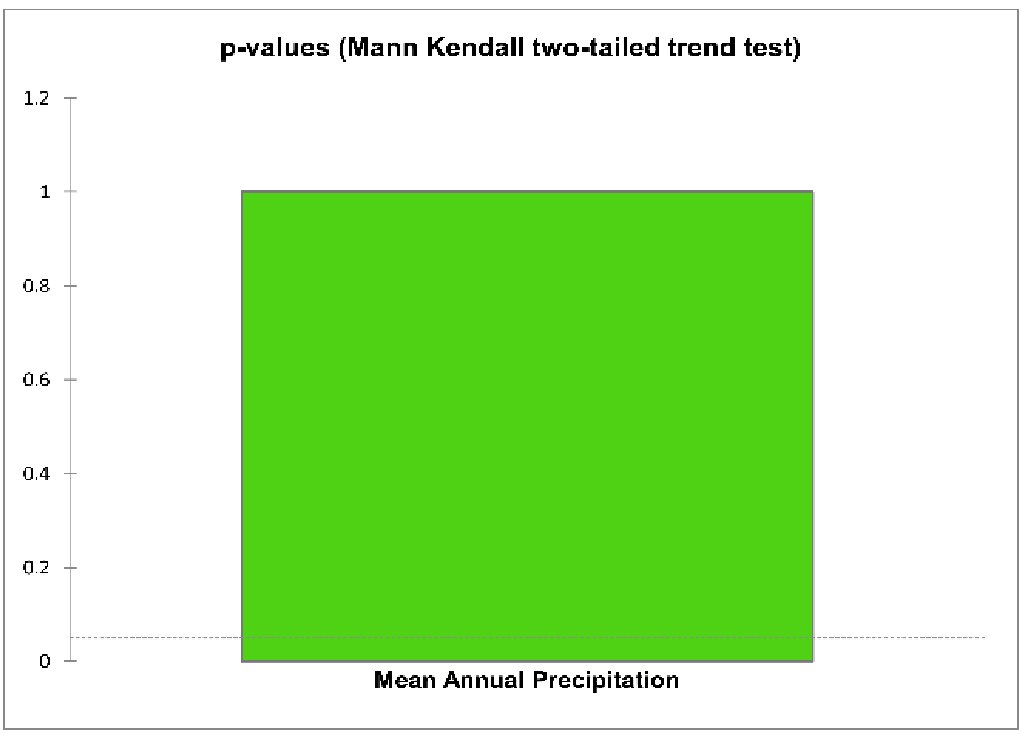
Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 100.00%.

Sen's slope:0.015
Confidence interval:]-0.261,0.818[



Summary:

Series\Test	Kendall's tau	p-value	Sen's slope
ANNUALA	0.010	1.000	0.015



Appendix 4.5: Mean Annual Precipitation (Mann-Kendall's Lower- Bound Trend Test)

XLSTAT2018.1.49205-Mann-Kendalltrendtests-Starttime:1/24/2018at8:52:54PM/Endtime: 1/24/2018at8:52:55PM

Timeseries:Workbook=meanannualprecipitation.xlsx/Sheet=Sheet1/Range=Sheet1!$N$1:$N$16/15rowsand1column

Significance level(%):5
Confidence interval(%)(Sen's slope):95

Summary statistics

Summary statistics:

Variable	No. of observations	Entries with missing data	Entries without missing data	Mean rainfall	Maximum rainfall	Minimum rainfall	Standard Deviation
Mean Ann	15	0	15	58.621	164.961	115.317	33.167

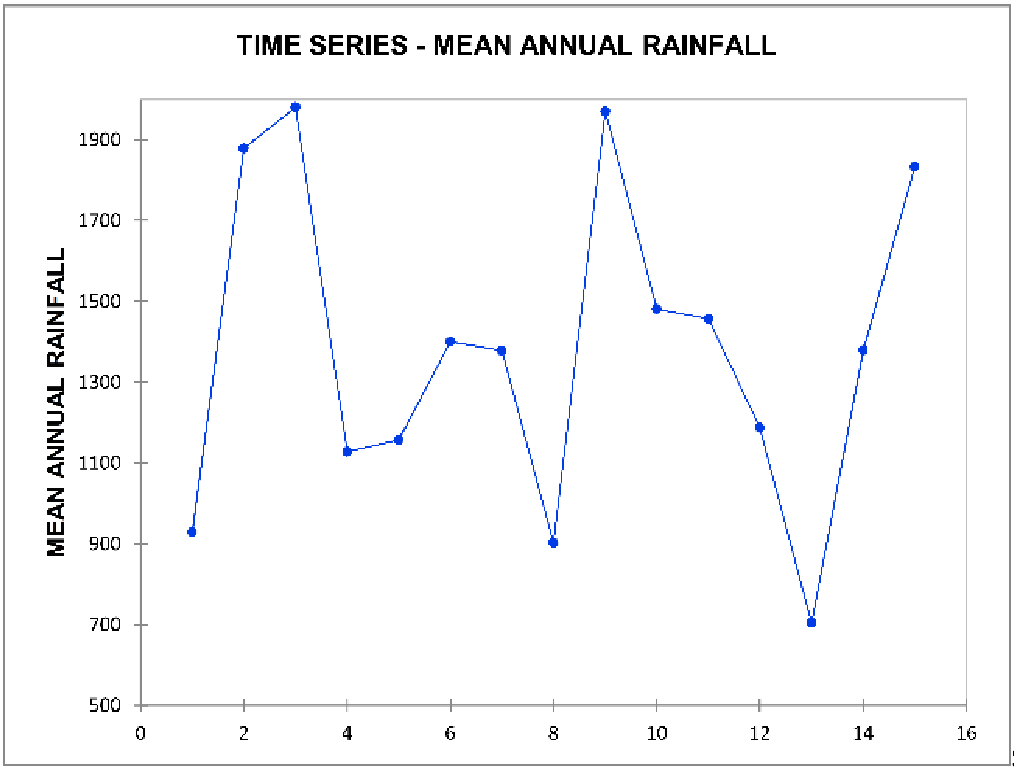
4.5.1 Mann-Kendall trend test/Lower-tailed test (ANNUAL AVERAGE RAINFALL):

Kendall's tau	0.010
S	1.000
Var(S)	408.333
p-value(on	0.539
alpha	0.05

An approximation has been used to compute the p-value.

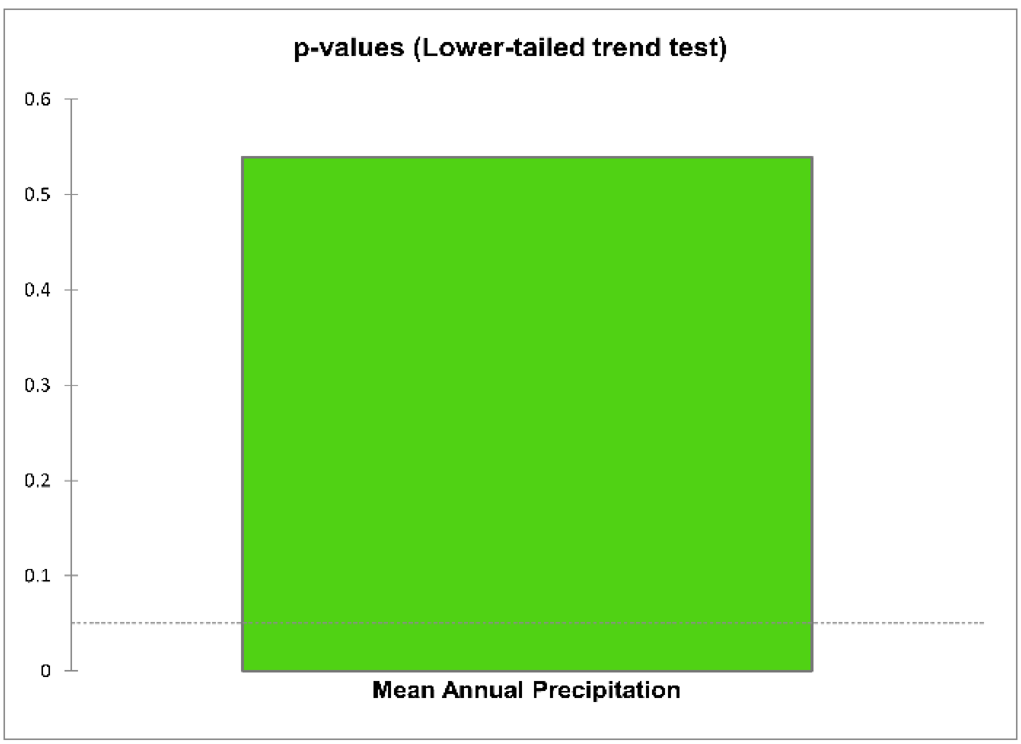
Test interpretation:
H0:There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 53.87%.

Sen's slope:0.015
Confidence interval:]-0.261,0.818[



Summary:

Series\Test	Kendall's tau	p-value	Sen's slope
ANNUALA	0.010	0.539	0.015



Appendix 4.6: Mean Annual Precipitation (Mann-Kendall's Upper Bound Trend Test)

XLSTAT2018.1.49205-Mann-Kendalltrendtests-Starttime:1/24/2018at8:53:26PM/Endtime: 1/24/2018at8:53:29PM

Timeseries:Workbook=meanannualprecipitation.xlsx/Sheet=Sheet1/Range=Sheet1!$N$1:$N$16/15rowsand1column

Significance level(%):5
Confidence interval(%)(Sen's slope):95

Summary statistics

Summary statistics:

Variable	No. of observations	Entries with missing data	Entries without missing data	Mean rainfall	Maximum rainfall	Minimum rainfall	Standard Deviation
Mean Ann	15	0	15	58.621	164.961	115.317	33.167

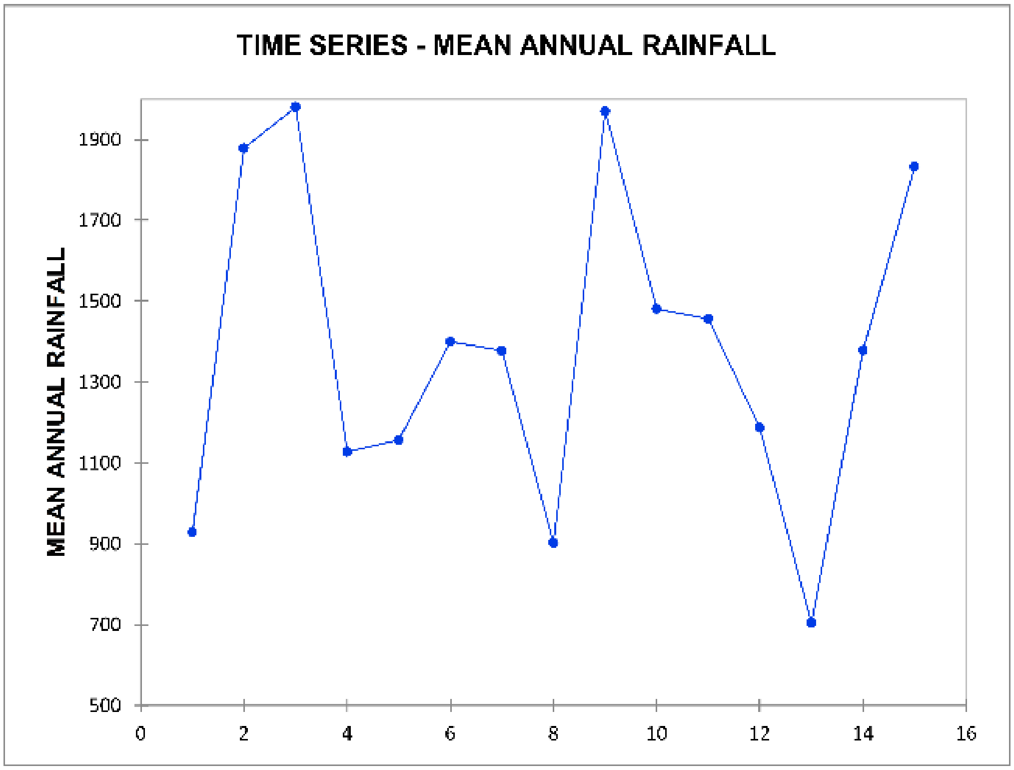
4.6.1 Mann-Kendall trend test/Upper-tailed test (ANNUAL AVERAGE RAINFALL):

Kendall's tau	0.010
S	1.000
Var(S)	408.333
p-value(on	0.500
alpha	0.05

An approximation has been used to compute the p-value.

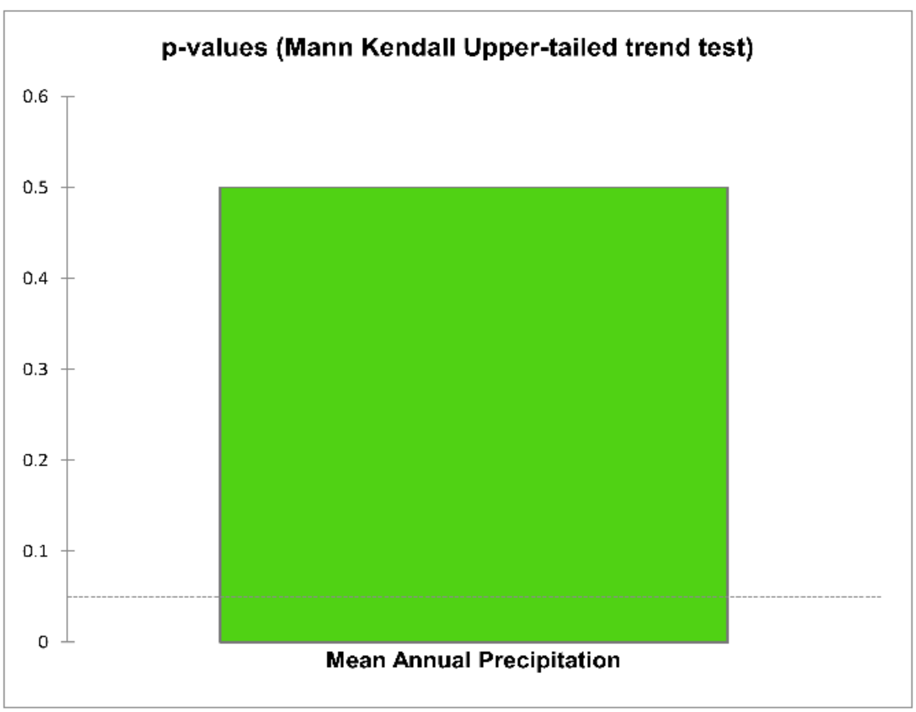
Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 50.00%.

Sen'sslope:0.015
Confidence interval:]-0.261,0.818[



Summary:

Series\Test	Kendall'stau	p-value	Sen's slope
ANNUALA	0.010	0.500	0.015



Appendix 4.7: Mean Monthly Discharge (Mann-Kendall's Two-tail Trend Test)

XLSTAT 2018.1.49205 - Mann-Kendall trend tests - Start time: 1/24/2018 at 10:16:25 PM / End time:1/24/2018 at 10:16:38 PM

Time series: Workbook = MSc. Mean MONTHLY DISCHARGE.xlsx / Sheet = Sheet1 / Range = Sheet1!$A$1:$L$42 / 41 rows and 12 columns

Significance level (%): 5

Summary statistics

Summary statistics:

Variable	No. of	Entries	Entries	Mean	Maximum	Minimum	Standard
JANUARY	41	0	41	284.034	8623.875	1824.499	1774.210
FEBRUARY	41	0	41	265.638	6620.180	1463.870	1378.889
MARCH	41	0	41	193.039	7313.974	1693.859	1457.473
APRIL	41	0	41	491.362	7209.613	2670.879	1501.883
MAY	41	0	41	614.647	9591.139	2824.015	1648.884
JUNE	41	0	41	410.246	7563.013	1744.075	1208.596
JULY	41	0	41	343.782	3836.178	1239.916	766.594
AUGUST	41	0	41	295.655	3832.019	1023.399	787.014
SEPTEMBER	41	0	41	230.508	3704.445	829.486	753.981
OCTOBER	41	0	41	378.175	3900.275	1459.705	992.803
NOVEMBER	41	0	41	973.558	6330.025	2674.226	1253.991
DECEMBER	41	0	41	637.754	6253.747	2446.422	1423.865

4.7.1 Mann-Kendall trend test / Two-tailed test (JANUARY):

Kendall's ta	0.667
S'	24.000
Var(S')	152.667
p-value (Tw	0.052
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

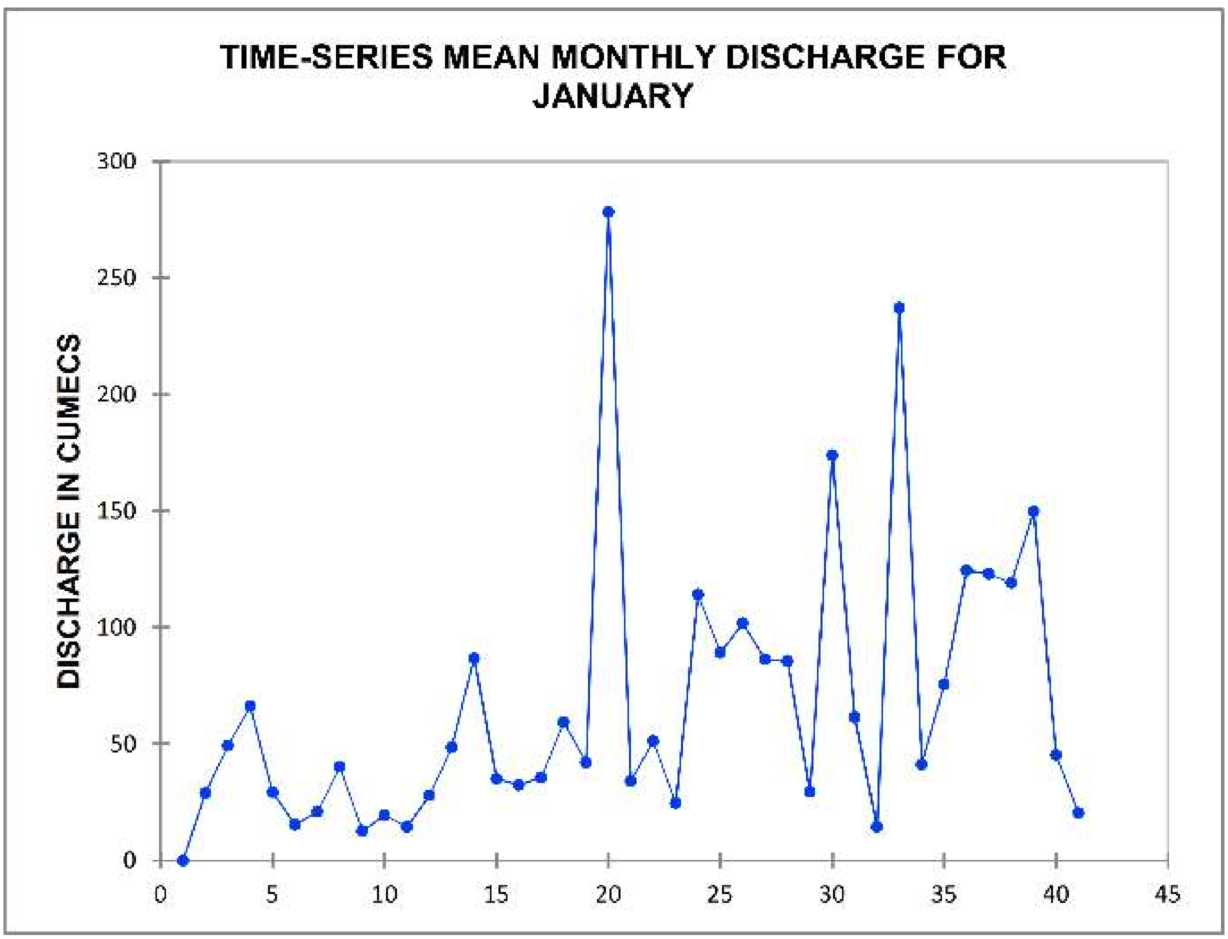
H0: There is no trend in the series

Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 5.21%.

Sen's slope (Period = 1 600.305



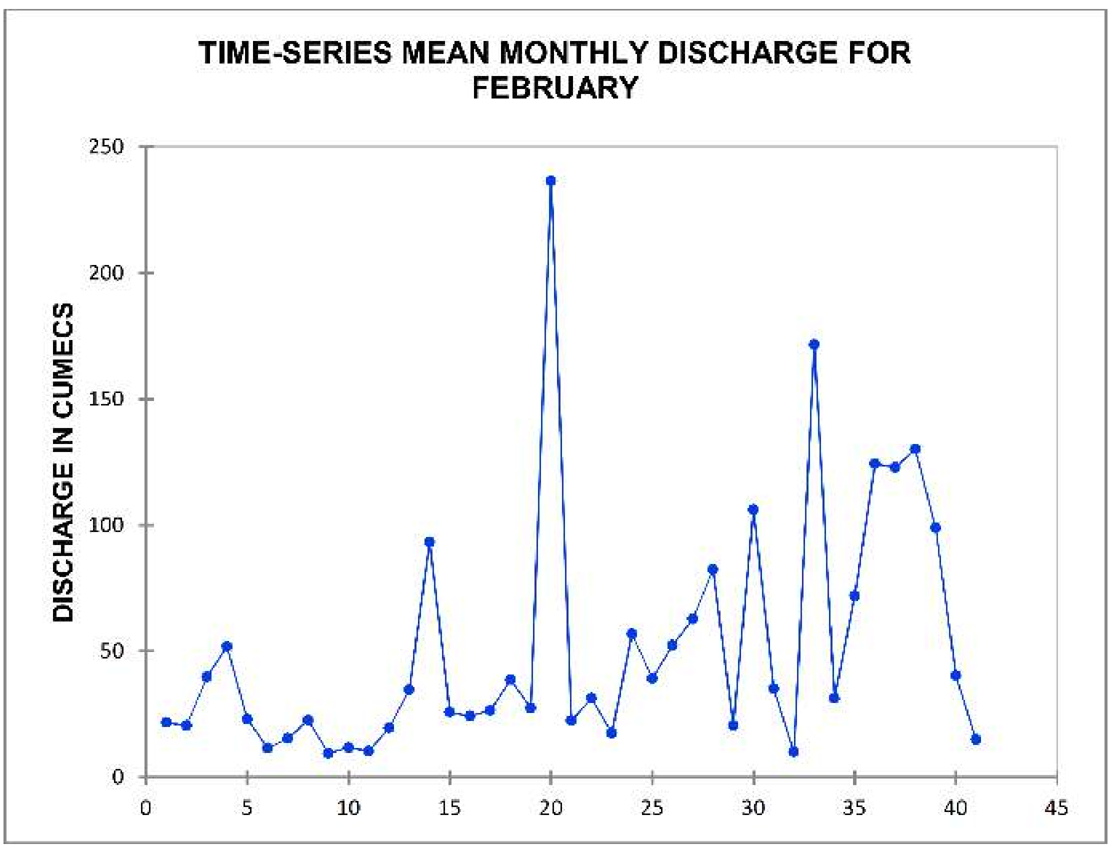
4.7.2 Mann-Kendall trend test / Two-tailed test (FEBRUARY):

Kendall's ta	0.556
S'	20.000
Var(S')	115.333
p-value (Tw	0.063
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 6.26%.

Sen's slope (Period = 1 366.162



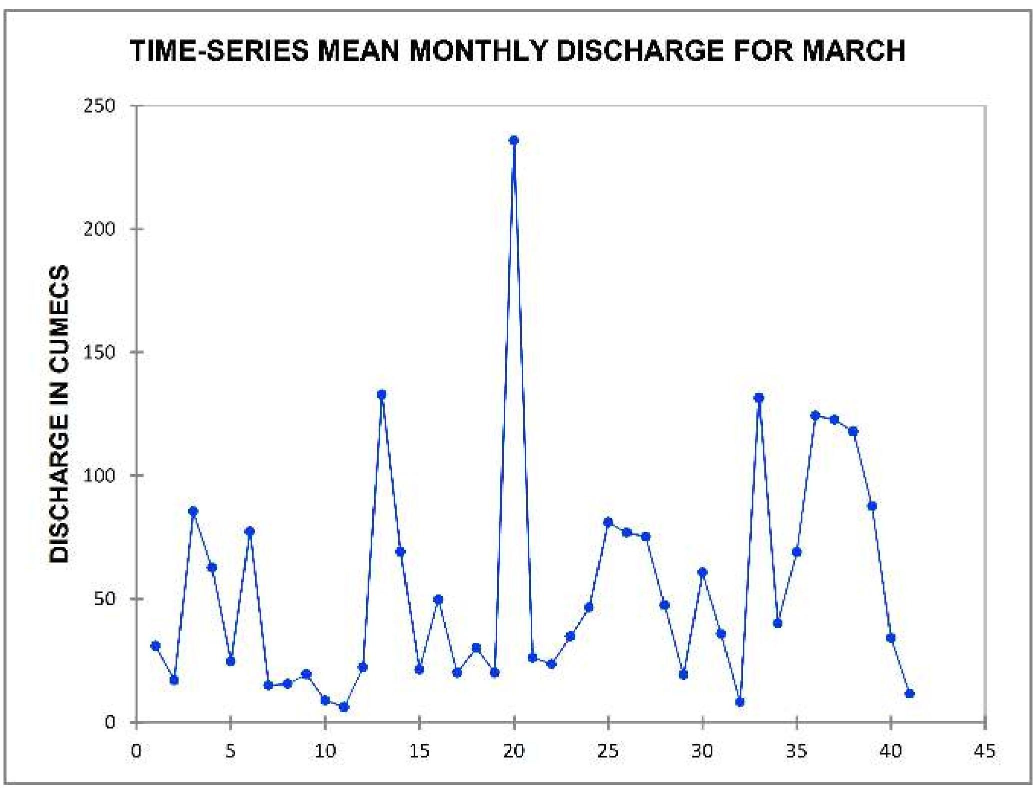
4.7.3 Mann-Kendall trend test / Two-tailed test (MARCH):

Kendall's ta	0.278
S'	10.000
Var(S')	40.000
p-value (Tw	0.114
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 11.38%.

Sen's slope (Period = 1 403.346



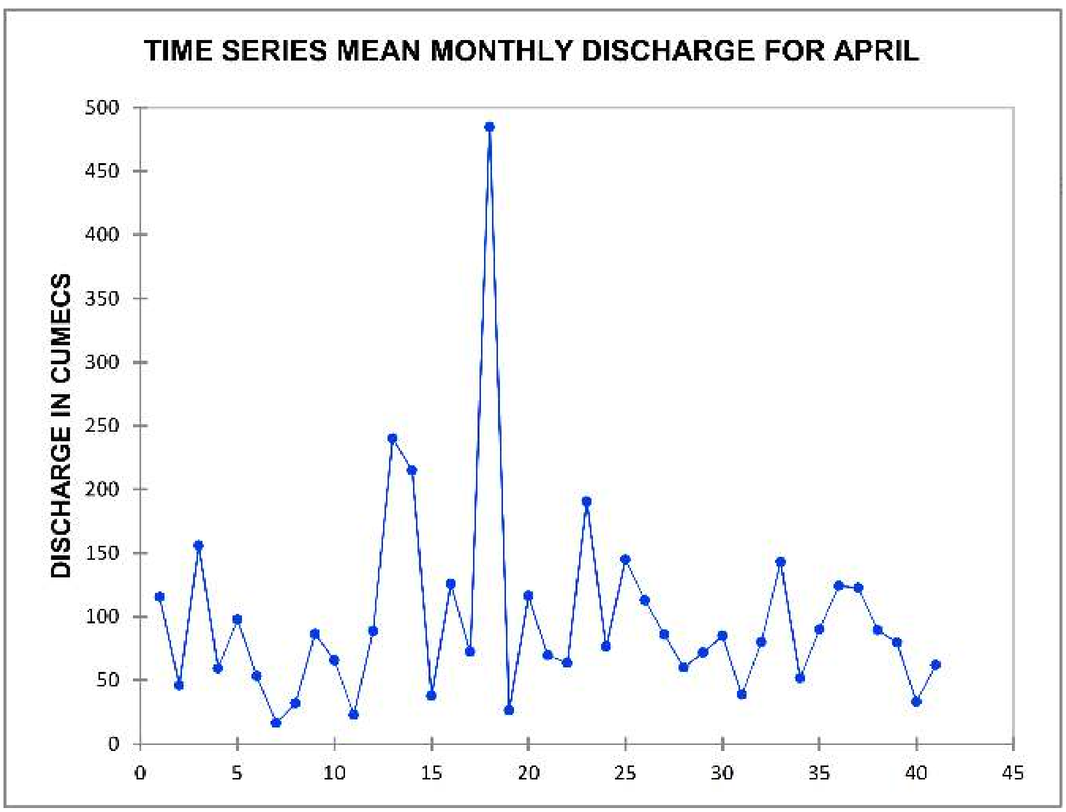
4.7.4 Mann-Kendall trend test / Two-tailed test (APRIL):

Kendall's ta	0.111
S'	4.000
Var(S')	48.667
p-value (Tw	0.566
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 56.64%.

Sen's slope (Period = 1 459.914



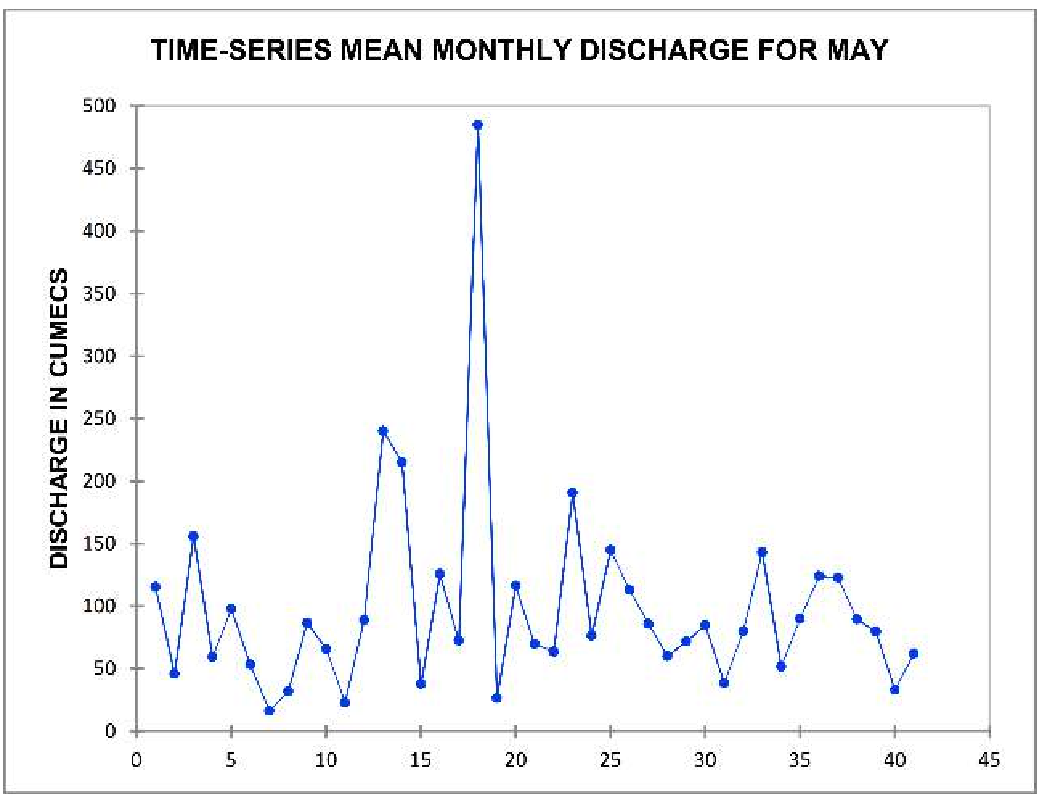
4.7.5 Mann-Kendall trend test / Two-tailed test (MAY):

Kendall's ta	0.056
S'	2.000
Var(S')	45.333
p-value (Tw	0.766
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 76.64%.

Sen's slope (Period = 1 204.489



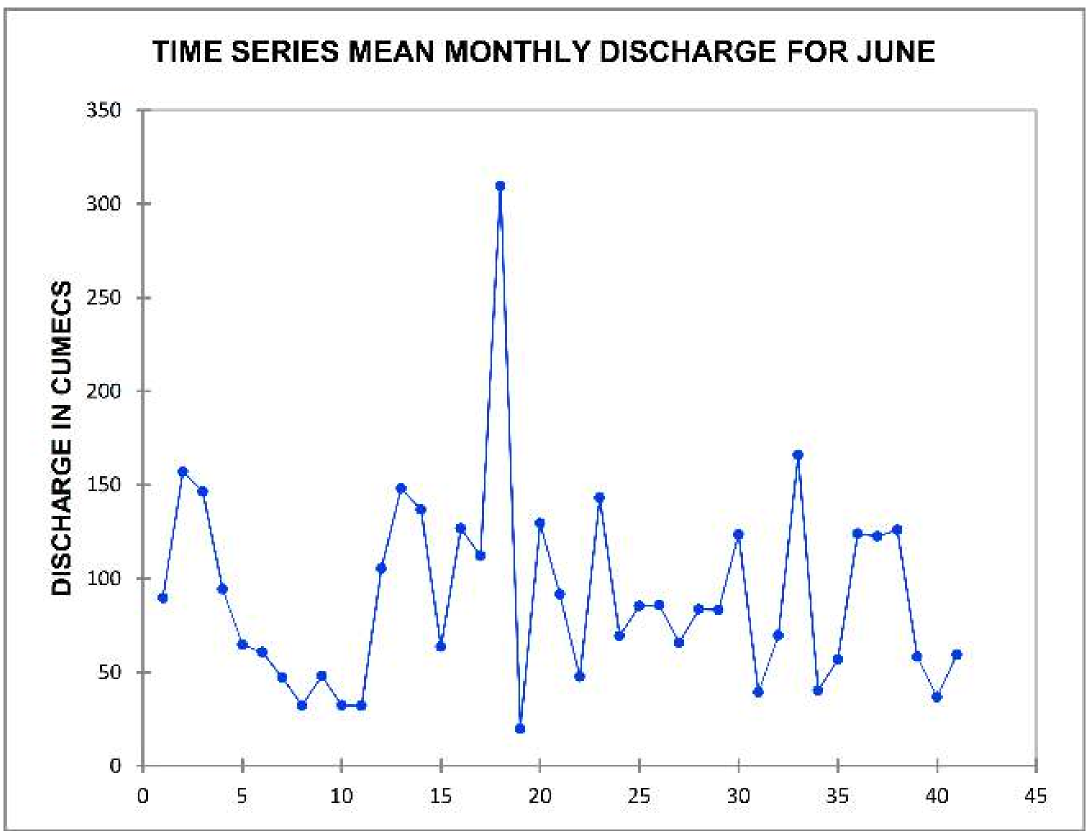
4.7.6 Mann-Kendall trend test / Two-tailed test (JUNE):

Kendall's ta	0.333
S'	12.000
Var(S')	88.667
p-value (Tw	0.203
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 20.25%.

Sen's slope (Period = 1 186.213



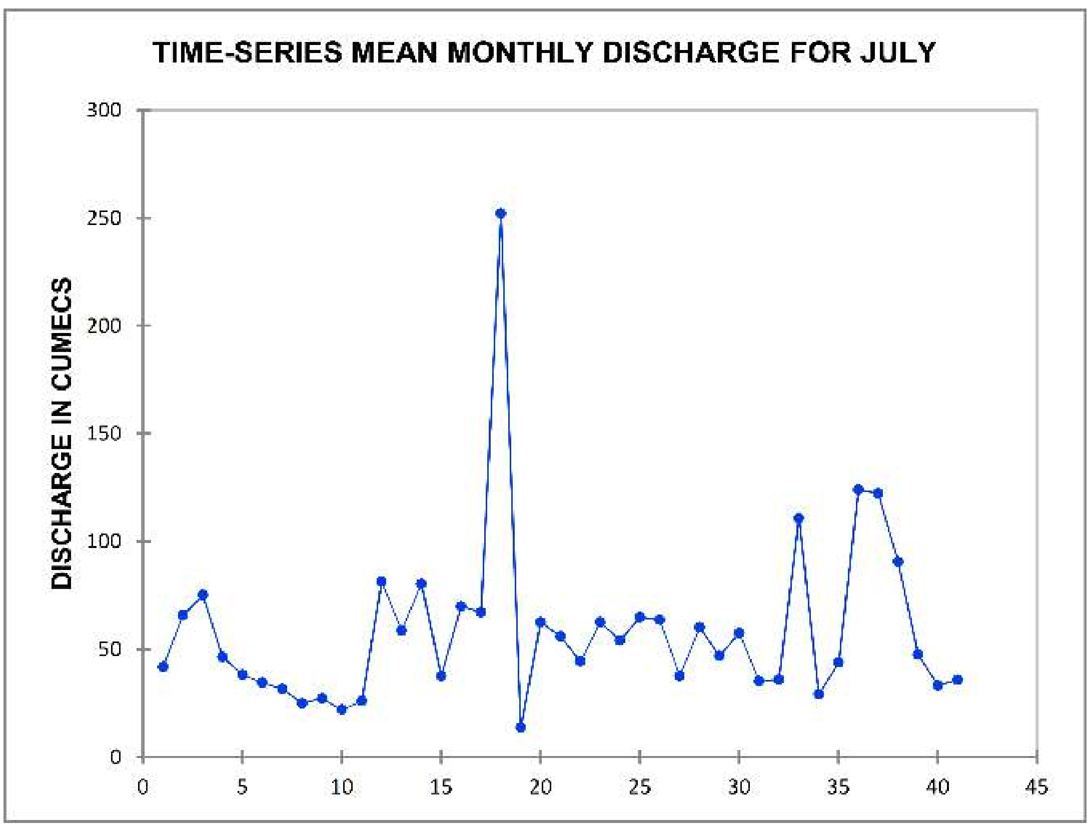
4.7.7 Mann-Kendall trend test / Two-tailed test (JULY):

Kendall's ta	0.611
S'	22.000
Var(S')	141.333
p-value (Tw	0.064
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 6.42%.

Sen's slope (Period = 1 181.375



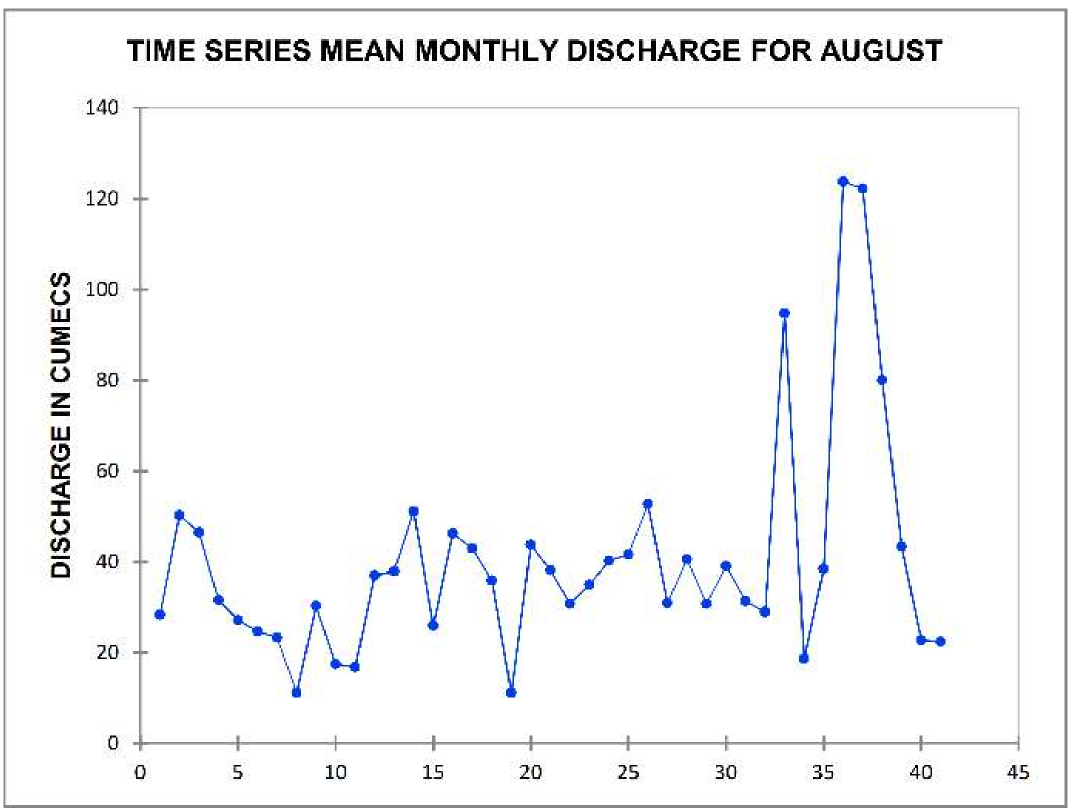
4.7.8 Mann-Kendall trend test / Two-tailed test (AUGUST):

Kendall's ta	0.333
S'	12.000
Var(S')	70.000
p-value (Tw	0.151
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 15.15%.

Sen's slope (Period = 1 94.937



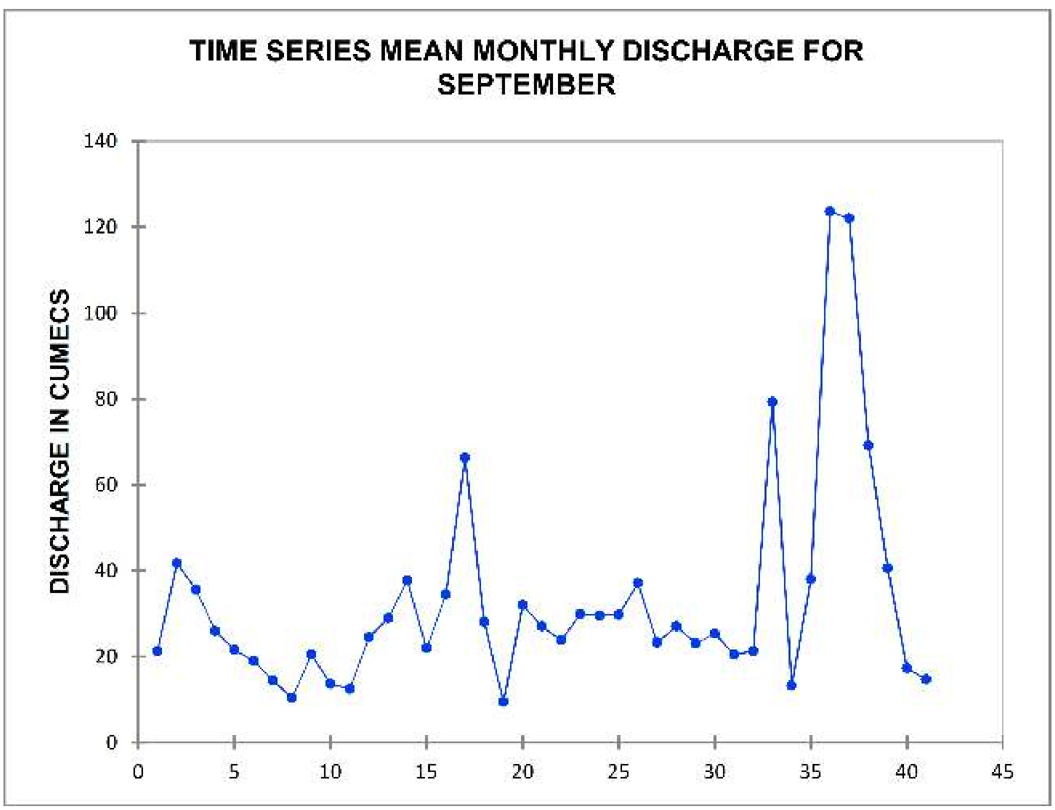
4.7.9 Mann-Kendall trend test / Two-tailed test (SEPTEMBER):

Kendall's ta	0.222
S'	8.000
Var(S')	46.000
p-value (Tw	0.238
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 23.82%.

Sen's slope (Period = 1 20.758



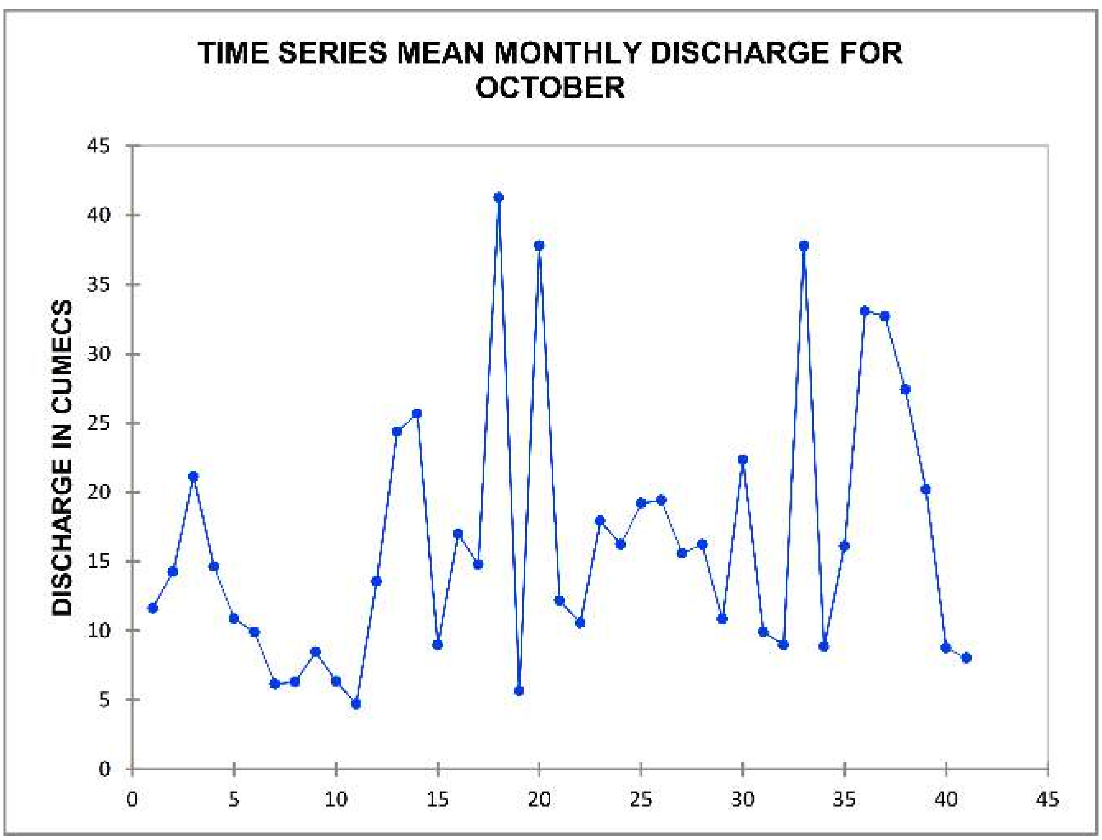
4.7.10 Mann-Kendall trend test / Two-tailed test (OCTOBER):

Kendall's ta	0.222
S'	8.000
Var(S')	46.000
p-value (Tw	0.238
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 23.82%.

Sen's slope (Period = 1 442.799



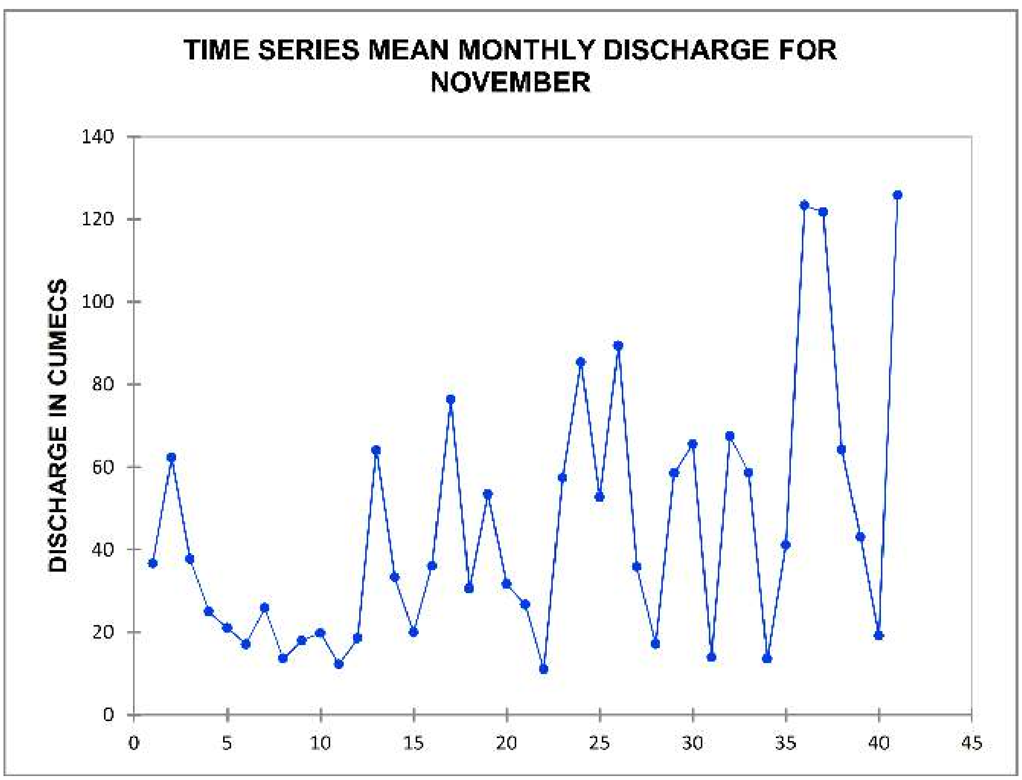
4.7.11 Mann-Kendall trend test / Two-tailed test (NOVEMBER):

Kendall's ta	0.167
S'	6.000
Var(S')	77.333
p-value (Tw	0.495
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 49.51%.

Sen's slope (Period = 1 237.216



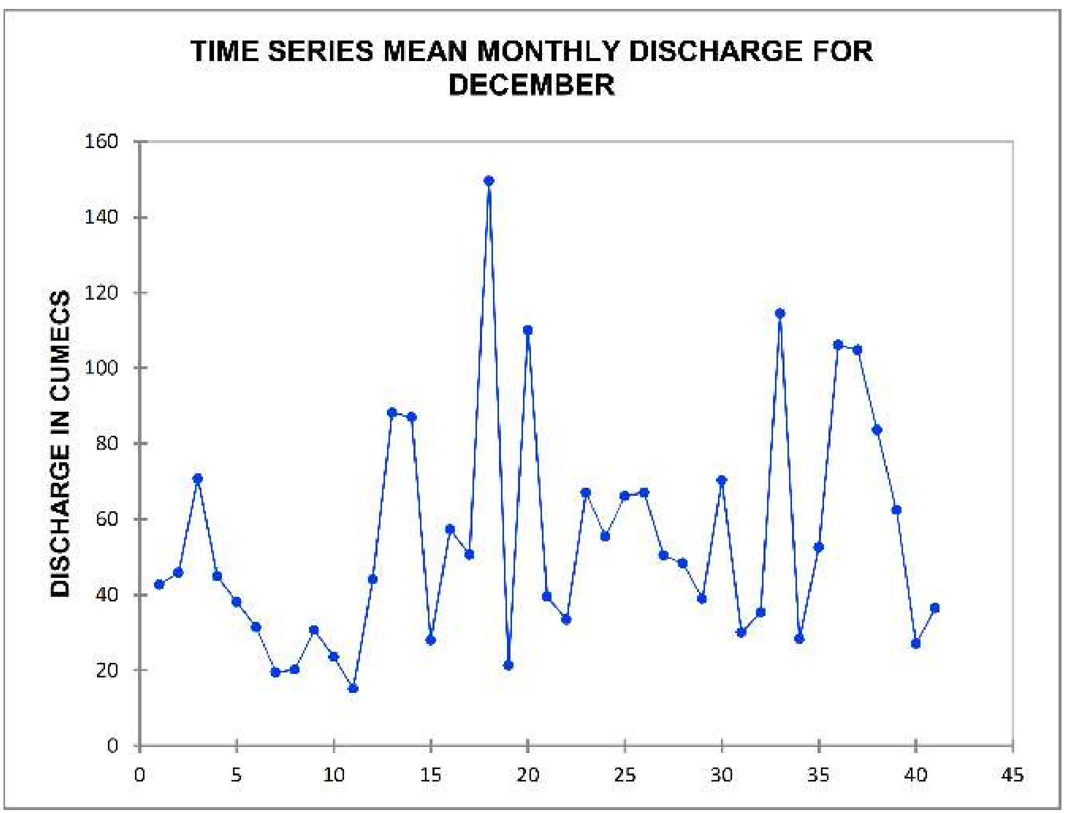
4.7.12 Mann-Kendall trend test / Two-tailed test (DECEMBER):

Kendall's ta	0.444
S'	16.000
Var(S')	75.333
p-value (Tw	0.065
alpha	0.05

An approximation has been used to compute the p-value.

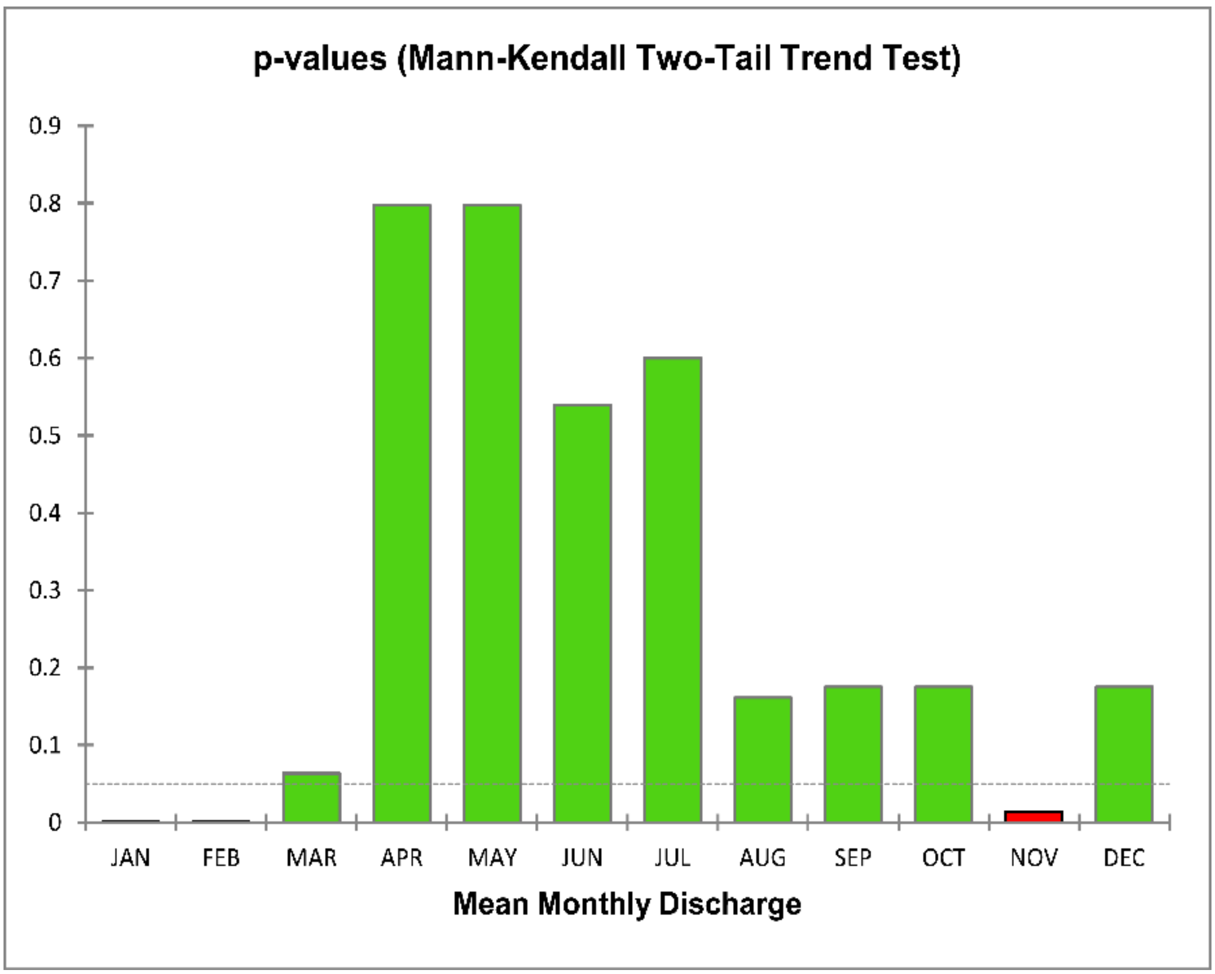
Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 6.53%.

Sen's slope (Period = 1 553.354



Summary:

Series\Test	Kendall's taU	p-value	Sen's slope
JANUARY	0.667	0.052	600.305
FEBRUARY	0.556	0.063	366.162
MARCH	0.278	0.114	403.346
APRIL	0.111	0.566	459.914
MAY	0.056	0.766	204.489
JUNE	0.333	0.203	186.213
JULY	0.611	0.064	181.375
AUGUST	0.333	0.151	94.937
SEPTEMBER	0.222	0.238	20.758
OCTOBER	0.222	0.238	442.799
NOVEMBER	0.167	0.495	237.216
DECEMBER	0.444	0.065	553.354



Appendix 4.8: Mean Monthly Discharge (Mann-Kendall's Upper Bound Trend Test)

XLSTAT 2018.1.49205 - Mann-Kendall trend tests - Start time: 1/24/2018 at 10:30:23 PM / End time:1/24/2018 at 10:30:35 PM

Time series: Workbook = MSc. MeanMONTHLY DISCHARGE.xlsx / Sheet = Sheet1 / Range = Sheet1!$A$1:$L$42 / 41 rows and 12 columns

Significance level (%): 5

Summary statistics

Summary statistics:

Variable	No. of observations	Entries with missing data	Entries without missing data	Mean rainfall	Maximum rainfall	Minimum rainfall	Standard Deviation
JANUARY	41	0	41	284.034	8623.875	1824.499	1774.210
FEBRUARY	41	0	41	265.638	6620.180	1463.870	1378.889
MARCH	41	0	41	193.039	7313.974	1693.859	1457.473
APRIL	41	0	41	491.362	7209.613	2670.879	1501.883
MAY	41	0	41	614.647	9591.139	2824.015	1648.884
JUNE	41	0	41	410.246	7563.013	1744.075	1208.596
JULY	41	0	41	343.782	3836.178	1239.916	766.594
AUGUST	41	0	41	295.655	3832.019	1023.399	787.014
SEPTEMBER	41	0	41	230.508	3704.445	829.486	753.981
OCTOBER	41	0	41	378.175	3900.275	1459.705	992.803
NOVEMBER	41	0	41	973.558	6330.025	2674.226	1253.991
DECEMBER	41	0	41	637.754	6253.747	2446.422	1423.865

4.8.1 Mann-Kendall trend test / Upper-tailed test (JANUARY):

Kendall's ta	0.667
S'	24.000
Var(S')	152.667
p-value (on	0.026
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

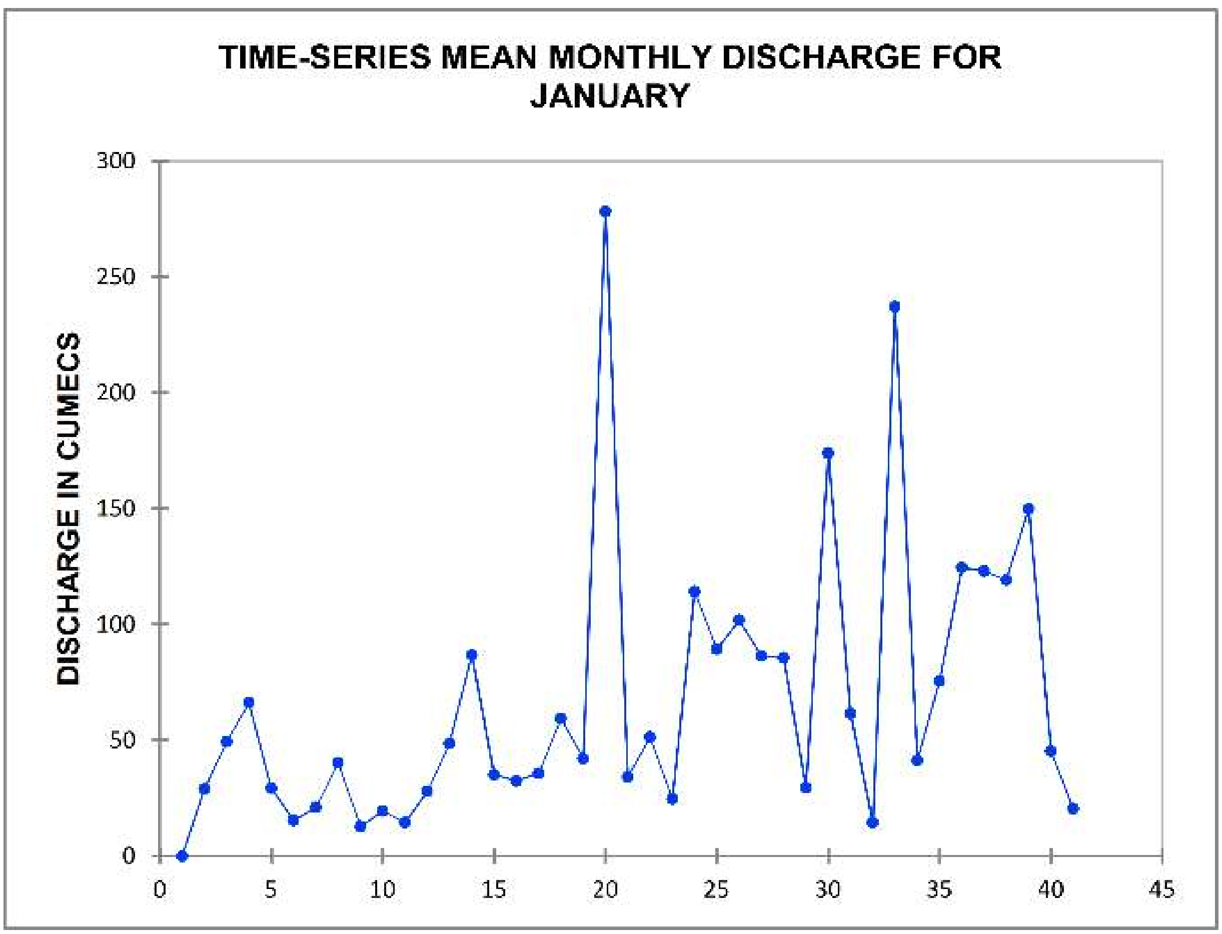
H0: There is no trend in the series

Ha: There is a positive trend in the series

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The risk to reject the null hypothesis H0 while it is true is lower than 2.60%.

Sen's slope (Period = 1 600.305



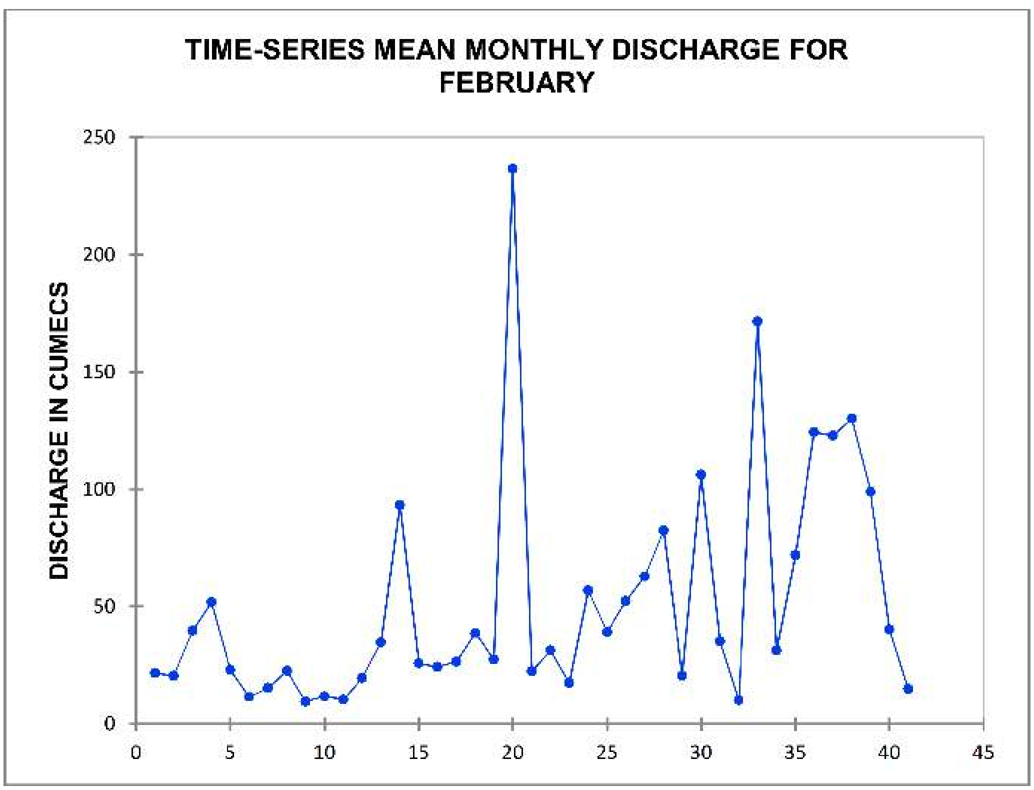
4.8.2 Mann-Kendall trend test / Upper-tailed test (FEBRUARY):

Kendall's ta	0.556
S'	20.000
Var(S')	115.333
p-value (on	0.031
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
The risk to reject the null hypothesis H0 while it is true is lower than 3.13%.

Sen's slope (Period = 1   366.162



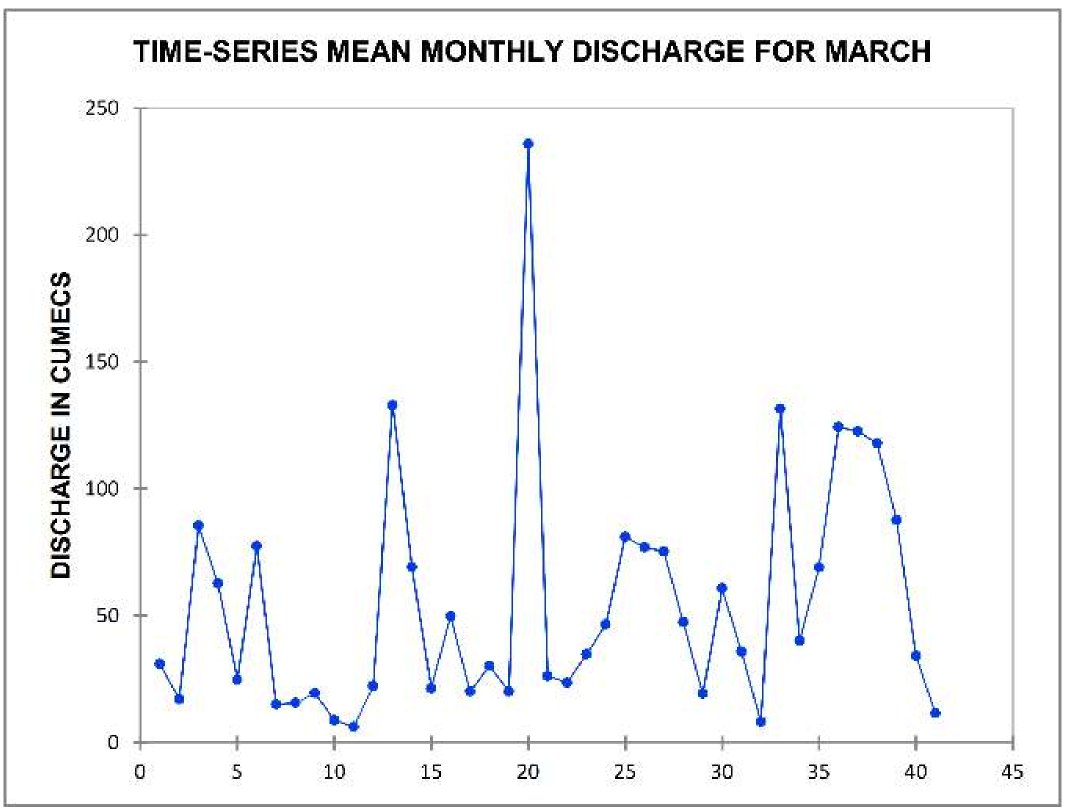
4.8.3 Mann-Kendall trend test / Upper-tailed test (MARCH):

Kendall's ta	0.278
S'	10.000
Var(S')	40.000
p-value (on	0.057
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 5.69%.

Sen's slope (Period = 1   403.346



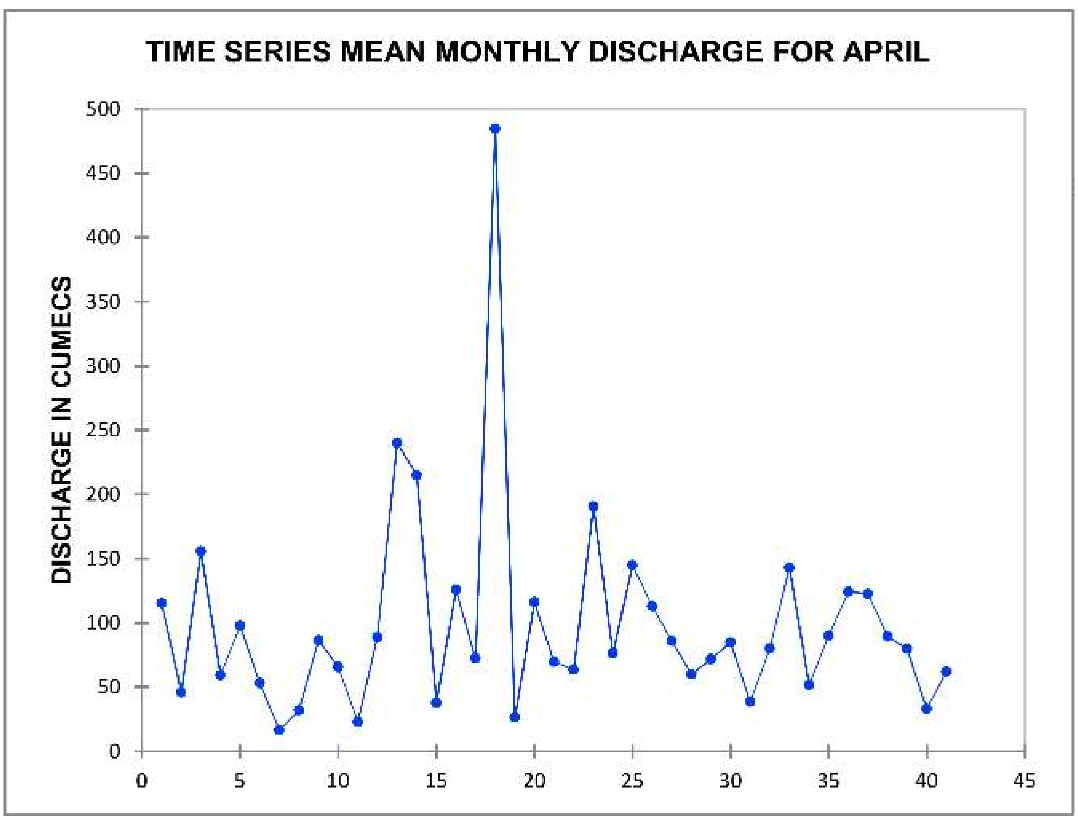
4.8.4 Mann-Kendall trend test / Upper-tailed test (APRIL):

Kendall's ta	0.111
S'	4.000
Var(S')	48.667
p-value (on	0.283
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 28.32%.

Sen's slope (Period = 1 459.914



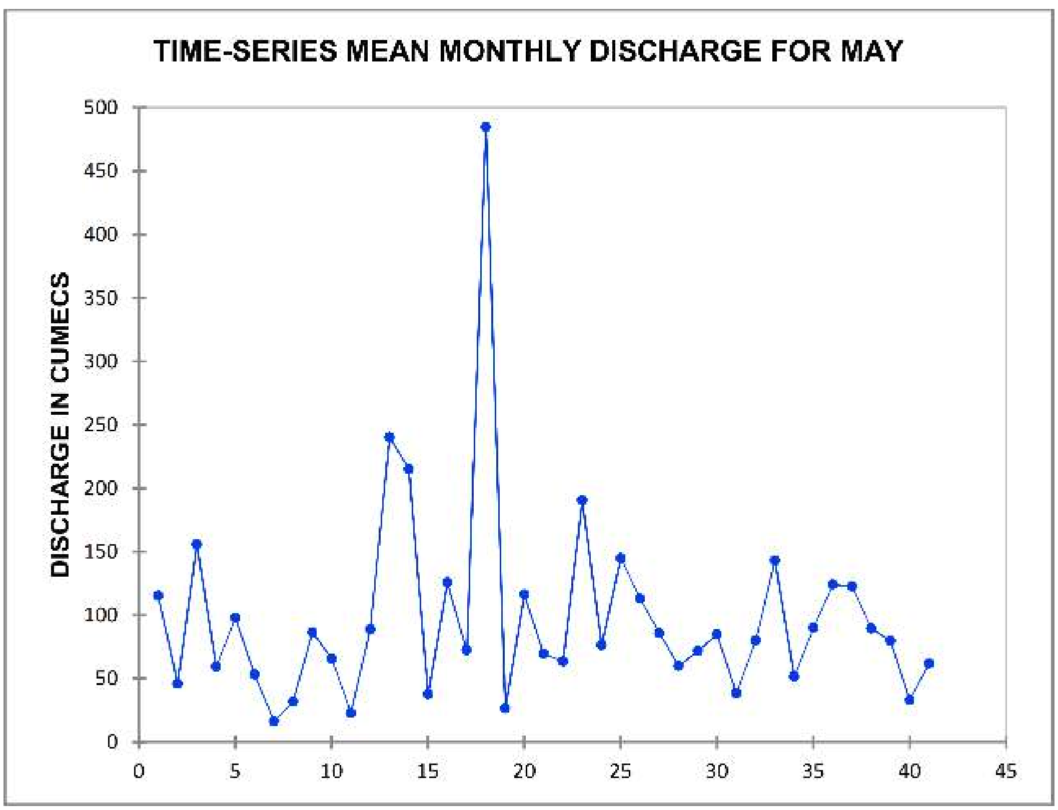
4.8.5 Mann-Kendall trend test / Upper-tailed test (MAY):

Kendall's ta	0.056
S'	2.000
Var(S')	45.333
p-value (on	0.383
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 38.32%.

Sen's slope (Period = 1 204.489



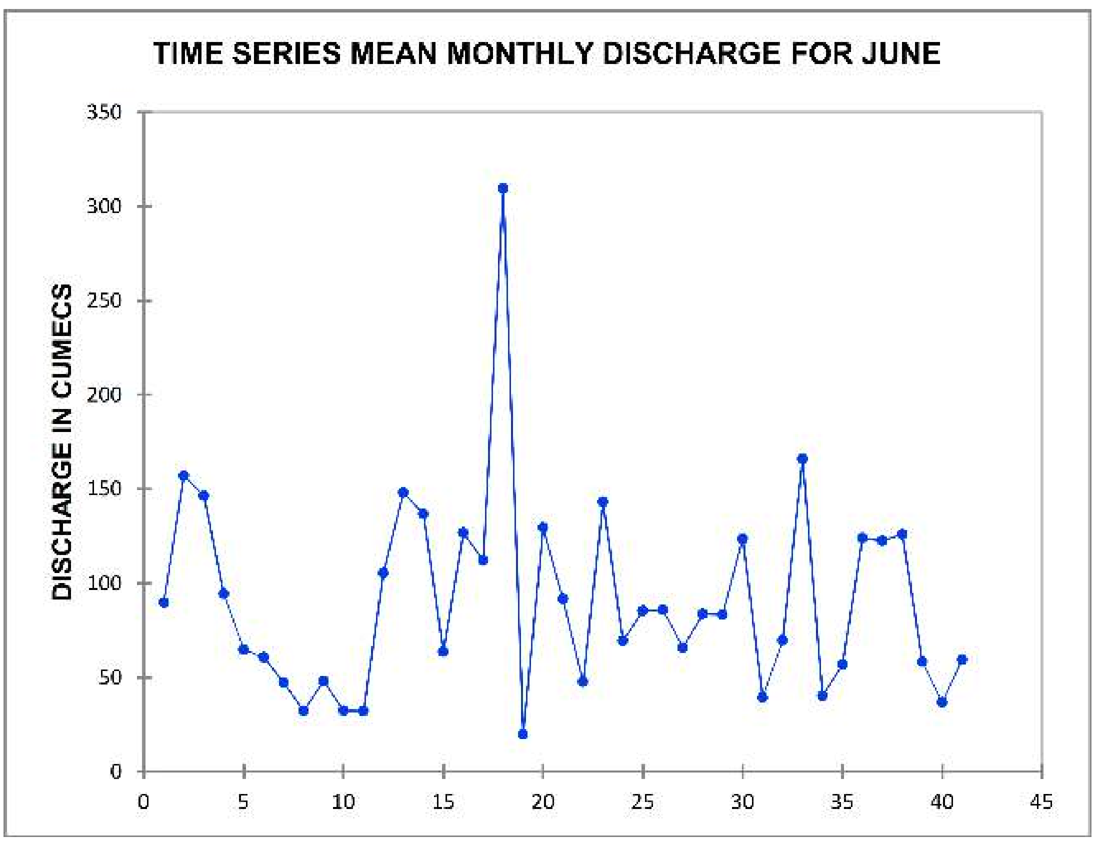
4.8.6 Mann-Kendall trend test / Upper-tailed test (JUNE):

Kendall's ta	0.333
S'	12.000
Var(S')	88.667
p-value (on	0.101
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 10.13%.

Sen's slope (Period = 1   186.213



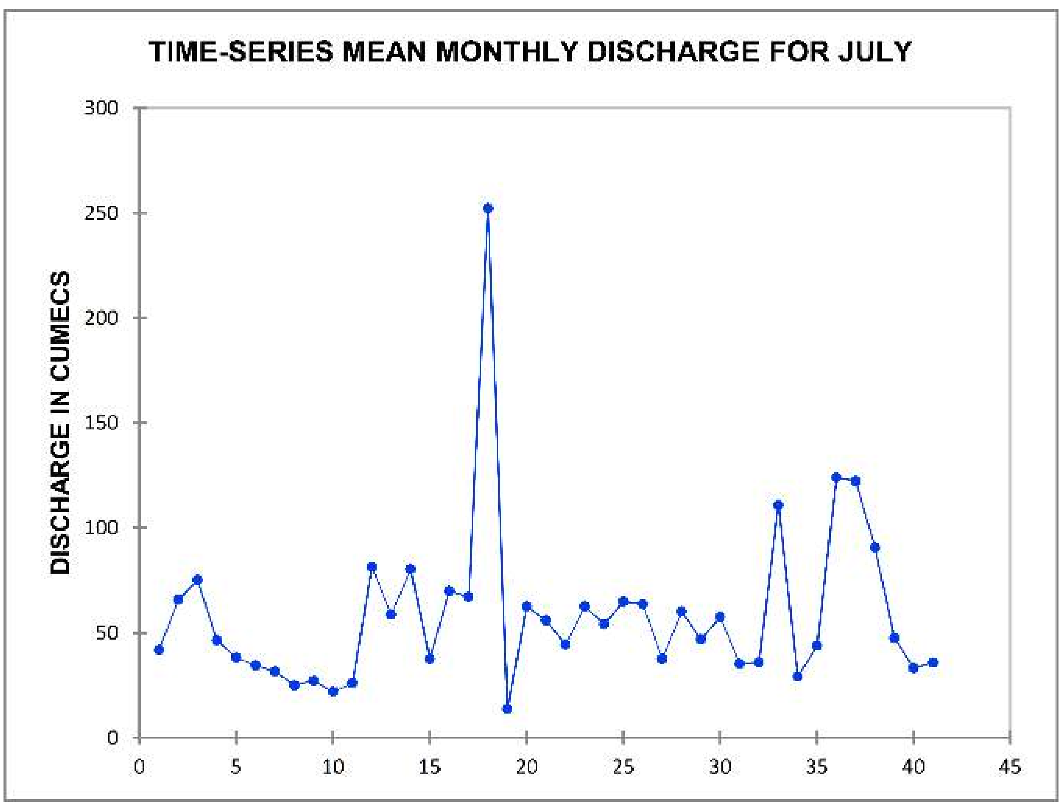
4.8.7 Mann-Kendall trend test / Upper-tailed test (JULY):

Kendall's ta	0.611
S'	22.000
Var(S')	141.333
p-value (on	0.032
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
The risk to reject the null hypothesis H0 while it is true is lower than 3.21%.

Sen's slope (Period = 1 181.375



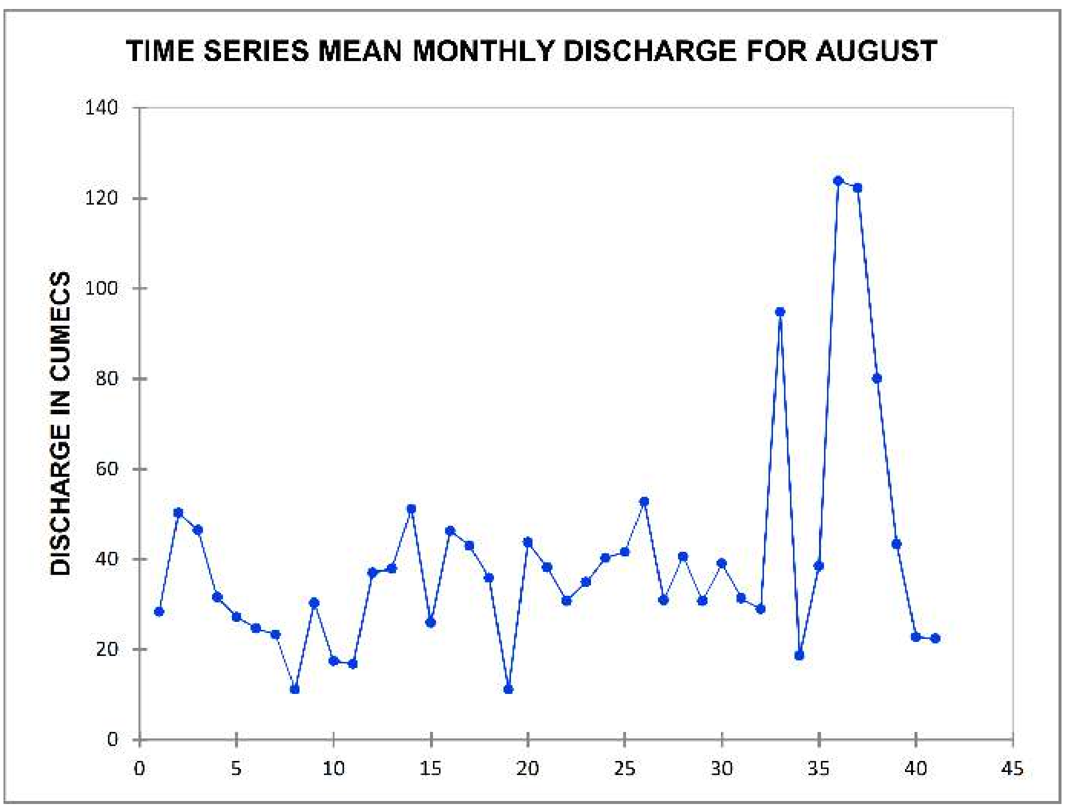
4.8.8 Mann-Kendall trend test / Upper-tailed test (AUGUST):

Kendall's ta	0.333
S'	12.000
Var(S')	70.000
p-value (on	0.076
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 7.57%.

Sen's slope (Period = 1 94.937



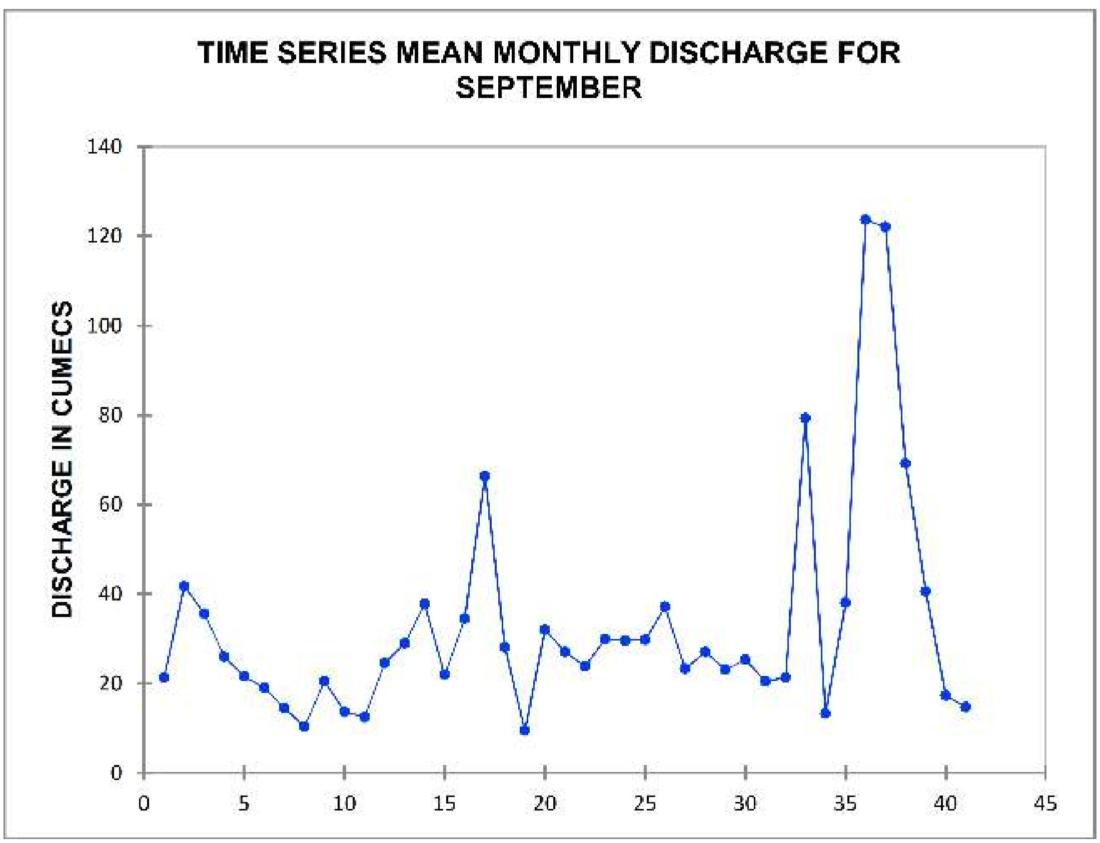
4.8.9 Mann-Kendall trend test / Upper-tailed test (SEPTEMBER):

Kendall's ta	0.222
S'	8.000
Var(S')	46.000
p-value (on	0.119
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 11.91%.

Sen's slope (Period = 1 20.758



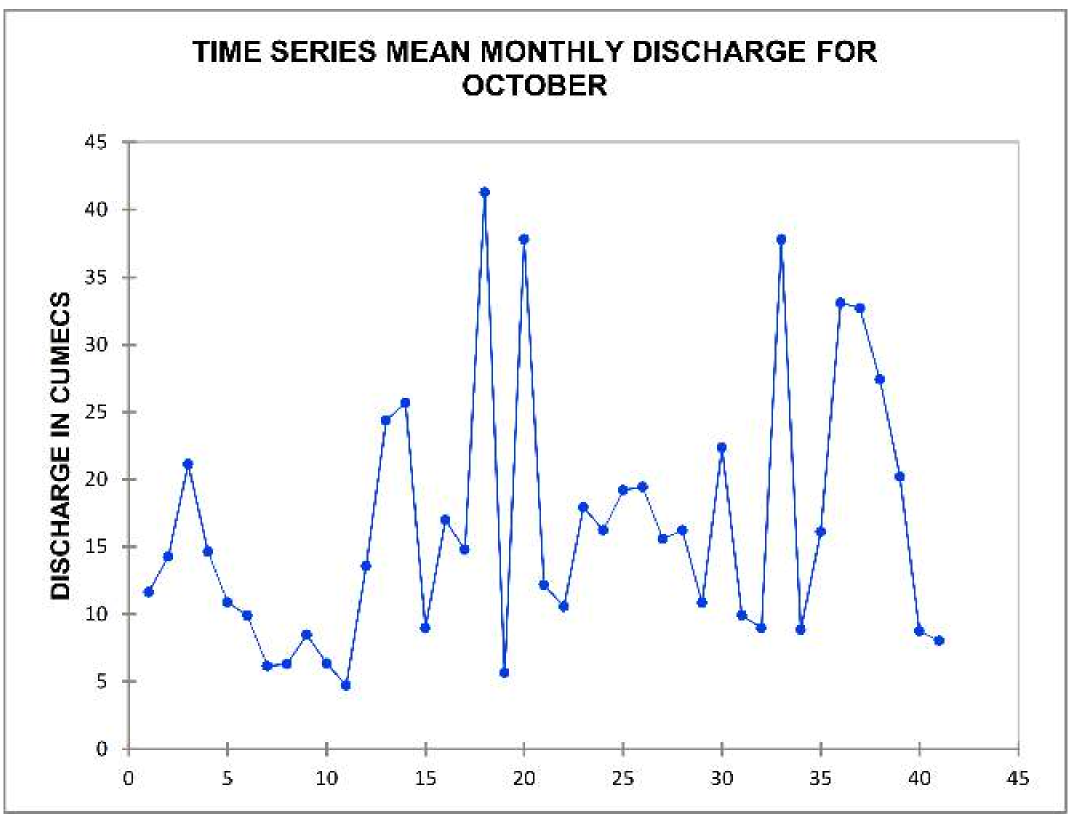
4.8.10 Mann-Kendall trend test / Upper-tailed test (OCTOBER):

Kendall's ta	0.222
S'	8.000
Var(S')	46.000
p-value (on	0.119
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 11.91%.

Sen's slope (Period = 1 442.799



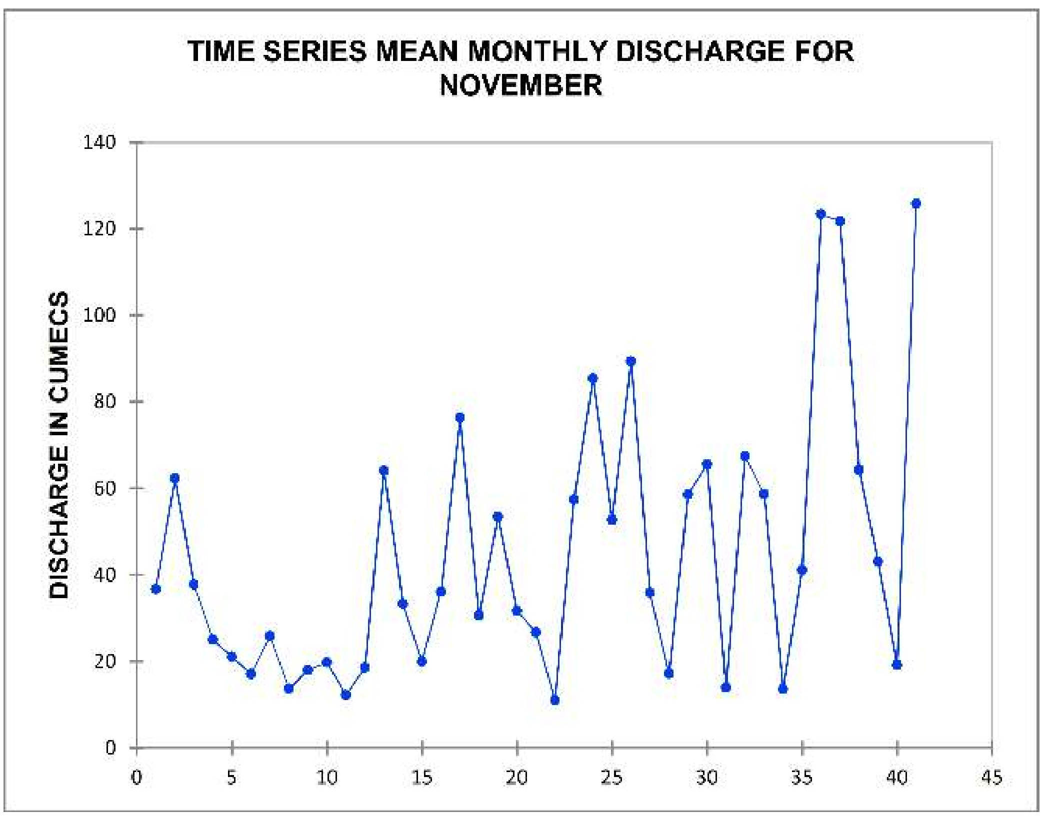
4.8.11 Mann-Kendall trend test / Upper-tailed test (NOVEMBER):

Kendall's ta	0.167
S'	6.000
Var(S')	77.333
p-value (on	0.248
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 24.75%.

Sen's slope (Period = 1   237.216



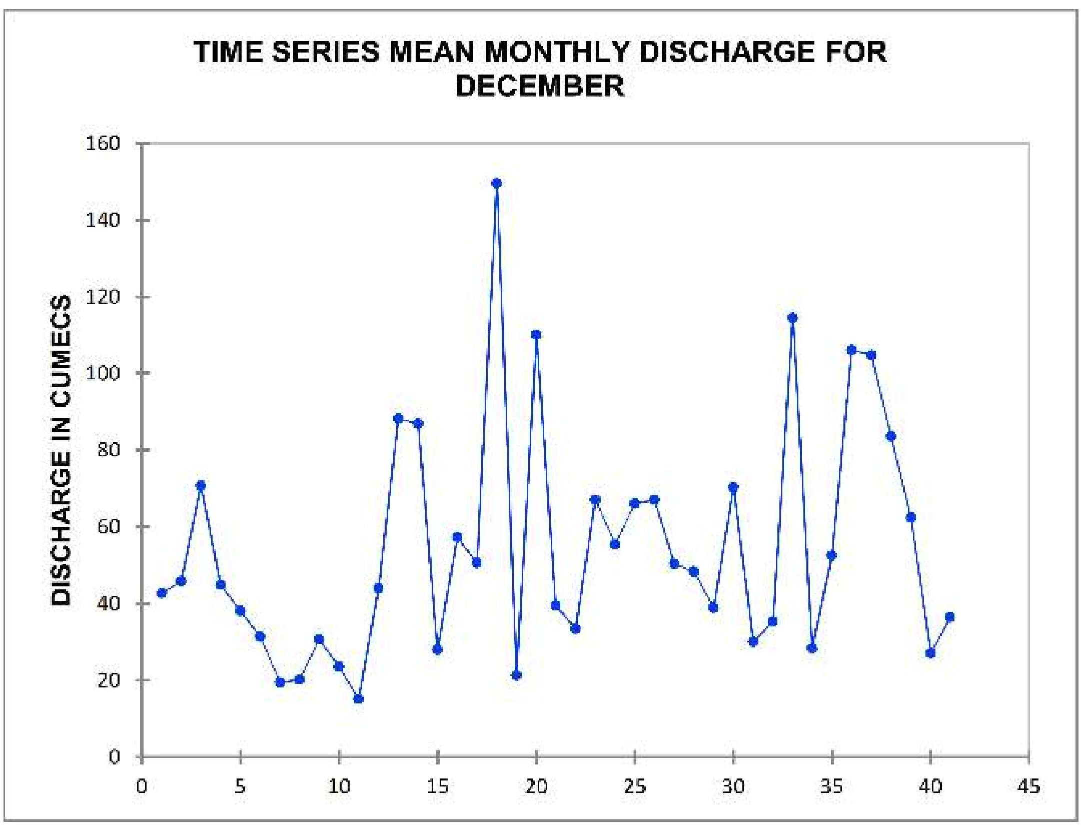
4.8.12 Mann-Kendall trend test / Upper-tailed test (DECEMBER):

Kendall's ta	0.444
S'	16.000
Var(S')	75.333
p-value (on	0.033
alpha	0.05

An approximation has been used to compute the p-value.

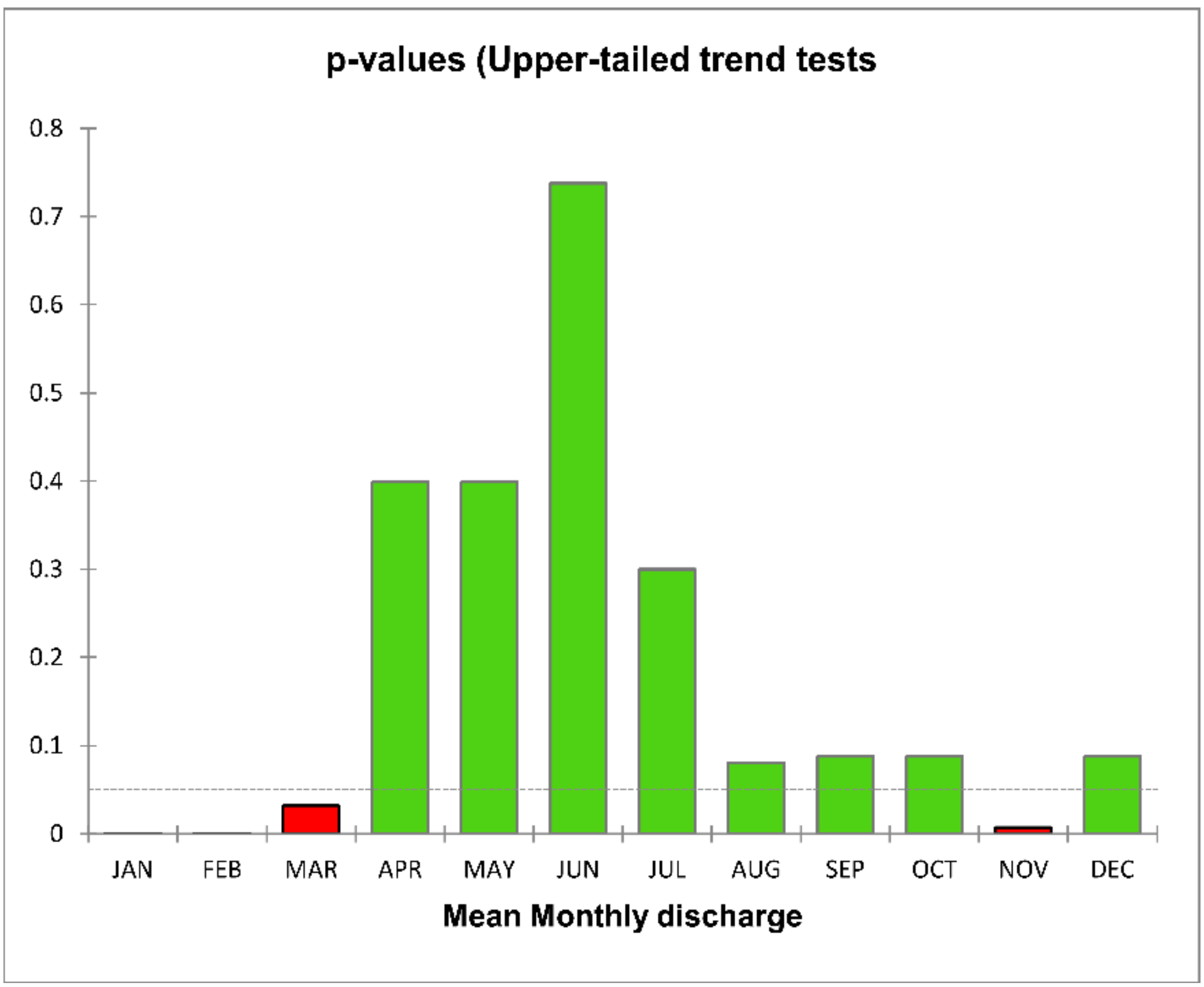
Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
The risk to reject the null hypothesis H0 while it is true is lower than 3.26%.

Sen's slope (Period = 1 553.354



Summary:

Series\Test	Kendall's tau	p-value	Sen's slope
JANUARY	0.667	**0.026**	600.305
FEBRUARY	0.556	**0.031**	366.162
MARCH	0.278	0.057	403.346
APRIL	0.111	0.283	459.914
MAY	0.056	0.383	204.489
JUNE	0.333	0.101	186.213
JULY	0.611	**0.032**	181.375
AUGUST	0.333	0.076	94.937
SEPTEMBER	0.222	0.119	20.758
OCTOBER	0.222	0.119	442.799
NOVEMBER	0.167	0.248	237.216
DECEMBER	0.444	**0.033**	553.354



Appendix 4.9: Mean Monthly Discharge (Mann-Kendall's Lower Bound Trend Test)

XLSTAT 2018.1.49205 - Mann-Kendall trend tests - Start time: 1/24/2018 at 10:23:40 PM / End time: 1/24/2018 at 10:23:51 PM

Time series: Workbook = MSc. Mean MONTHLY DISCHARGE.xlsx / Sheet = Sheet1 / Range = Sheet1!$A$1:$L$42 / 41 rows and 12 columns

Significance level (%): 5

Summary statistics

Summary statistics:

Variable	No. of	Entries	Entries	Mean	Maximum	Minimum	Standard
JANUARY	41	0	41	284.034	8623.875	1824.499	1774.210
FEBRUARY	41	0	41	265.638	6620.180	1463.870	1378.889
MARCH	41	0	41	193.039	7313.974	1693.859	1457.473
APRIL	41	0	41	491.362	7209.613	2670.879	1501.883
MAY	41	0	41	614.647	9591.139	2824.015	1648.884
JUNE	41	0	41	410.246	7563.013	1744.075	1208.596
JULY	41	0	41	343.782	3836.178	1239.916	766.594
AUGUST	41	0	41	295.655	3832.019	1023.399	787.014
SEPTEMBER	41	0	41	230.508	3704.445	829.486	753.981
OCTOBER	41	0	41	378.175	3900.275	1459.705	992.803
NOVEMBER	41	0	41	973.558	6330.025	2674.226	1253.991
DECEMBER	41	0	41	637.754	6253.747	2446.422	1423.865

4.9.1 Mann-Kendall trend test / Lower-tailed test (JANUARY):

Kendall's ta	0.667
S'	24.000
Var(S')	152.667
p-value (on	0.974
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

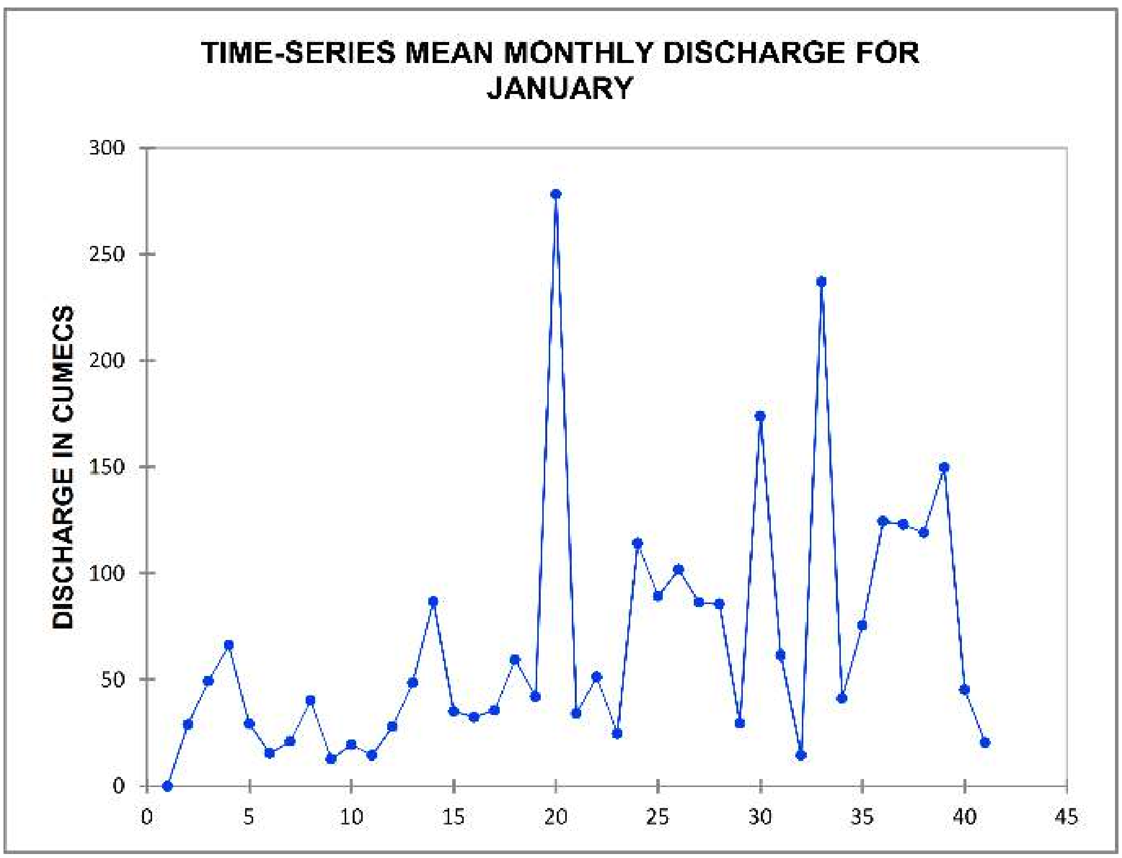
H0: There is no trend in the series

Ha: There is a negative trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 97.40%.

Sen's slope (Period = 1 600.305



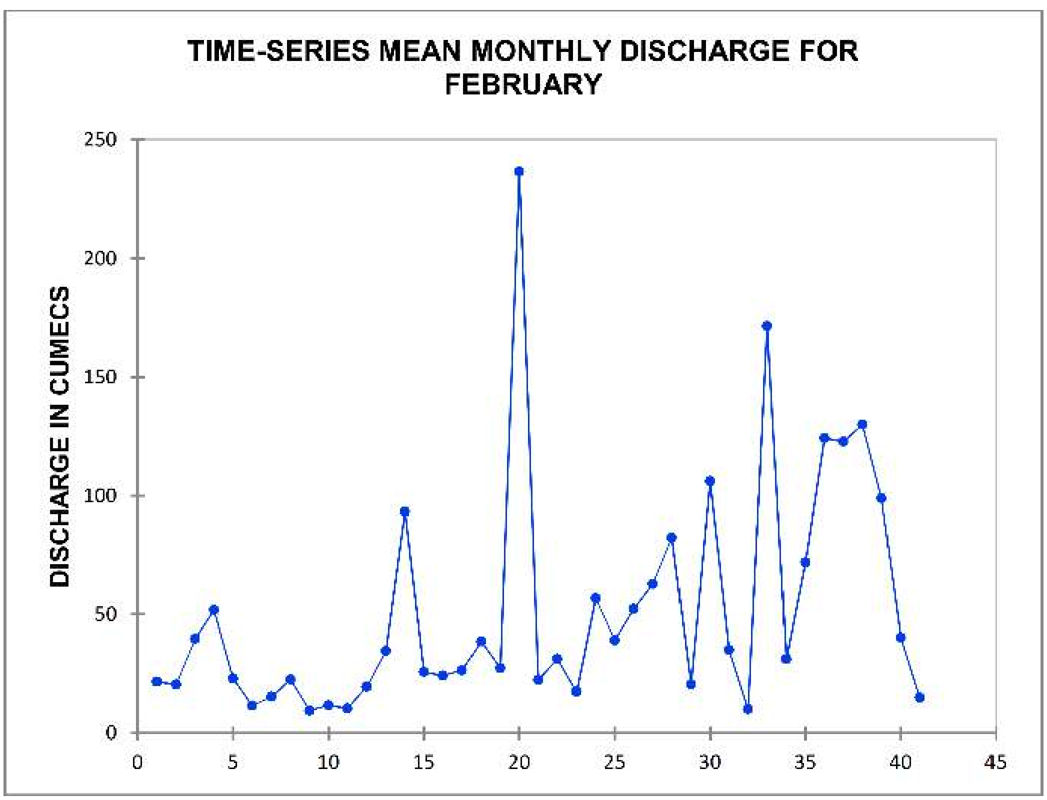
4.9.2 Mann-Kendall trend test / Lower-tailed test (FEBRUARY):

Kendall's ta	0.556
S'	20.000
Var(S')	115.333
p-value (on	0.969
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 96.87%.

Sen's slope (Period = 1 366.162



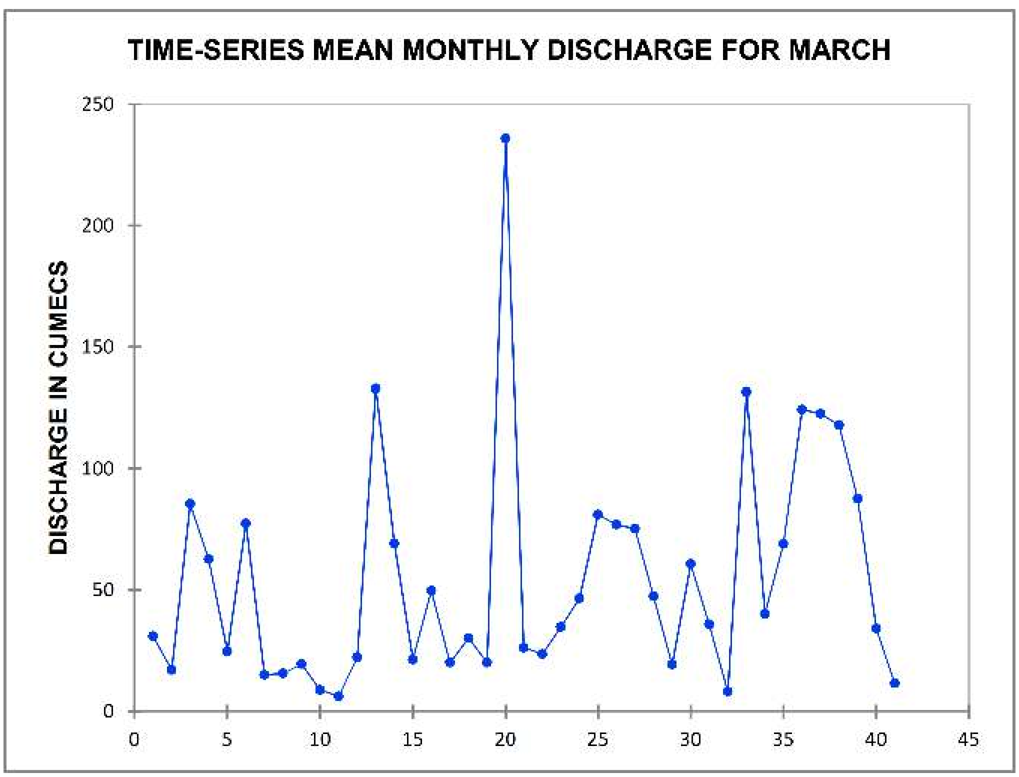
4.9.3 Mann-Kendall trend test / Lower-tailed test (MARCH):

Kendall's ta	0.278
S'	10.000
Var(S')	40.000
p-value (on	0.943
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 94.31%.

Sen's slope (Period = 1 403.346



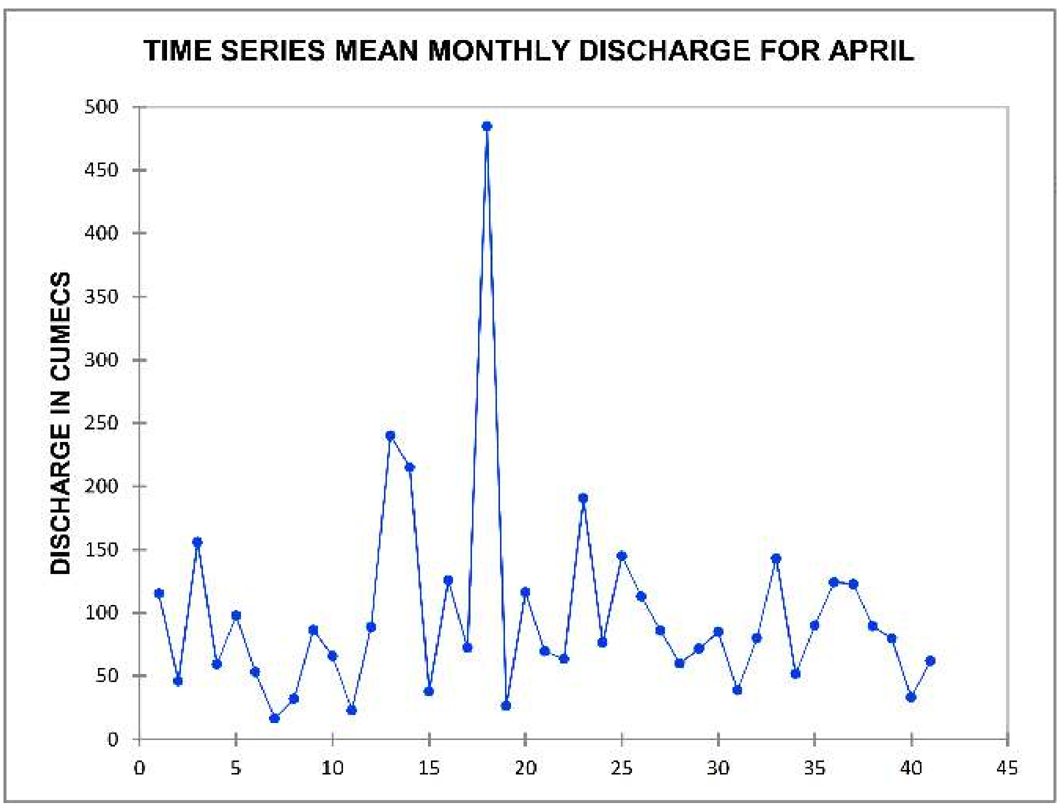
4.9.4 Mann-Kendall trend test / Lower-tailed test (APRIL):

Kendall's ta	0.111
S'	4.000
Var(S')	48.667
p-value (on	0.717
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 71.68%.

Sen's slope (Period = 1   459.914



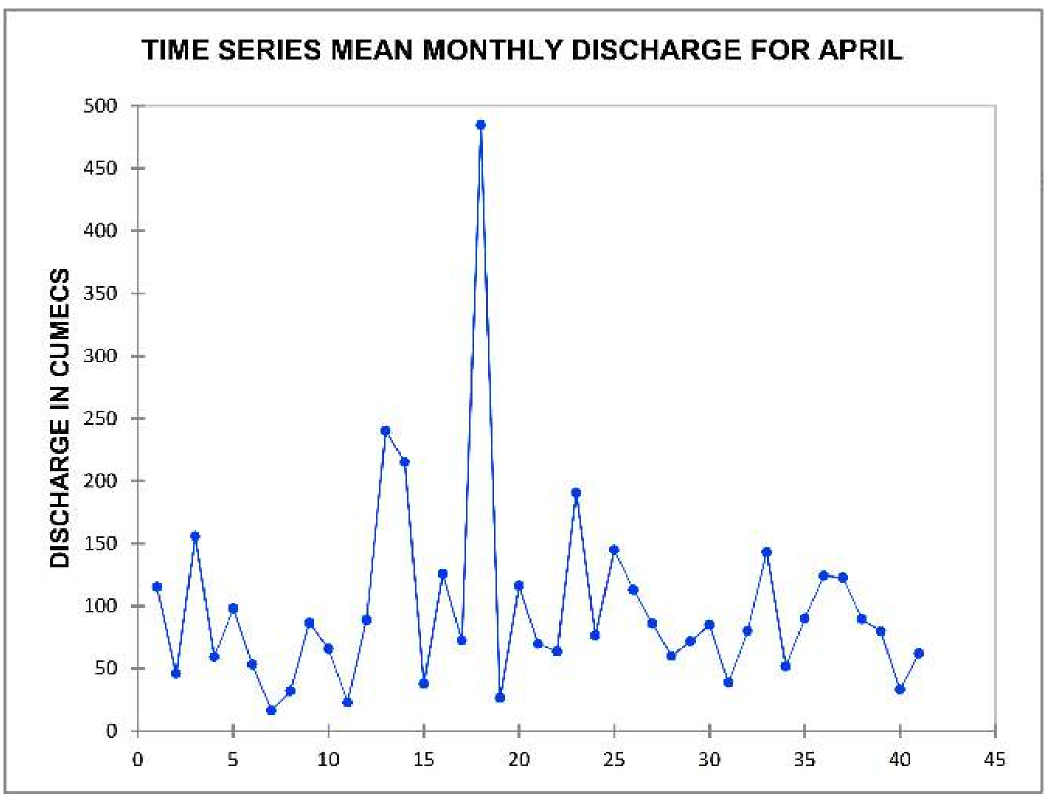
4.9.5 Mann-Kendall trend test / Lower-tailed test (MAY):

Kendall's ta	0.056
S'	2.000
Var(S')	45.333
p-value (on	0.617
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 61.68%.

Sen's slope (Period = 1 204.489



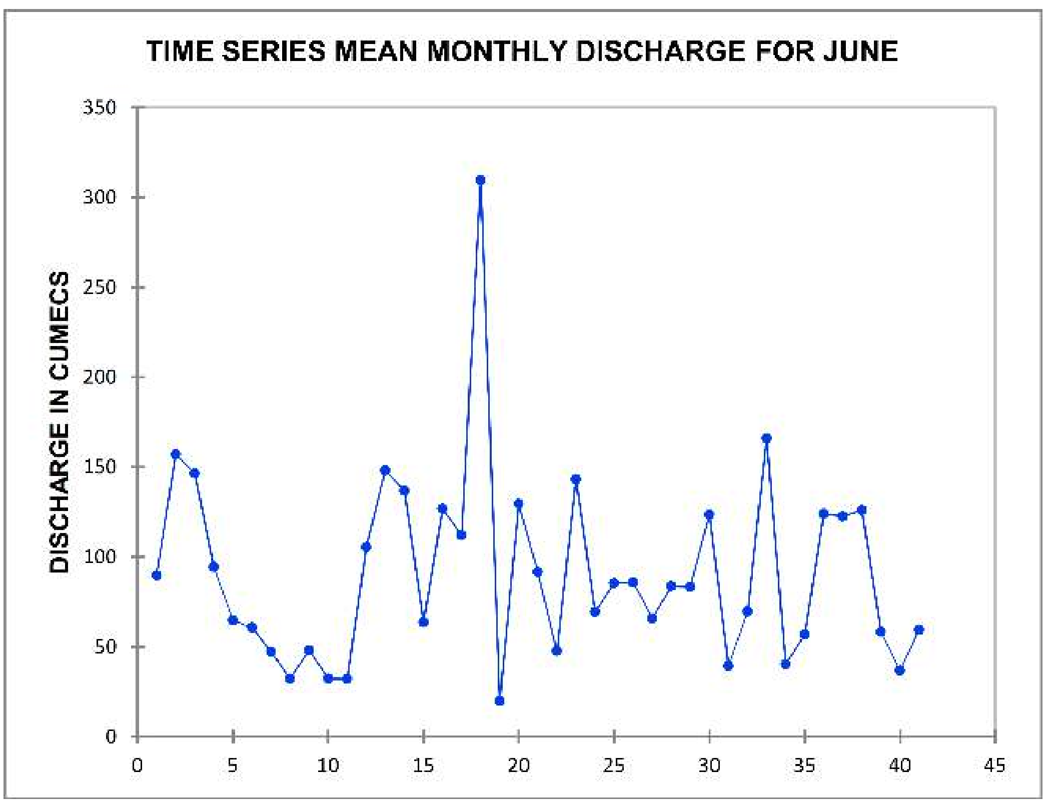
4.9.6 Mann-Kendall trend test / Lower-tailed test (JUNE):

Kendall's ta	0.333
S'	12.000
Var(S')	88.667
p-value (on	0.899
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 89.87%.

Sen's slope (Period = 1 186.213



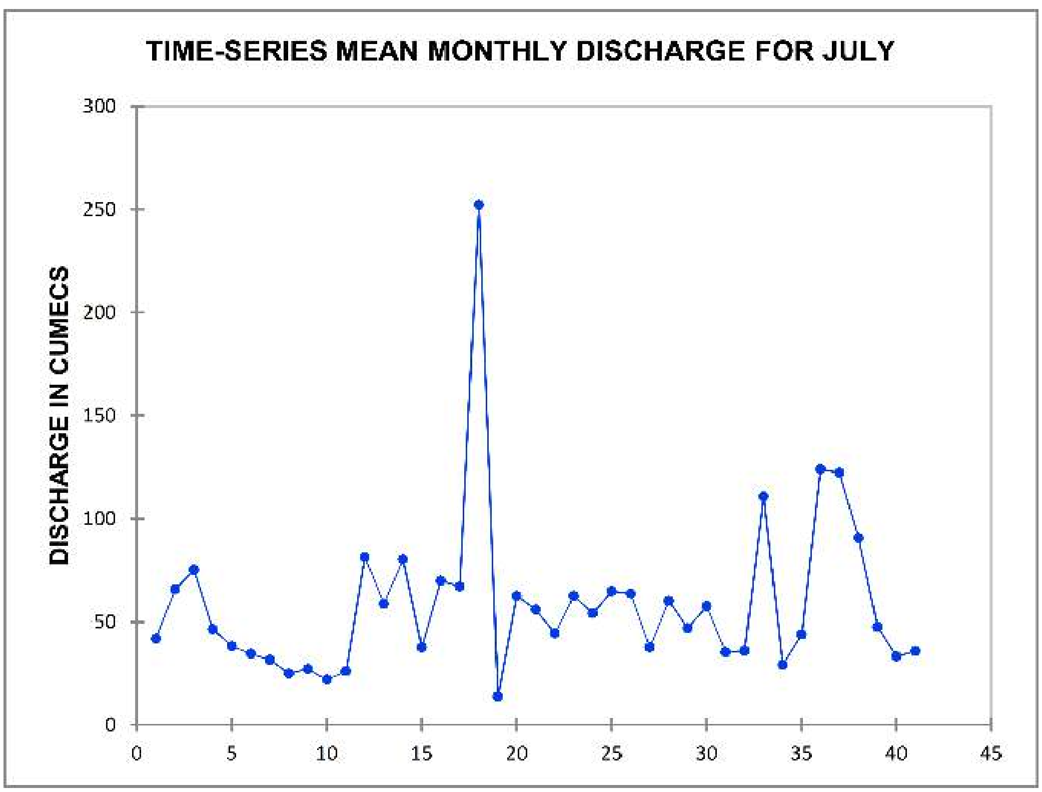
4.9.7 Mann-Kendall trend test / Lower-tailed test (JULY):

Kendall's ta	0.611
S'	22.000
Var(S')	141.333
p-value (on	0.968
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 96.79%.

Sen's slope (Period = 1   181.375



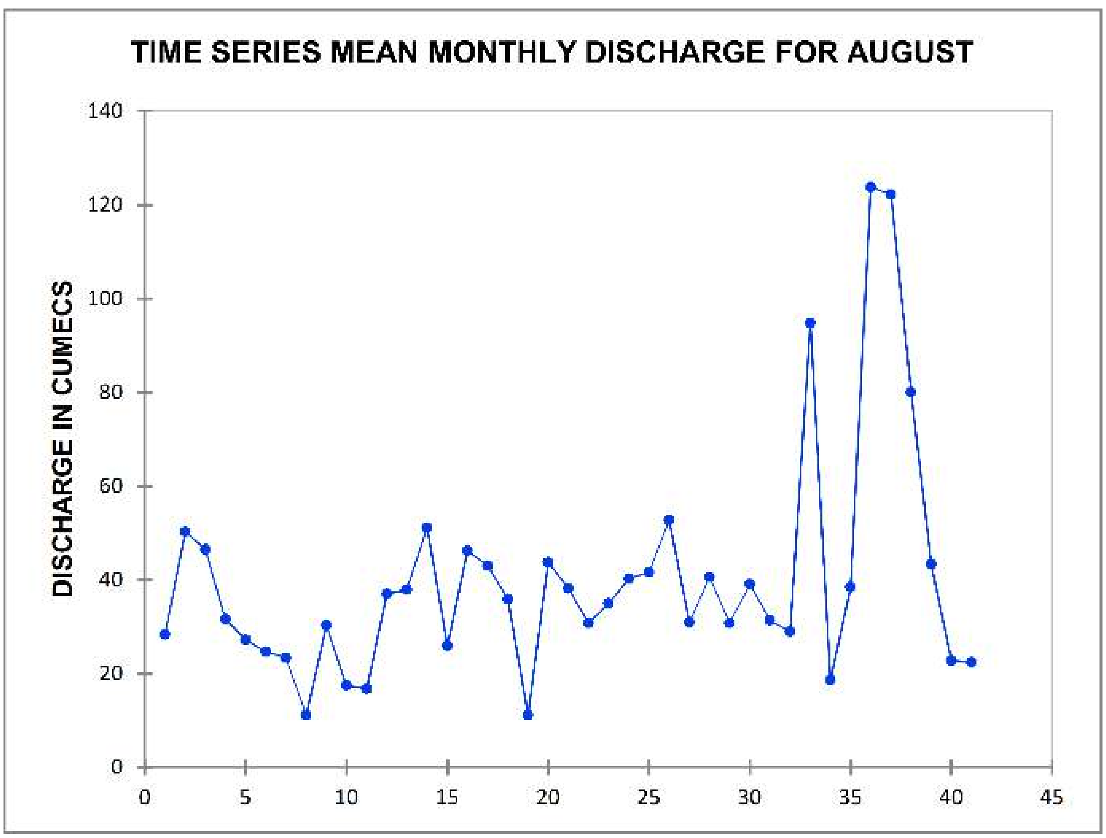
4.9.8 Mann-Kendall trend test / Lower-tailed test (AUGUST):

Kendall's ta	0.333
S'	12.000
Var(S')	70.000
p-value (on	0.924
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 92.43%.

Sen's slope (Period = 1 94.937



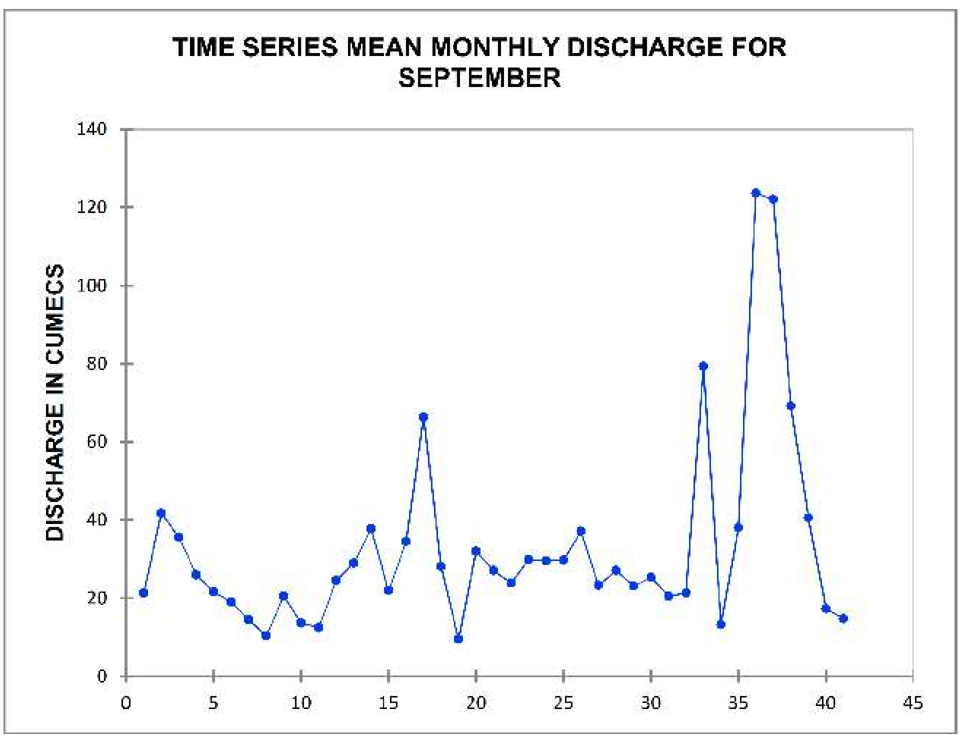
4.9.9 Mann-Kendall trend test / Lower-tailed test (SEPTEMBER):

Kendall's ta	0.222
S'	8.000
Var(S')	46.000
p-value (on	0.881
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 88.09%.

Sen's slope (Period = 1 20.758



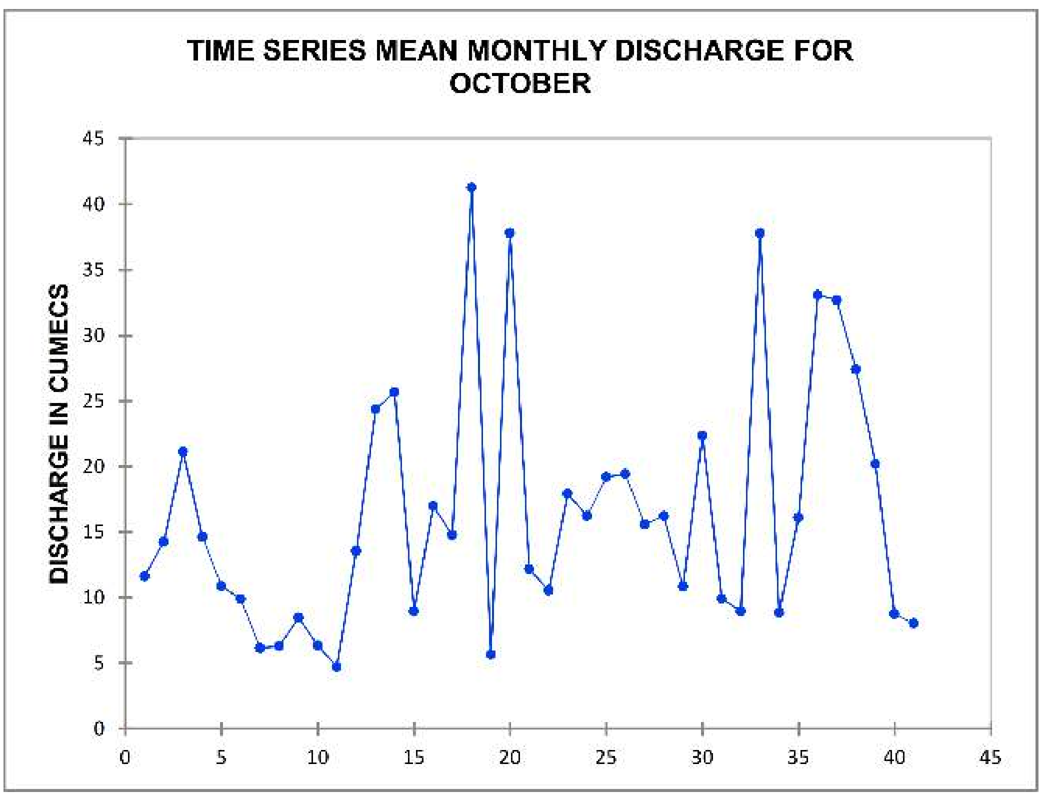
4.9.10 Mann-Kendall trend test / Lower-tailed test (OCTOBER):

Kendall's ta	0.222
S'	8.000
Var(S')	46.000
p-value (on	0.881
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 88.09%.

Sen's slope (Period = 1 442.799



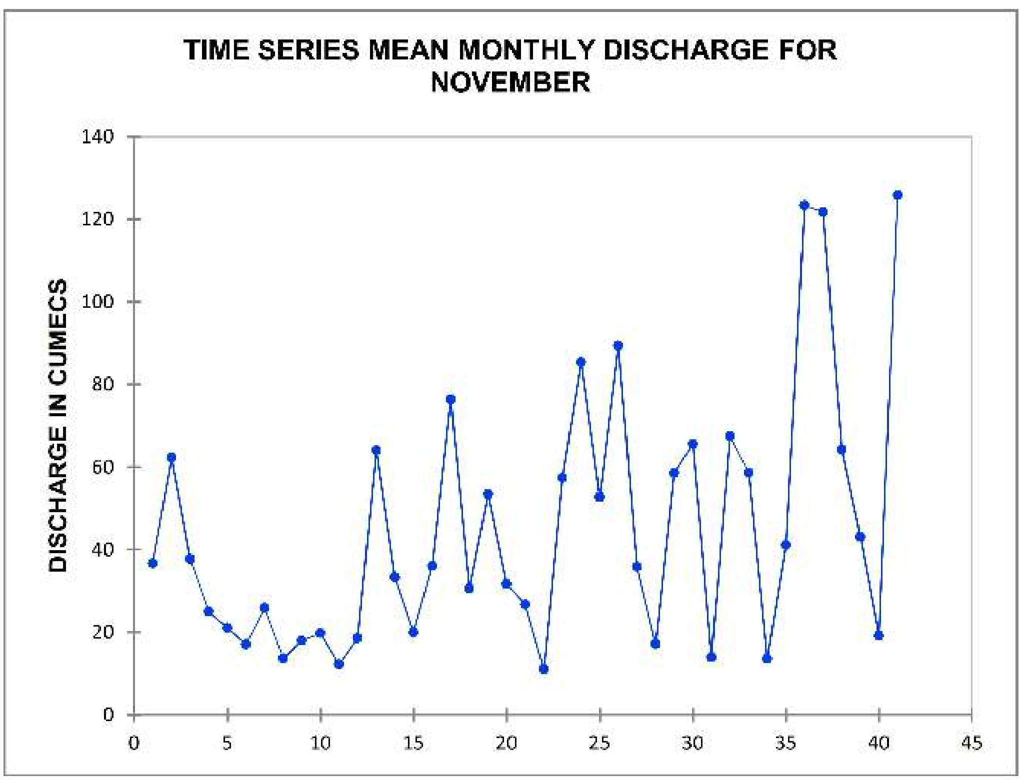
4.9.11 Mann-Kendall trend test / Lower-tailed test (NOVEMBER):

Kendall's ta	0.167
S'	6.000
Var(S')	77.333
p-value (on	0.752
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 75.25%.

Sen's slope (Period = 1 237.216



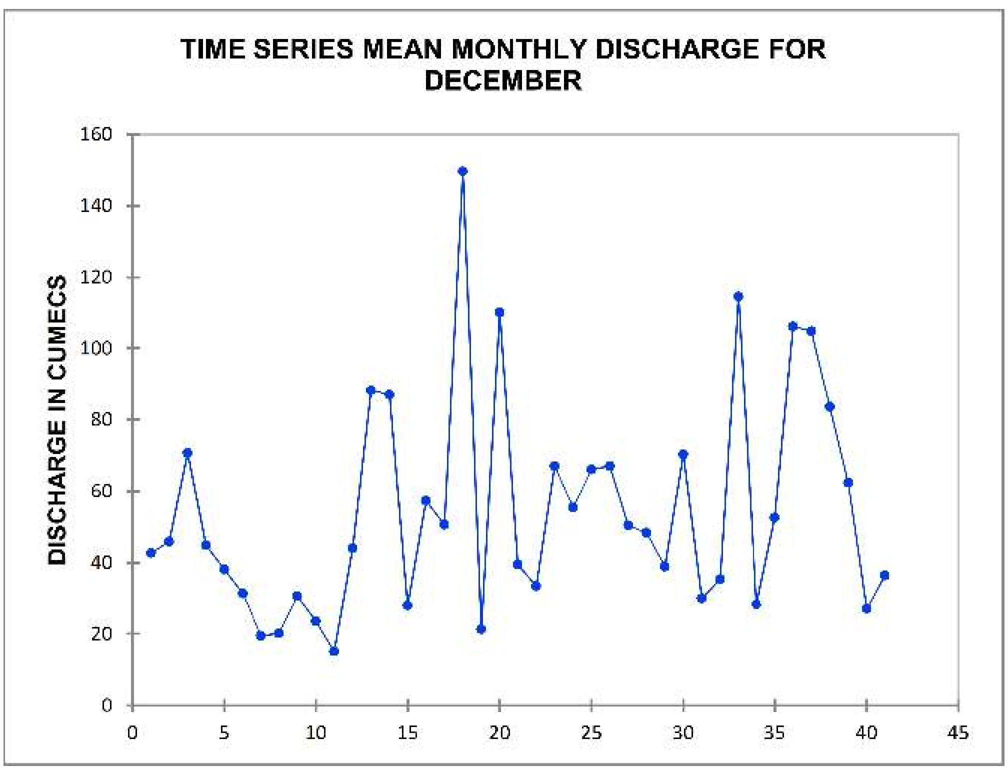
4.9.12 Mann-Kendall trend test / Lower-tailed test (DECEMBER):

Kendall's ta	0.444
S'	16.000
Var(S')	75.333
p-value (on	0.967
alpha	0.05

An approximation has been used to compute the p-value.

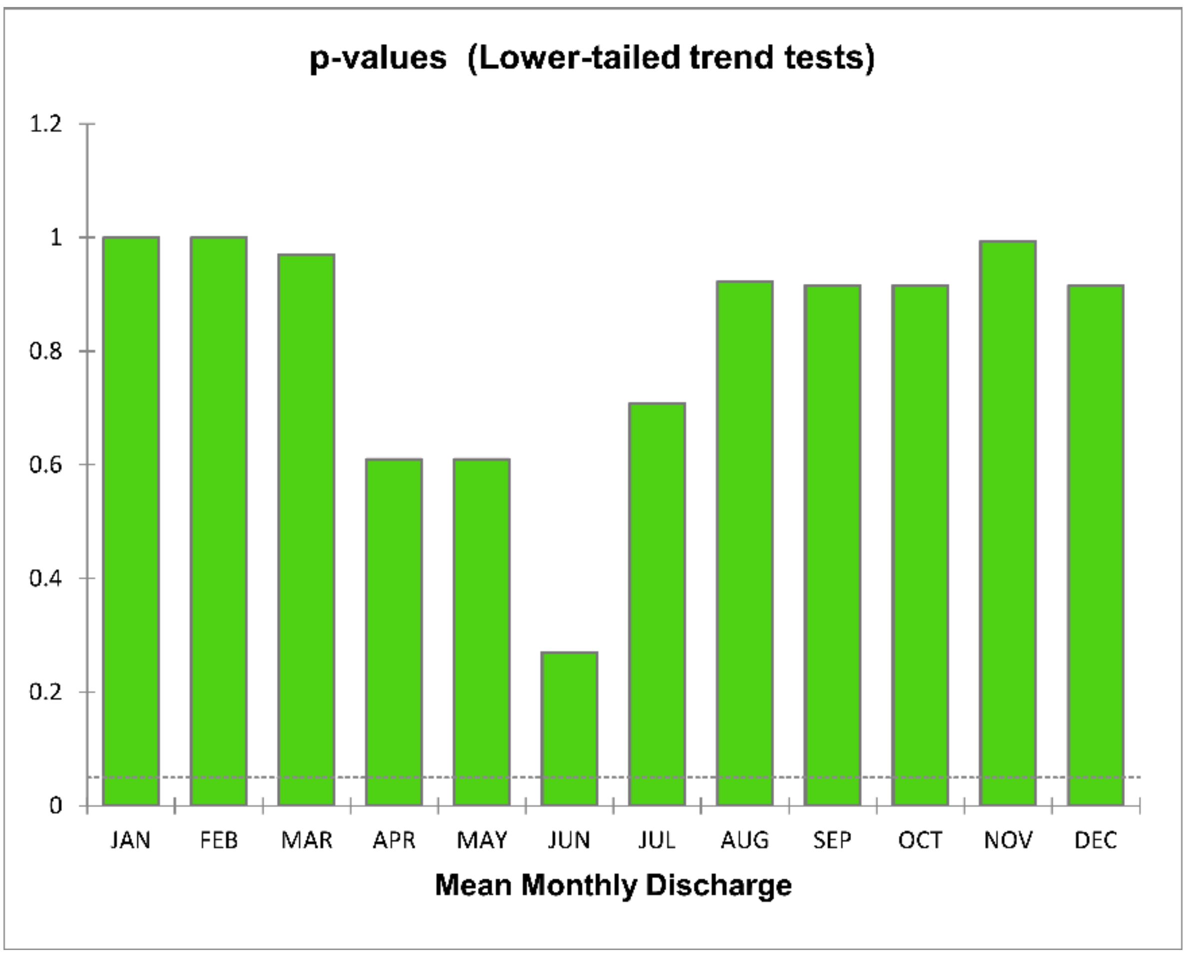
Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 96.74%.

Sen's slope (Period = 1 553.354



Summary:

Series\Test	Kendall's tau	p-value	Sen's slope
JAN	0.667	0.974	600.305
FEB	0.556	0.969	366.162
MAR	0.278	0.943	403.346
APR	0.111	0.717	459.914
MAY	0.056	0.617	204.489
JUN	0.333	0.899	186.213
JUL	0.611	0.968	181.375
AUG	0.333	0.924	94.937
SEP	0.222	0.881	20.758
OCT	0.222	0.881	442.799
NOV	0.167	0.752	237.216
DEC	0.444	0.967	553.354



Appendix 4.10: Mean Annual Discharge (Mann-Kendall's Two-tail Trend Test)

XLSTAT2018.1.49205-Mann-Kendalltrendtests-
Starttime:1/22/2018at9:37:33PM/Endtime:1/22/2018at9:37:36PM

Timeseries:Workbook=meanannualdischarge.xlsx/Sheet=Sheet1/Range=Sheet1!$A$1:$A$42/41rowsand1column

Significance level(%):5

Confidence interval(%)(Sen's slope):95

Summary statistics

Summary statistics:

Variable	No. of observations	Entries with missing data	Entries without missing data	Mean discharge	Maximum discharge	Minimum discharge	Standard Deviation
Mean Ann	41	0	41	627.061	3765.831	1824.529	825.872

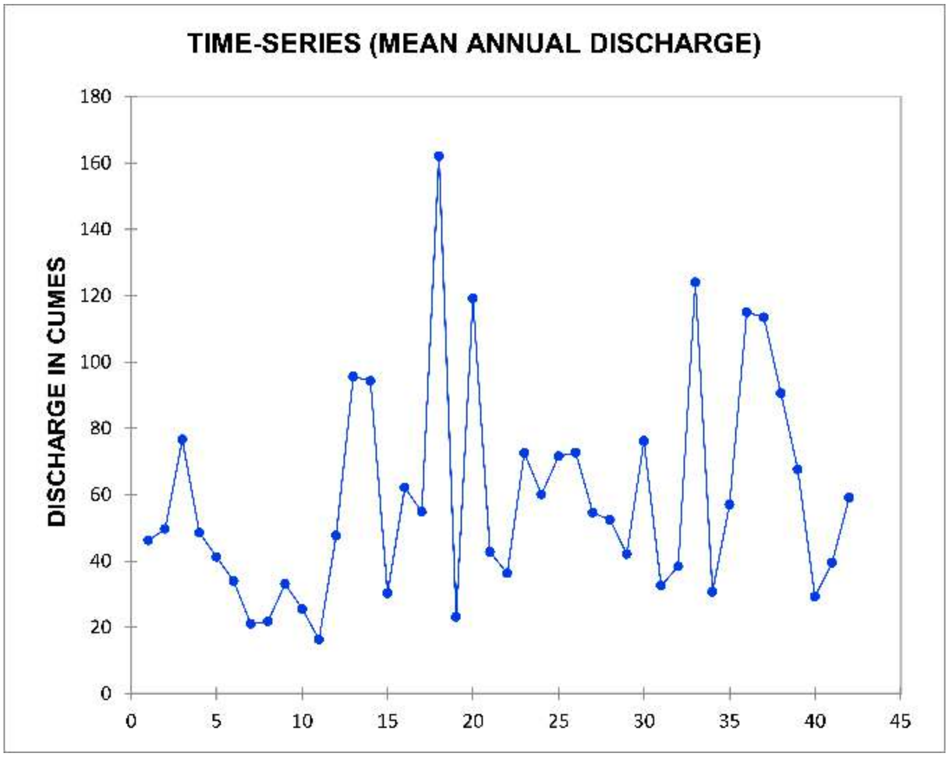
4.10.1 Mann-Kendall trend test/Two-tailed test (Mean Annual Discharge):

Kendall's tau	0.190
S	156.000
Var(S)	7926.66
P-value	0.082
alpha	0.05

An approximation has been used to compute the p-value.

Test Interpretation:
H0: There is not Trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 8.18%.

Sen's slope: 20.391
Confidence interval:]15.215 ,26.707[



Summary:

Series\Test	Kendall's tau	p-value	Sen'sslope
Mean Ann	0.190	0.0822	0.391

Appendix 4.11: Mean Annual Discharge (Mann-Kendall's Upper-Bound Trend Test)

XLSTAT2018.1.49205-Mann-Kendalltrendtests-Starttime:1/24/2018at10:43:04PM/Endtime: 1/24/2018at10:43:15PM
Timeseries:Workbook=meanannualdischarge.xlsx/Sheet=Sheet1/Range=Sheet1!$A$1:$A$42/ 41rowsand1column

Significance level (%): 5
Continuity correction: Yes
Confidence interval(%) (Sen's slope):95

Summary statistics

Summary statistics:

Variable	No. of observations	Entries with missing data	Entries without missing data	Mean discharge	Maximum discharge	Minimum discharge	Standard Deviation
Mean Ann	41	0	41	627.061	3765.831	1824.529	825.872

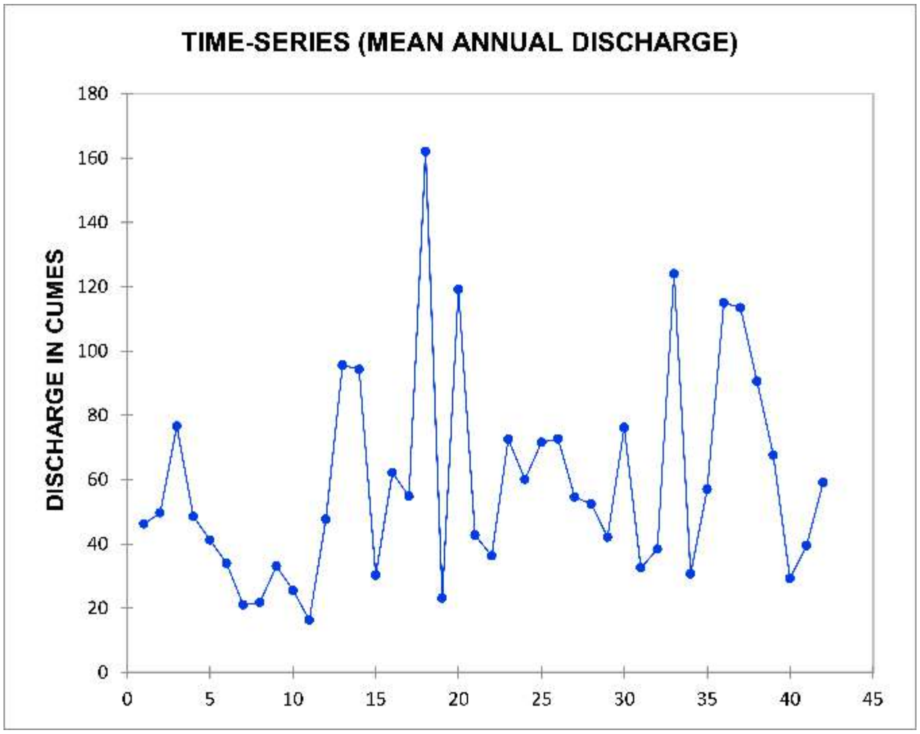
4.11.1 Mann-Kendall trend test/Upper-tailed test (Mean Annual Discharge)

Kendall's tau	0.190
S	156.000
Var(S)	7926.667
p-value	0.041
alpha	0.05

The p-value is computed using an exact method.

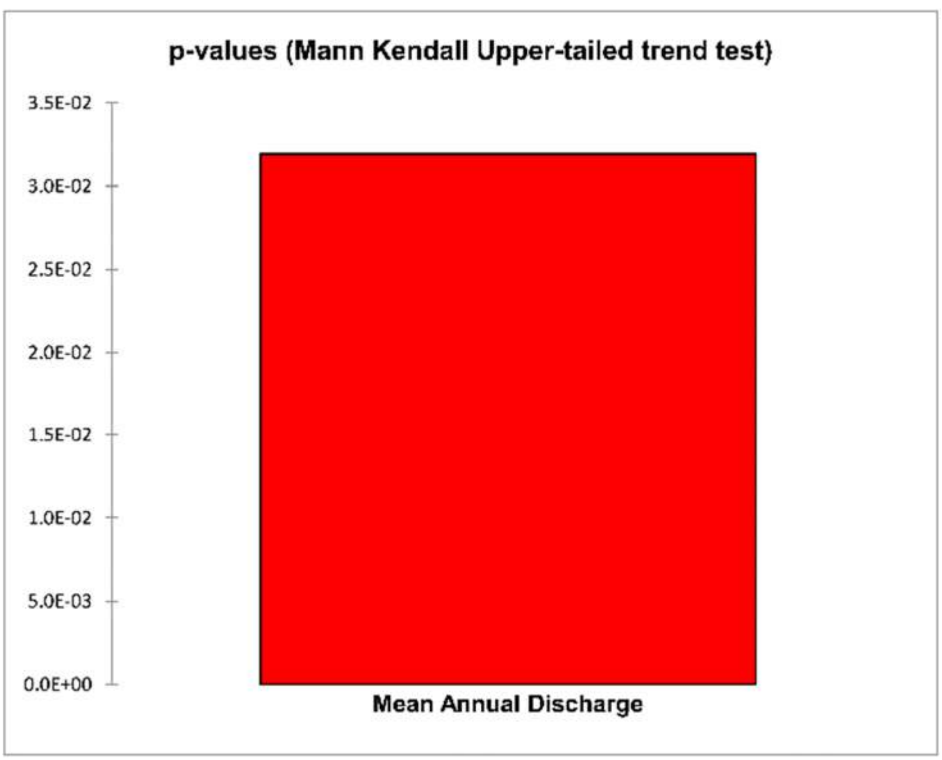
Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
The risk to reject the null hypothesis H0 while it is true is lower than 4.08%.

The continuity correction has been applied. Sen's slope: 20.391
Confidence interval:]15.215, 26.707[



Summary:

Series\Test	Kendall's tau	p-value	Sen'sslope
Mean Ann	0.190	**0.041**	20.391



Appendix 4.12: Mean Annual Discharge (Mann-Kendall's Lower-Bound Trend Test)

XLSTAT2018.1.49205-Mann-Kendalltrendtests-Starttime:1/24/2018at10:37:29PM/Endtime: 1/24/2018at10:37:40PM

Timeseries:Workbook=meanannualdischarge.xlsx/Sheet=Sheet1/Range=Sheet1!$A$1:$A$42/ 41rowsand1column

Significance level(%): 5

Confidence interval(%) (Sen's slope):95

Summary statistics

Summary statistics:

Variable	No. of observations	Entries with missing data	Entries without missing data	Mean discharge	Maximum discharge	Minimum discharge	Standard Deviation
Mean Ann	41	0	41	627.061	3765.831	1824.529	825.872

4.12.1 Mann-Kendall trend test/Upper-tailed test (Mean Annual Discharge)

Kendall's tau	0.190
S	156.000
Var(S	7926.667
p-value	0.961
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

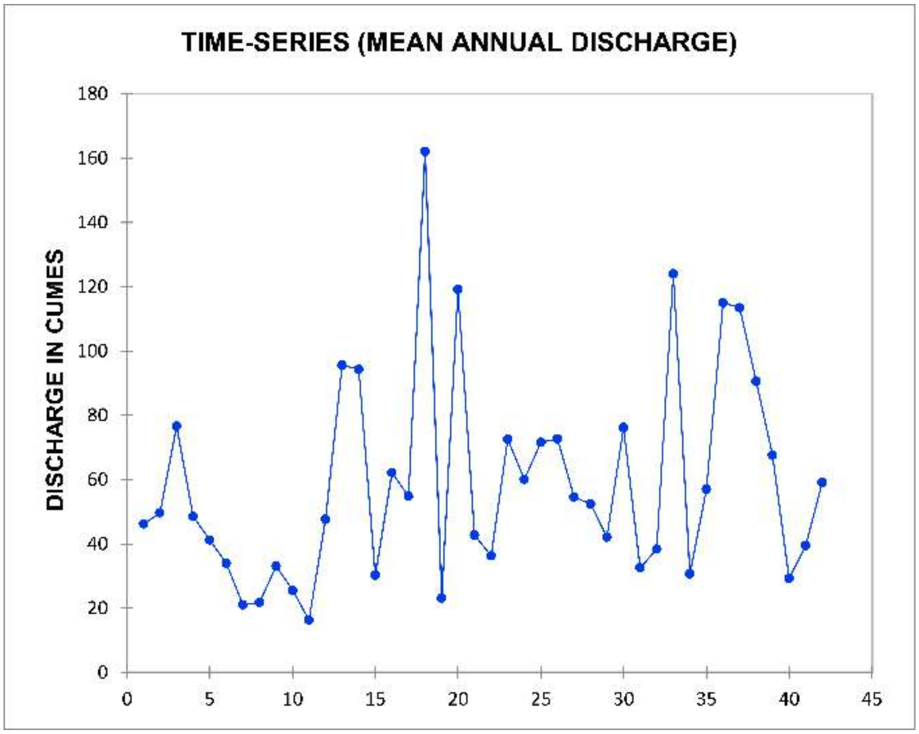
Ha: There is a negative trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 96.11%.

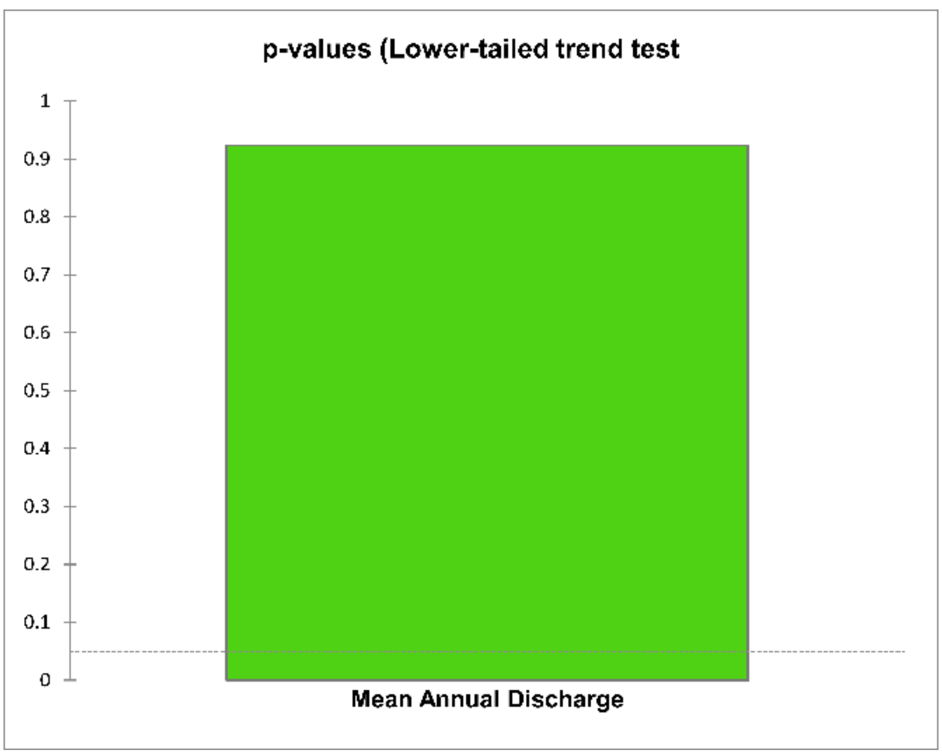
Sen's slope: 20.391

Confidence interval:]15.215,26.707[



Summary:

Series\Test	Kendall's tau	p-value	Sen'sslope
Mean Ann	0.190	0.961	20.391



Appendix 4.13: Mean Annual Discharge 1966-2000 (Mann-Kendall's Two-Tail Trend Test)

XLSTAT 2018.1.49386 - Mann-Kendall trend tests - Start time: 2/9/2018 at 5:37:56 PM / End time: 2/9/2018 at 5:37:57 PM

Time series: Workbook = 2018 annual discharge outliers.xlsx / Sheet = Sheet1 / Range = Sheet1!$N$1:$N$36 / 35 rows and 1 column

Significance level (%): 5

Summary statistics

Summary statistics:

Variable	No. of observations	Entries with missing data	Entries without missing data	Mean discharge	Maximum discharge	Minimum discharge	Standard Deviation
MEAN ANN	35	0	35	16.307	162.060	56.166	32.081

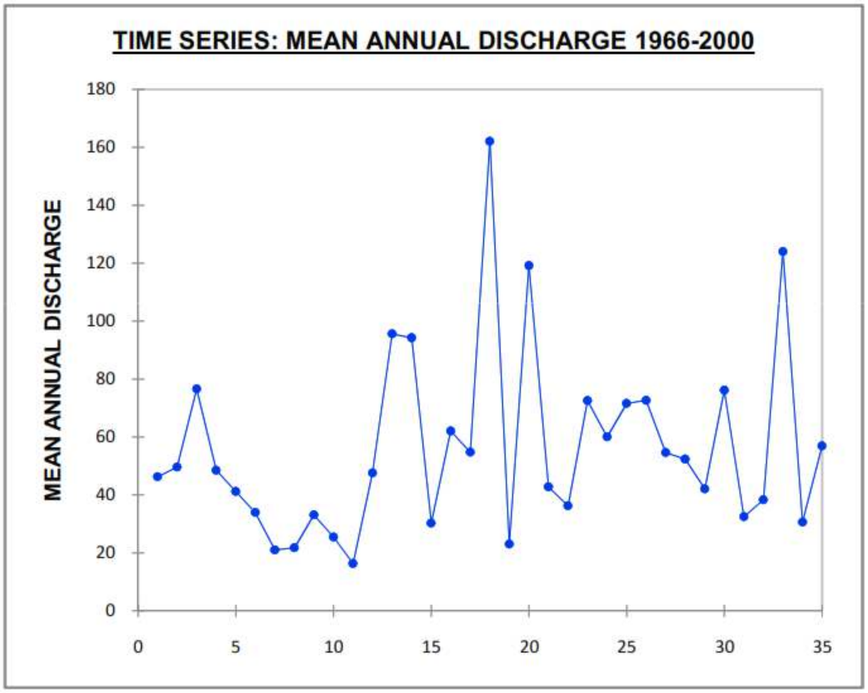
4.13.1 Mann-Kendall trend test / Two-tailed test (Mean Annual Discharge)

EXCLUDING OUTLIERS):

Kendall's tau	0.123
S	73.000
Var(S)	4958.333
p-value	0.309
alpha	0.05

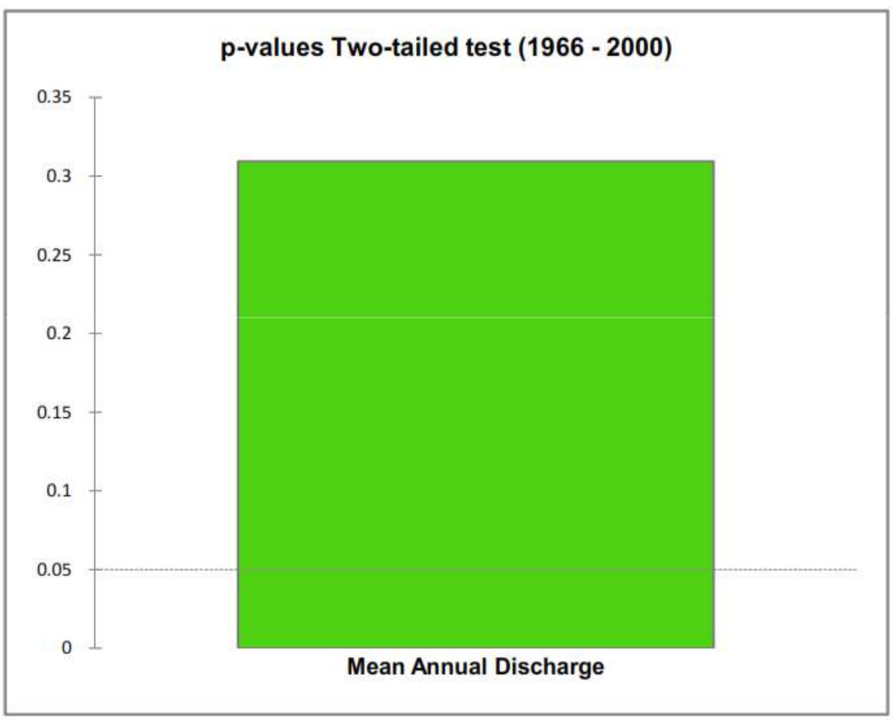
An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 30.93%.



Summary:

Series\Test	Kendall's ta	p-value	Sen's slope
MEAN ANN	0.123	0.309	0.473



Appendix 4.14: Mean Annual Discharge 1966-2000 (Mann-Kendall's Upper-Tail Test)

XLSTAT 2018.1.49386 - Mann-Kendall trend tests - Start time: 2/9/2018 at 5:38:46 PM / End time: 2/9/2018 at 5:38:46 PM
Time series: Workbook = 2018 annual discharge outliers.xlsx / Sheet = Sheet1 / Range = 'Sheet1'!$N$1:$N$36 / 35 rows and 1 column
Significance level (%): 5

Summary statistics

Summary statistics:

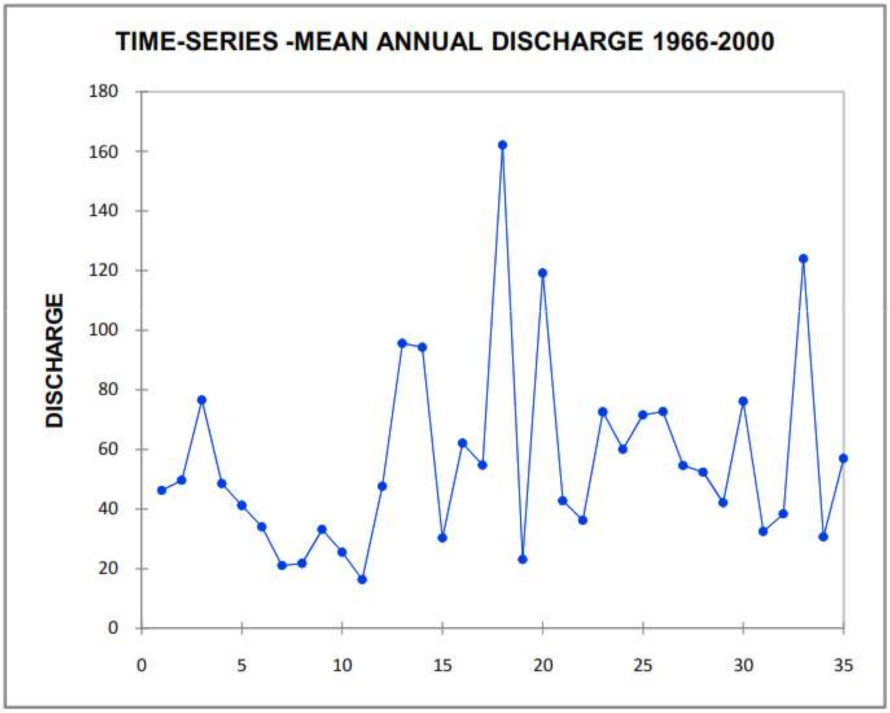
Variable	No. of observations	Entries with missing data	Entries without missing data	Mean discharge	Maximum discharge	Minimum discharge	Standard Deviation
MEAN ANN	35	0	35	16.307	162.060	56.166	32.081

4.14.1 Mann-Kendall trend test / Upper-tailed test (Mean Annual Discharge)

Kendall's ta	0.123
S	73.000
Var(S)	4958.333
p-value (on	0.155
alpha	0.05

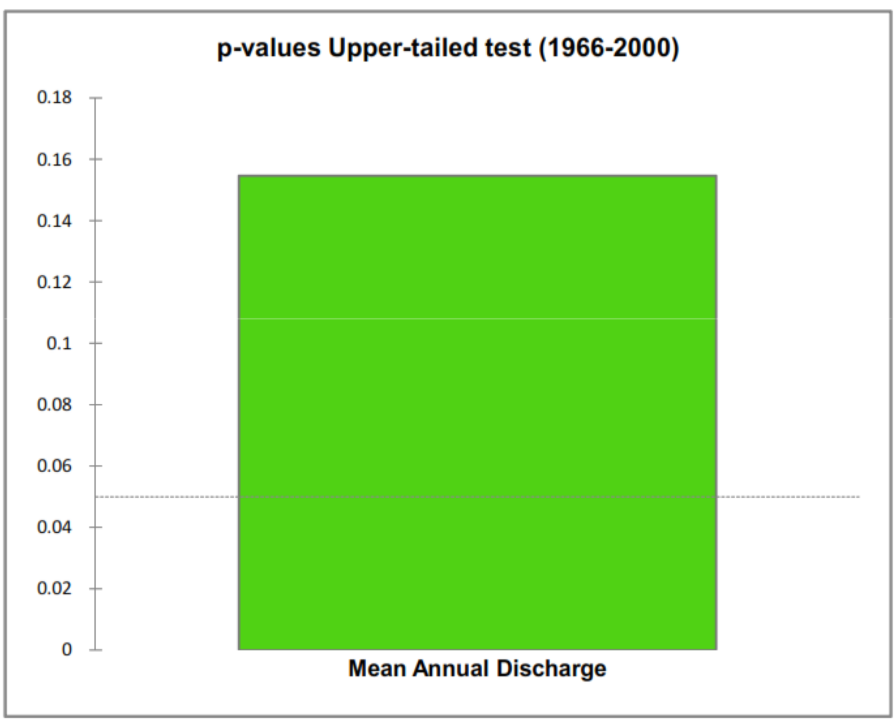
An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a positive trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 15.46%.



Summary:

Series\Test	Kendall's tau	p-value	Sen's slope
MEAN ANN	0.123	0.155	0.473



Appendix 4.15: Mean Annual Discharge 1966-2000 (Mann-Kendall's Lower-Tail Test)

XLSTAT 2018.1.49386 - Mann-Kendall trend tests - Start time: 2/9/2018 at 5:38:25 PM / End time: 2/9/2018 at 5:38:25 PM

Time series: Workbook = 2018 annual discharge outliers.xlsx / Sheet = Sheet1 / Range = 'Sheet1'!$N$1:$N$36 / 35 rows and 1 column

Significance level (%): 5

Summary statistics

Summary statistics:

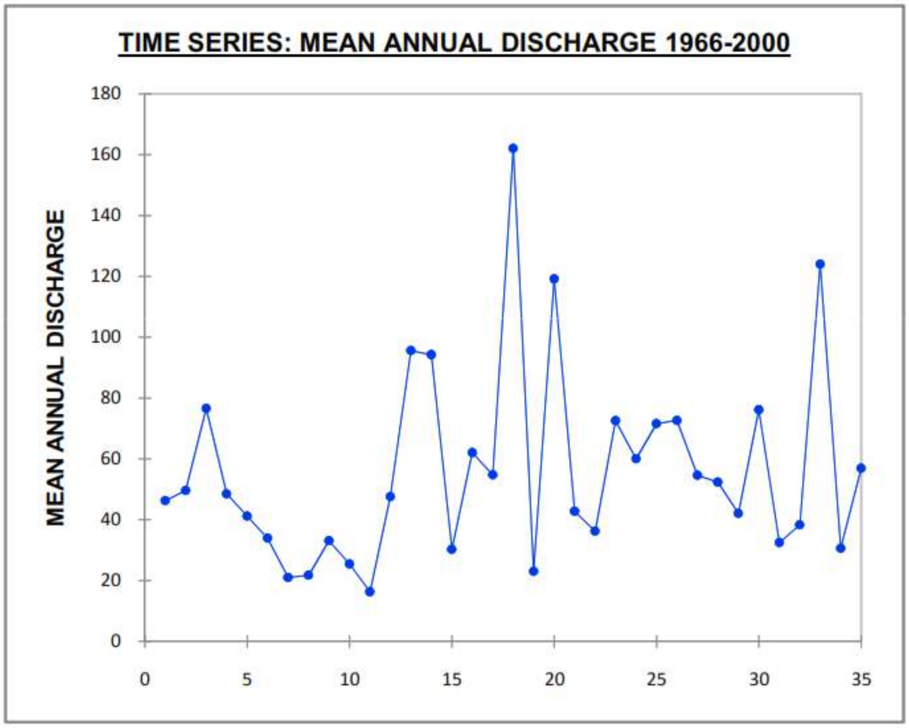
Variable	No. of observations	Entries with missing data	Entries without missing data	Mean discharge	Maximum discharge	Minimum discharge	Standard Deviation
MEAN ANN	35	0	35	16.307	162.060	56.166	32.081

4.15.3 Mann-Kendall trend test / Lower-tailed test (Mean Annual Discharge)

Kendall's ta	0.123
S	73.000
Var(S)	4958.333
p-value (on	0.852
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: There is no trend in the series
Ha: There is a negative trend in the series
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 85.20%.



Summary:

Series\Test	Kendall's tau	p-value	Sen's slope
MEAN ANN	0.123	0.852	0.473