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Effects of Rainfall Variability on Stream Flow and Its Impact on Small Scale Irrigation: The Case of Gedemso River, Central Rift Valley of Ethiopia

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A thesis submitted the School of Graduate Studies of Addis Ababa University, College of Development studies, Center for Environmental and Development Studies, in partial fulfillment of Master of Arts Degree in Water and Development.

June, 2013
Addis Ababa University

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This is to certify that the thesis prepared by *Mulugeta Bekele*, entitled: *Effects of Rainfall Variability on Stream Flow and Its Impact on Small Scale Irrigation: The Case of Gedemso River, Central Rift Valley of Ethiopia* and submitted in partial fulfillment of requirements for the Degree of Master of Art in Water and Development, complies with the regulation of the University meets the accepted standards with respect to originality and quality.

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Acknowledgment

I would like to express my deepest gratitude to my advisor, Professor *Taffa Tulu,* who has given me his scientific guidance, constructive comments and unreserved encouragements to complete this thesis in time.

I am very much grateful to *Tigneh Eshete* and *Mulugeta Tesfa* (Hawassa University, Wondo Genet College of Forest and Natural Resources) for their unreserved support in spatial data analysis using GIS and SPSS respectively.

My thanks go also to my employer, the Ministry of Education for sponsoring me to join the graduate school and Horn of Africa Regional Environment Center and Network (HoA REC/N) (STRONGBOW Project Office) for funding the thesis work.

I am grateful to Ministry of Water and Energy, Ethiopian Mapping Agency, National Meteorological Service Agency and Oromiya Region Arsi Negele Woreda office of water and irrigation development for their support in providing data required for this study.

Very special thanks to my mother, father, sisters and brothers, especially to my sister *Senait Bekele* for their necessary support during the study period.

My very special thanks go to all my class mates and especially to *Yericho Berhanu* for our friendly stay during the study period. Moreover very special thanks to all my teachers.

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List of Acronyms

AMO: Atlantic Multidecadal Oscillation.

CFCs: Chlorofluorocarbons.

CRV: Central Rift Valley

CSA: Central Statistics Agency

DEM: Digital Elevation Model

ERM: Environmental Resources Management.

EU: European Union

GHGs: Green House Gases.

IPCC: Intergovernmental Panel on Climate Change

IOD: Indian Ocean Dipole

ITCZ: Inter-Tropical Convergence Zone.

MoA: Ministry of Agriculture

NMSA: National Meteorology Service Agency.

PDO: Pacific Decadal Oscillation

SOI: Southern Oscillation Index

SRTM: Shuttled Radar Terrain Model

SSI: Small Scale Irrigation.

Abstract

The availability and accessibility of water in space and time, both in quality and quantity, depends on the existing climate of an area and it could significantly vary with climate change. In developing countries, like Ethiopia where agriculture becomes the major source of the economy and dominantly rain-fed based, the farming system is vulnerable to climate change mainly rainfall variability. To reduce such impacts, introduction of irrigation system is taken as one major solution. In this regard, development of sustainable irrigation requires reliable agro-meteorological data and irrigation management system. Therefore, this is study aimed at analyzing rainfall variability, which is leading to stream flow fluctuation and its impact on Gedemso SSI scheme in central Rift Valley region of Ethiopia. Five stations rainfall data, stream flow gauged data, topographic map of the catchment, Digital Elevation Model and data collected from irrigation beneficiary households were major data types used. Data analysis was undertaken using descriptive statistical tools and IDW spatial interpolation using SPSS and ArcGIS software respectively. The analysis of rainfall variability over the catchment resulted in coefficient of variation of 55.25%, 27, 49%, and 14.7% during Bega (October-January), Belg (February-May) and Kiremt (Jun-September) seasons respectively. Years of low rainfall with values less than one standard deviation below the mean, i.e., 1997 and 2002 were drought year. The variability of rainfall and stream flow has strong positive correlation with r value of 0.719 and R^2 *of 63.5%. The study also investigated the existence of irrigation hazards associated with problems of stream fluctuation, canal structure and water use management, which was explained by 53% decline in tomato yield per hectare observed during low stream flow. Therefore, in order to have sustainable irrigation development; well designed canals, sound water use management plan and best irrigation system technology should be promoted and implemented.*

Key Words: *Climate Change, Climate Variability, Rainfall variability, Stream flow, Small Scale irrigation*

1. Introduction

1.1. Background and Justification

Climate Change has significant impacts on the availability and accessibility of water both in quality and quantity. Changing in temperature affects the hydrological cycle which leads to the occurrence of sometimes dry season and other times wet season. This would bring subsequently heightened risks of more extreme and frequent floods and drought (ERM. 2007).

Climate change is rapidly emerging as one of the most serious threats that humankind ever face. Although no country is immune from climate change impacts, poor countries which contributed least to the problem occurrence are the most vulnerable and least adaptive to its impacts. In Ethiopia, climate change and variability poses particular risks to poor farmers' who have an immediate daily dependence on climate sensitive livelihoods and natural resources (Ahmed et al. 2011). Rainfall variability has direct impacts on agricultural output, and water-intensive industry and power production (World Bank. 2006). In rain-fed agricultural dependent areas, irrigation is the wide solution taken to overcome the rainfall variability problem by proper utilization of natural water resource. The water forms used in irrigation are ground water, river diversion, surface runoff and rain water harvesting in small or large reservoir. For all of these, the ultimate source of water is rainfall. But if the climate does change dramatically in the future, and on the speed and direction in which such changes occur, it is possible that sustainability of a number of developmental strategies and programs could be undermined with considerable losses to both national and individual's economies and therefore, if water supplies are limited due to climate changes, dependence on irrigation can be risky (Jesse et. al 2005).

Agriculture in Ethiopia is at risk in most of the years due to high rainfall variability. To overcome the hazards resulting from rainfall deficiency, especially in food security, development of irrigation is important. But in order for optimum utilization of rain water for irrigation, it is important to have reliable information about the total rainfall water and its variability in time and space (NMSA.1996). So, with continuous rainfall variability due to climate change, the hydraulic drought (challenge of water resource sustainability) may occur. The hydraulic drought reduces the stream flow and ground water levels, which leads to water shortage in the irrigation scheme and as a whole in the environmental ecosystem. This study investigates, how an effect of rainfall variability on the stream flow and affects the water resource used for irrigation scheme.

1.2. Statement of the Problem

Climate change in connection with spatio-temporal variability of rainfall, temperature and humidity could have strong impact on agriculture needs a profound and ongoing research to act accordingly. In this regard, climate change in the form of rainfall variability owing to the fluctuation of stream flow has become a major challenge for small scale irrigation development in many parts of developing agrarian economies especially in Ethiopia where the agricultural system is largely rain-fed.

In this regard, the effect of rainfall variability on the stream flow of Gedemso River could be a major threat on the sustainability and management of Gedemso SSI schemes. Based on report of Oromiya Bureau of Water and Energy (2009) at the beginning the Gedemso small irrigation project was planned to irrigate 177 hectares depending on the stream flow of Gedemso river, however due to stream flow fluctuation, there have been time in which the actual irrigated area were only 90 hectares without any change and /or intervention in the upper course of the Stream. Hence, developing proper rainfall forecasting and improving water storage capacity could help to optimize the water resources use and management of the irrigation scheme.

The hypothesis in the area is that there are no adequate short and long term rainfall forecasting for water resource availability and sustainability, the Gedemso irrigation schemes have been facing water stress situation under expanding irrigation. The expansion & development of irrigation practices in the area without proper management of water storage and rainfall forecasting would lead to problems of water stress and yield reduction.

Therefore investigating the extent and the specific ways in which rainfall variability affect stream flow of Gedemso River and its implication on Gedemso SSI scheme could help to develop proper management and sustainable water use in irrigated areas.

1.3. Significance of the study

The study will provide important information for local community for effective and efficient use of water resource development planning. Based on the study's information, management option will be proposed, such as scheduling of irrigation activities as a function of rainfall variability and stream flow. The study will provide information on the potential of the Gedemso river water resource for irrigation development. Which means total irrigated area will be estimated. It will also help to understand the past and the current rainfall variability effects on the Gedemso River stream flow.

It will also give the idea of application of rainfall variability analysis on stream flow to researchers on the other existing stream in Ethiopia especially those operating for irrigation and hydropower projects for proper operational management of water resource. And describe the assessment of water resources in the area and compilation of relevant climatic and stream flow information.

1.4. Scope and Limitation

The research venue for this study was in Gedemso River small scale irrigation and its catchment area only. The research was addressed the impacts of rainfall variability on stream flow fluctuation on Gedemso River other things being constant. Other factors contributing for stream flow variations such as livestock water use, land cover change, land degradation and evaporation was not assessed. This study also not assessed the effects of excess rainfall on stream flow and irrigation. However, related literature and studies cited for this study came from different parts of the globe to draw a more clear description on the subject of employee motivation.

1.5. Research Objectives

The main aim of the study is to explore how rainfall variability affects the potential utilization of water resource of Gedemso River for sustainable small scale irrigation.

The specific objectives are to:

- assess the rain fall variability of the Gedemso river catchment;
- identify the Gedemso river stream flow variability;
- evaluate the correlation of rain fall variability and stream flow variation; and
- assess the impacts of Gedemso river stream flow variability on Gedemso I and Gedemso II small scale irrigation schemes and suggest suitable mitigation measures

2. Literature Review

2.1. Concept of Climate Change

Climate change is caused by greenhouse gasses (GHGs). GHGs allow solar radiation from the sun to travel through the atmosphere but prevent the reflected heat from earth's surface and atmosphere back into space, which causes the earth's temperature to rise. GHG emissions have been rising since industrialization in the 1900s, due to increased burning of fossil fuels. Further significant increases in GHG levels are expected, particularly as developing countries become more industrialized. Based on present trends, different studies forecast global temperature increment due to continued GHGs emissions. As evidence, IEA World Energy Outlook predicts a 53 percent increase in global primary energy demand by 2030, with 70 percent of that coming from developing countries. As emerging economies, such as China and India, grow their contribution to energy demand will account for an increasing proportion of the total. Fossil fuels are expected to dominate this increase, and the subsequent GHG emissions will in turn lead to rising temperatures. According to EU, since 1900, global temperatures have risen by 0.7 degrees Celsius and are continuing to rise at an estimated rate of 0.2 degrees per decade (ERM, 2007).

In other investigation of IPCC 1990:23 and IPCC 1990 cited in Jesse C. et al. al 2005; the global mean surface air temperature has increased by 0.3-0.6 °C over the last 100 years with predicted at 0.3 °C average rate of increase during the next century per decade. Which this rapid change is the projected due to increasing atmospheric concentrations of carbon dioxide (CO_2) , methane, nitrous oxide and chlorofluorocarbons (CFCs). The accelerated accumulation of these anthropogenic greenhouse gases causes rapid climate change.

2.2. Climate and Rainfall Variability in Ethiopia

According to Ishappa and Aruchamy (2010), Variability is defined as "the deviation from mean" or "ratio of the standard deviation to the mean rainfall" and in other words variability of coefficient of variation. Among meteorological parameters, rainfall is a highly variable parameter in respect to climate change both spatially and temporally (Wisuwat T. and Nutchanart S., 2009 and PANDE, B. et all., 1978).

El Niño event, topography, Indian and Atlantic Oceans are factors which brought inter-annual variability of rain fall in East Africa. Short rains variability with coefficient o f variability of 74% contributes greater than long rains variability with coefficient of variability 35% for inter-annual rain fall variability in East Africa. Especially, Monsoon activity over India is a major trigger for July– September rainfall variability in the East African highlands (DFID, 2009).

Climate indices were used by previous studies to explain rainfall variability over Ethiopia. Four climate indices were selected by previous studies to explain anomalous rainfall over Ethiopia with the data for the period 1964–2009. These indices represent influences from three oceans: Pacific, Indian, and Atlantic. The indices are Pacific Decadal Oscillation (PDO), Southern Oscillation Index (SOI), the Indian Ocean Dipole (IOD) and Atlantic Multidecadal Oscillation (AMO) (Meron and P. Willems, 2012).

Ethiopia is found in the tropics of East Africa. But its climate is different from East African countries climate, which, is modified by altitude, which has led to the existence of diverse microclimates (Dega, Weina-Dega, kola and Bereha). According to the patterns of rainfall, Ethiopia has four climatic zones. These are those one wet and one dry season, two wet and two dry seasons, two wet seasons and one dry season in between, and an undefined rainy season(NMSA.1996 and Tsegay et al., 2000).

In addition to local factor of altitude and four climate indices, the wide external factors of Inter-Tropical Convergence Zone (ITCZ) is one of the major causes of rainfall variation in Ethiopia. The ITCZ moves to north ward during northern hemisphere summer and toward south during southern hemisphere summer. The High Pressures created in the Maskarin and St. Helena areas also influence the moisture-carrying winds to go to Ethiopia and drop their precipitation. The weakening of these high pressures reduces the amount of rainfall in Ethiopia. The three-seasons Kiremt, Bega and Belg with big rains from June-September, dry from October-January and small rains from February- May respectively are characterized the crop-producing areas of Ethiopia (Tsegay et al., 2000).

The intensity and fluctuation of the rain-producing systems during the Kiremt season influence the amount and distribution of rainfall in Ethiopia (Babu 1999a, 65 cited in Tsegay et al., 2000).

2.3. The Linkage of Rainfall Variability and Stream Flow

Much of the solar energy received by the Earth is used to drive the hydrological cycle, higher levels of solar energy trapped in the atmosphere will lead to an intensification of this cycle, resulting in changes in precipitation patters. These changes will result in increased floods and drought, which will have significant impacts on the availability of freshwater (ERM, 2007).

Changes in rainfall trends have strong impact on stream flow. Emphasize the strong impacts of rainfall variations on stream flow plays a great roll in giving information in planning and strategic management of water resources (Garbrecht et al., 2004).

To explanation for the observed flow variability, investigated basin-wide rainfall is important. Rainfall and river flow variability have positive relation. Hence, basin-wide rainfall is the major driving factor for river flows variability. For instance, the river flow volumes and extremes at El Diem have similar oscillation patterns with that of rainfall in the region, which confirms that there is a high (0.8,) positive relation between two variables (Meron and P. Willems, 2012). Other study shows that the flow of watercourses more determined by rainfall variability than other factors such as different human activities act up on water bodies and its catchment. For instance, Lake Tana out flow highly fluctuates with rainfall variability (S. Kebede et al., 2006).

Since, rainfall plays an important role in the hydrologic cycle which controls our water supplies and water disasters, knowing the nature and characteristics of it is important. Rainfall data can predict its effects in runoff, infiltration, evapotranspiration, and water yield. Therefore as possible accurate rainfall data is important to improve the hydrograph prediction results. Because of the topographic variability of the catchment area, rainfall is never evenly distributed over the given area. Therefore, estimate of areal rainfalls which represent the actual rainfalls over the catchment is important with having as many rainfall stations as possible. But, due to limiting factors such as difficulty of certain areas, or lack of available staff, installs rainfall stations in as many locations is not possible. Now today several areal rainfall estimation techniques are used for averaging rainfall depths collected at ground stations. The Arithmetic mean, Isohyetal, Thiessen polygon and spatial interpolation such as IDW, Spline, Kriging, Voronoi techniques are conventional techniques that are usually applied to estimate the areal rainfall over the entire basin (Wisuwat T. and Nutchanart S., 2009, PANDE, B. et al., 1978 and Elizabeth M. Shaw and P.P. Lynn 1972).

There are a number of curve models to explain the trends. But the models do not explain the trend in the same manner. According to Taffa (2003), model accepted for one scenario, might not necessarily provide an acceptable solution for others. Therefore, selection of best model for curve fitting was done by using the standard error of estimates (SE) and residual of the mean squares (RMS). The loWest SE and RMS value is best model.

2.4. Small Scale Irrigation Agriculture Development

Ethiopia practiced irrigated agriculture since 1960 with the objective of producing industrial crops such as sugar and cotton on large-scale basis. Local farmers however, had already been practicing irrigation by diverting water from rivers in the dry season for the production of survival food crops as traditional irrigation. However, the small-scale irrigation (SSI) development and management started in the 1970s by the Ministry of Agriculture (MoA), in reaction to major droughts, which caused wide spread crop failures and consequent starvation (Seleshi and Douglas undated).

Criteria's for the classification of irrigation schemes are different from country to country. Irrigated area, scale of operation and management types are frequently used as main criteria for the classification of irrigation schemes in to small, medium and large scale irrigation. According to Rahemet (1999) cited in Mengistu (2008), in Ethiopia during the Dergue regime, based on size irrigation schemes were categorized into three types; small-scale (less than 200 ha), medium scale (200-3000 ha) and large scale (greater than 3000 ha).

Another classification takes into account size and management as thought of Werfring et al., (2004) cited in Mengistu (2008), for the classification of irrigation schemes in to traditional small-scale irrigation schemes up to 100 ha built and operated by farmers in local communities; modern commercial schemes up to 200 ha built by Government agencies with farmer participation; modern private schemes up to 2,000 ha owned and operated by private investors individually, in partnership, or as corporations; and Public schemes of over 3,000 ha owned and operated by public enterprises as state farms.

Based on water sources used for irrigation, the study of programmatic environmental assessment of small-scale irrigation in Ethiopia also classifies irrigation system as the following systems. These are diversion, spate, spring systems, and storage and lift systems. Diversion system uses natural river flows and referred to as off-take systems. It the most common form of irrigation system in Ethiopia. Spate systems use occasional flood flows of temporary streams and operate occasionally during part of the year. Run-off (run-off from rainfall received in the same catchment from natural waterways on to agriculture land) and foothill site (diverts flood flows originating in highland areas) system are the two common types of the spate systems used in Ethiopia. Spring systems utilize flows from small springs. Water is often stored over night in small reservoirs and emptied daily. Storage systems referred to as tanks in South Asia and earthen dams in Ethiopia, store water for an extended period behind dams. In Ethiopia, storage systems are introduced recently and pose technical and production challenges. It is important to consider the catchment flow and amount of sediment in designing storage systems. Cropping must be planned according to the amount of water stored and available for irrigation. Lift systems referred extract water from rivers, irrigation canals, reservoirs and wells (CRS, 1999 cited in Mengistu, 2008).

2.4.1. Water Use Management in Small Scale Irrigation

Changes to accessibility of water have the potential to increase conflict, as the competing demands of private, agricultural, and industrial uses for water put pressure on resources. This may exacerbate conflict in existing water stressed areas competing locally for access to natural springs and rivers, as well as lead to conflicts on a larger international trans-boundary scale (ERM, 2007).

In irrigation and improved agriculture, water management practice could provide opportunities to cope with impact of climatic variability, enhance productivity per unit of land, and reduce conflicts. However, assessments show that with SSI in all parts of Ethiopia relate to the need to improve communication, community consultation and involvement in project planning and implementation, proper design with adequate timing and reference to local information and indigenous knowledge, technology choice and market related issues, as well as adequate baseline studies prior to implementation. Lack of clear water use and irrigation development policies; lack of co-operation and coordination among organizations involved in SSI funding, development and management are the cause for failures of irrigation in Ethiopia. Ambitious irrigation planning without securing sufficient skilled manpower, local capacity to run the schemes (management, financial, and technical capacity) have also been considered as a source of failure in all parts of Ethiopia. During scheme design, irrigation structures should fully incorporate farmer's indigenous knowledge and traditional experience, and take local level capacity into consideration is important (Seleshi and Douglas undated).

In the Central Rift Valley of Ethiopia, there are number of irrigation practices with open field smallholder vegetable and fruit productions are the predominant irrigation systems in the area with complex and vulnerable hydrological systems in the watershed (Wim, P., 2010).

In the large areas of CRV irrigation take place for the production of cash crops. The increased use of water for irrigation puts a great pressure on the local hydrology and management of water resources in the CRV is complex due to increased competition for irrigation water. Because of climate change and water use competition, the challenge that irrigated agriculture faces in the coming years is how to increase water productivity in the face of growing water scarcity and the limited availability of water for agriculture (Mengistu, 2008).

2.4.2. The Impact of Rainfall Variability on Agricultural Irrigation

Rainfall variability is shown to be highly relevant and negatively correlated to economic performance; that is, the greater the level of variability modeled into the system, the worse the growth and poverty outcomes (Seleshi et. al 2007). Irrigation is one of the major safeguard against drought. But it may not always buffer against drought. Evidences show that high levels of irrigation in Mexican States such as Sonora and Sinaloa, do have much drought losses than many of the states with smaller proportions of irrigated land. However, in 1970, Aguascalientes and San Luis Potosi, with about 20% of their land irrigated, reported drought losses of 70% and 50%, respectively which indicate that dependence on irrigation can be risky if water supplies are limited, or climate changes (Jesse C. et. al 2005).

Access to water plays a key role in development to sustain human life, through direct consumption, use in agriculture for food security as well as use in industrial activities. While water availability deteriorated by the changes to the hydrological cycle. Water for drinking, industrial to fuel economic growth and agriculture purposes is essential. The demands from these sectors can cause conflict over water availability and use. Today, more than one billion people still lack access to safe water, while over two billion lack safe sanitation (ERM, 2007).

Agriculture is one of the hardest-hit sectors by climate change, reinforcing the unequal distribution of impacts. Many of the world's countries already struggle under existing water stress from pressures such as irrigation demands. Warmer temperatures will lead to increased water evaporation, intensifying the need for irrigation in particular as water becomes even less available. For many regions will result in reduced rainfall and increasing temperatures, further reducing the availability of water for agriculture.

As seasonal water quantities decrease as a result of changes in hydrological cycle, competition for available resources will increase. Demand for agricultural and domestic water in particular increases significantly at hotter and drier times of the year. Agriculture has always been the dominant end-use of diverted water; this will only intensify with increasing needs for irrigation brought on by higher temperatures and reduced precipitation, coupled with increasing populations.

Increasing supply for irrigation will simply not be possible in many regions, particularly where irrigation capacity is not sufficiently developed to accommodate changing precipitation patterns. Changes in rainfall will have a significant social and economic impact. Meanwhile, it is estimated that a temperature increase of 2-3.5 degrees Celsius in India could result in a decline in farm revenues of between 9 and 25 percent.

The International Rice Research Institute, for example, estimates that for every degree Celsius of night time temperature increase, there is at least a 10 percent decrease in rice production for the African region. In regions already affected by food shortage and famine, this could cause further disruptions in food supply (ERM, 2007).

According to Ahmed et al. (2011), the Oromia National Regional State is characterized by altitude of the region ranges from below 500masl at the Rift Valley to 4377masl at mountain Tullu Dimtu. The region experiences annual temperature ranging from 10^0C to 30^0C, with mean annual temperature of 19^0C and has bi-modal rainy seasons with the annual rainfall ranges from 400-2400mm. The region is predominantly an agricultural economy, which is rain-fed and small scale farming providing livelihoods for 85 percent of the population. This Agriculture is highly dependent on the timely onset, amount, duration, and distribution of rainfall. The consequences of climate variability and climate change have severely threatened the sector and it's a potential to cause natural environmental hazards and the potential to undermine the regions as well as the country's economic development.

2.5. Conceptual Framework

This study tags along the pass of sold line. The conceptual framework guides the work to achieve the objectives. It stars from the original causes of the problem. The original cause of the problem is climate change due to natural and anthropogenic factors, which assessed through literature review.

This climate change leads to variability in rainfall which will be assessed by uses of rainfall data of five stations in and around the Gedemso River catchment. Rainfall variability causes sometimes dry season and other times wet season. During the occurrence of dry season, meteorological, agricultural, and hydrological droughts is occurs.

According to Pereira et al. (2002), some authors prefer to adopt an operational definition that distinguishes between meteorological, agricultural, and hydrological droughts. These usually focus on the indicator variable of prime interest, which could be the precipitation (meteorological drought), soil moisture (agriculture drought), stream flow discharges or groundwater levels (hydrological drought and groundwater drought).

Next to precipitation (meteorological drought) is happens, the stream flow discharge (hydrological drought) which affects the irrigation development by reducing the availability of water resource in the stream.

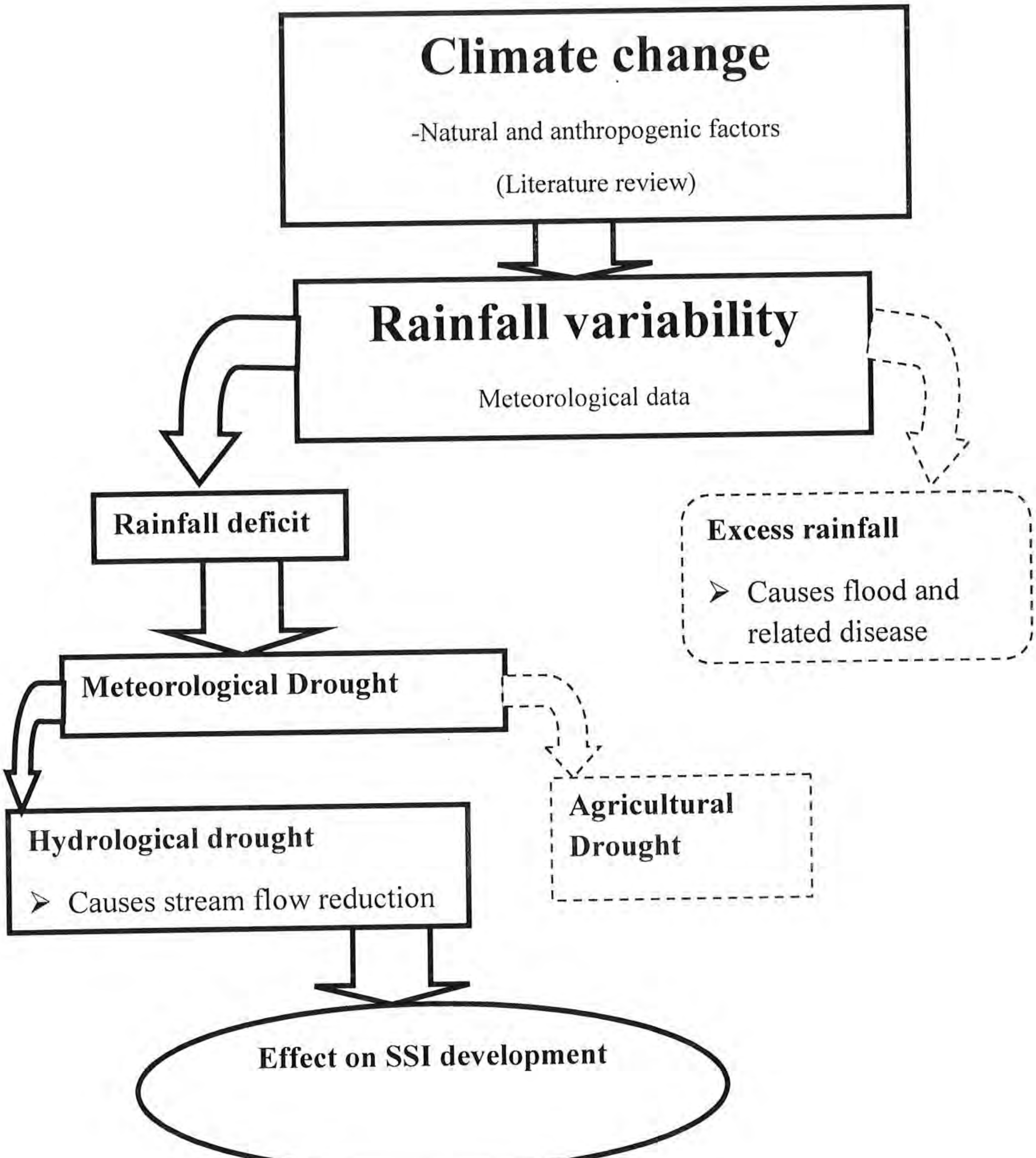


Figure 1 **Conceptual framework**

3. Materials and Methods

3.1. Description of the study Area

3.1.1. Location

The study area is found in Arsi Negele Worada, West Arsi Zone Oromia Region. It extends from 38^0 25'E to 38^0 54'E longitude and 07^0 09' to 07^0 42'N latitude with altitude of 1500-3500m.a.s.l.. It is part of central Rift Valley of Ethiopia and 230 kilo meters distant from Addis Ababa.

According to Arsi-Negele Woreda Agriculture and Rural Development Office: 2012, the total area of Arsi-Negele district is 155727ha with 5979.035ha house occupied land, 59325ha cultivated land, 6434.029ha grazing land, 3483ha forest and bush land, 2190.26ha community land, 44734ha water body and 33581ha other land. It has 43 Rural Kebeles and 5 Urban Kebeles.

3.1.2. Gedemso Catchment Area

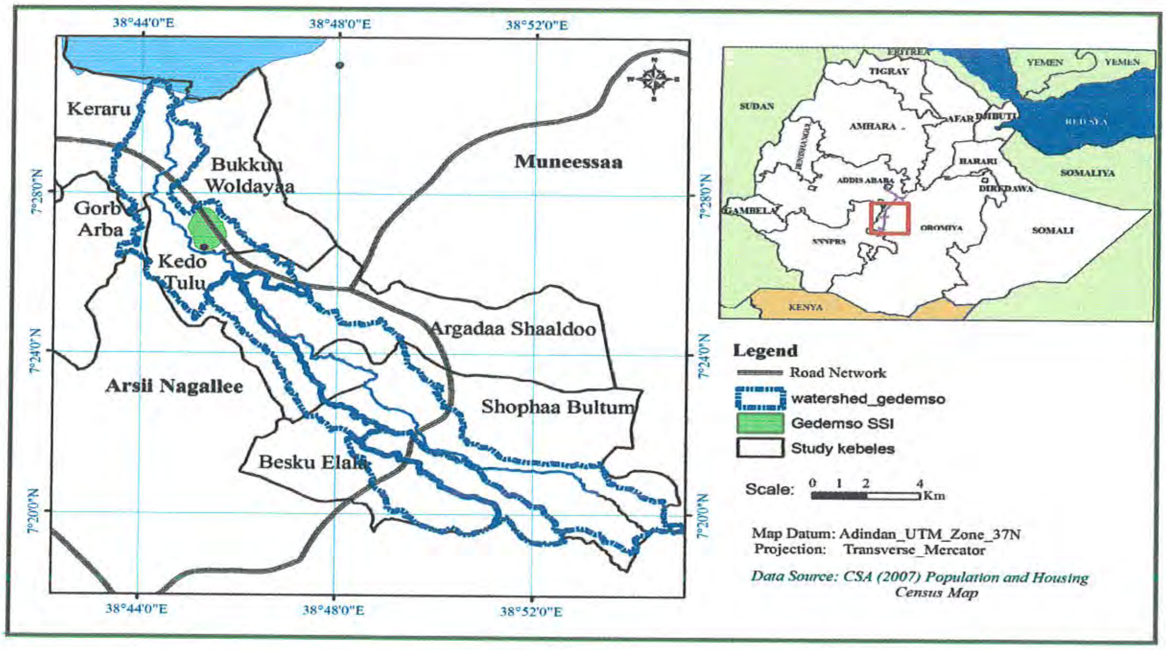


Figure 2 Location Map of Gedemso Catchment

Gedemso catchment is one of the sub catchments found in the upper Rift Valley lakes region in Langano-Ziway catchment. The Geographical location of Gedemso river water catchment is found between $7^{0}19'02"$E- $7^{0}30'50"$E latitude and $38^{0}43'20"$ N - $38^{0}55'04"$N longitude. The total area of the catchment is about 100.09 km sq.

3.1.3. Relief and Drainage

The relief of the area is part of the eastern escarpment of the great east African Rift Valley and characterised by a relatively moderate slope in upper part declining to roll plain in its lower catchment. The elevation within the catchment varies from 1583 to 2748 masl. Numerous small streams drain to Gedemso river catchment. Gedemso River originates from small portion of Kore Woreda to north-eastern part of Arsi negele and ends up in Lake Langano.

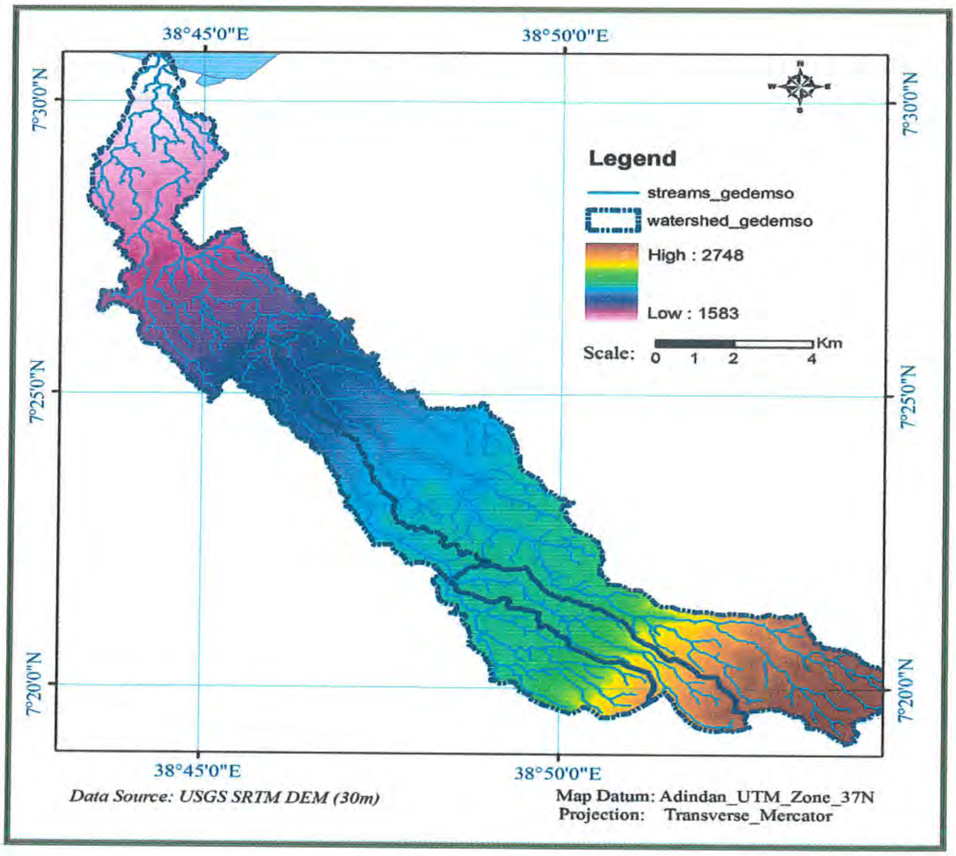


Figure 3 Relief and Drainage of Gedemso Catchment

3.1.4. Socio-economic setting

Based on CSA projection report the total population of Arsi Negele Woreda in 2012 was 326422. The distribution of rural and urban population indicates that 51% of the populations were females. The overall population density was 210 persons per sq.km (Table 1).

Table 1Population data in the Arsi Negele Woreda

Urban population			Rural population				Total	
Male	Female	Total	Male	Female	Total	Male	Female	Total
126085	132719	258804	33522	34096	67618	159607	166815	326422

Source: Arsi Negele Woreda Agriculture and Rural Development Office (2012)

Gedemso river catchment traverses about 7 Kebeles among the 48 Kebeles found in Arsi Negele Woreda, these include Kararu, Gorbi Arba, Bukku Walda, Kedo Tulu, Basku Ilala, Shopa and Argada Shsldo which are found in the Gedemso River catchment (fig. 3 and table 2).

Table 2 Populations in the Gedemso River Water Catchment (2012 data)

Demographic Characteristics		**Name of Kebele (Arsi's Negele Woreda)**							**Total**
		Kararu	Gorbi Arba	Bukku Walda	Kedo Tulu	Basku Ilala	Shopa	Argada Shsldo	
No. Of house	Male HH	703	853	1218	775	1503	1126	947	7125
	Female HH	45	75	72	33	72	64	46	407
	Total	748	928	1290	808	1575	1190	993	7532
Population Size	Male	2135	2464	4860	2550	6198	5460	3362	27029
	Female	2757	2632	5460	2493	6248	6767	3087	29444
	Total	4892	5096	10320	5043	12446	12227	6449	56473

Agriculture crop production with the major crops maize, wheat, teff, sorghum and haricot bean, and livestock rearing are the main economic activities of the district. On the Gedemso River there are two small scale irrigation projects, namely Gedemso I small-scale irrigation scheme and Gedemso II small-scale irrigation scheme. The river diversion for both irrigations is at one site of the river. Gedemso I small-scale irrigation scheme uses direct water diverted from river and Gedemso II small-scale irrigation scheme uses water stored in the dam during night time that released from Gedemso I small-scale irrigation scheme.

3.2. Data Types and Sources

In this study, both primary and secondary data sources were used. Primary data source include both quantitative and qualitative data. Quantitative data including rainfall record of nearby meteorological stations, stream flow, and spatial data such as SRTM DEM, questionnaire and one focus group discussions were used.

Rainfall and stream flow gage data were collected from National Meteorology Service Agency and Ministry of Water and Energy respectively. SRTM DEM and topographic map were collected from EMA. The rainfall series of Arsi Negele and Kuyera stations have gaps and different length of years in their record. Therefore, based on the similarity of the five stations (Arsi Negele, Bulbula, Kuyera, Langano and Dagaga) data series, the period of 12 years (1996-2007) rain fall data were selected and used.

Secondary Data such as 1:50,000 topographic maps of the area, population data, and existing documents were used.

3.2.1. Sampling Design and Methods of Data Collection

The total populations of the Gedemso SSI beneficiaries are 323 householders. Since the population is homogeneous, taking 15% sample size of the householders could best represent the total population and hence 50 households were sampled. In order to select sampled respondents, random sampling technique was employed.

Questionnaires were developed and data were collected through interview from beneficiary farmers to see the overall impacts of stream flow fluctuation on irrigation development and water use management in the irrigation scheme. In addition to this, group discussion within SSI scheme co-operative and Arsi Negele Woreda irrigation department representative were discussed.

3.3. Methods of Data Analysis

Data organization and analysis was made using descriptive statistical tools and software such as SPSS, ArcGIS and micro office packages.

3.3.1. Rainfall Data Analysis

The rainfall record at a certain station may become discontinued due to operational reasons. One way of approximating the missing rainfall record was using the records of the three rain gauge stations closet to the affected station by the "Normal Ratio Method" as given below:

$$P_4 = \frac{N_4 P_1}{N_1} - \frac{N_4 P_2}{N_2} - \frac{N_4 P_3}{N_3} \qquad \text{(eq.1)}$$

Where P_4 is the precipitation at the missing location, N_1, N_2, N_3 and N_4 are the normal annual precipitation of the four stations and P_1, P_2 and P_3 are the rainfalls recorded at the three stations 1, 2 and 3 respectively.

Since the flow of streams at pour point (gauging station) depend on drained the catchment area, it is required to estimate the areal rainfall of the catchment. However, for a given duration of time, the average depth of rainfall falling over a catchment can be estimated by varies methods. In this regard, the arithmetic mean method and spatial interpolation using inverse distance weighted (IDW) technique were compared. Based on comparison results (Table 4), spatial interpolation that could result with low standard deviation was selected to estimate the areal rainfall over the catchment.

The study used five meteorological station networks in order to calculate rainfall indices and for areal rainfall interpolations during the last twelve years.

Average rainfall as the arithmetic mean of all the records of the five rain gauges were evaluated as shown in eq.2:

$$\overline{P} = \frac{p_1 + p_2 + \dots p_n}{n} \qquad \text{(eq. 2)}$$

Where $\overline{P}$ = arithmetic mean of the catchment, **p** represents point rainfall and **n** is number of stations.

Inverse Distance Weighted (IDW) interpolation is based on the basic law of geography that states things that are close to one another are more alike than things that are far apart. To predict a value for any unmeasured location in a neighborhood, IDW uses the measured values surrounding the prediction location.

Areal rainfall using IDW can be predicted (estimated) using the equation 3.

$$z(\mathbf{x}) = \sum_i w_i z_i \Big/ \sum_i w_i \qquad \text{(eq.3)}$$

$$w_i = 1/d_i^2 \qquad \text{(eq. 4)}$$

Where:

Z(X) = the value of the predicted continuous areal rainfall within the neighborhoods,

w_i = weight of each corresponding point,

z_i = the value of the stations point rainfall and

d_i^2 = the squared distance of each station from the predicted 30 * 30 m cell matrix areas.

Maximum, minimum, mean, standard deviation and coefficient of variation of monthly, seasonal and annual rainfall pattern of the catchment and at each station were calculated.

The mean ($\bar{X}$) is given by a formula:

$$\bar{X} = \frac{\sum x_i}{N} \qquad \text{(eq. 5)}$$

Where:

x = the individual values making up the data series and

N = the number of observation.

Standard deviation (SD) it indicates how the data scatter around the mean of a series of observation data. It is given by equation 6.

$$SD = \sqrt{\frac{\sum (x - \bar{X})^2}{N}} \qquad \text{(eq. 6)}$$

Coefficient of Variation (CV)

Coefficient of variation can be estimated using the deviation each observation from the mean normalized by the mean value, which is given by equation 7.

$$CV = \frac{SD}{\bar{X}} * 100\% \qquad \text{(eq. 7)}$$

The value of CV gives a general indication of the probable percentage variation around the mean of the annual and seasonal rainfall of the study area. Then based on the coefficient of variation the magnitude and degree of rainfall variability were determined.

3.3.2. Stream Flow Data Analysis

The mean, coefficient of variation and standard deviation for 10 gauged years were computed. Based on Neumann et al. (1941) cited in Taffa (2003) mean square successive difference (Δ^2) and variance (s^2) were used to analysis the existence of trend in time series of stream flow. The Δ^2 and s^2 are given as:

$$\Delta^2 = [\sum (x_i - x_{i+1})^2]/n-1 \quad \text{(eq. 8)}$$

$$s^2 = [\sum (x_i - \mu)^2]/n-1 \quad \text{(eq. 9)}$$

Where x individual observation, n number of observation and μ is mean of the sample data.

When the ratio of mean square successive difference (Δ^2) and variance (s^2) is less than the critical point, the trend was taken as significant. The critical point (Cr) for a given sample size n, can be obtained from tables.

Selection of best model for curve fitting was done by using the standard error of estimates (SE) and residual of the mean squares (RMS). And the model with lowest values of SE and RMS were selected.

The candidate models are:

Linear $y = a + bx$ (eq.10)

Quadratic $y = a + bx + cx^2$ (eq.11)

Exponential $y = ae^{bx}$ (eq.12)

Logarithm $y = a + b\ln x$ (eq.13)

Power $y = ax^b$ (eq.14)

Where y is dependent variable (in this case stream flow), x is independent variable (in this year), a, b and c are constants. The constant a is the y-intercept in linear and quadratic model and b is slop.

3.3.3. Correlating Rainfall Variability with Stream Flow

From the analyzed rainfall and stream flow data, the influence of rainfall variability on stream flow was found by using Correlation and Regression whether the variability of rainfall and stream flow are correlated or not. Correlation is important to find a relationship between two variables; it's possible that one variable is the cause of the other. It is used to determine both the magnitude and the direction of the relationship. Regression, on the other hand, is primarily concerned with using the relationship between the variables to predict values of one variable from the values of the other variable(s).

The equation for the correlation coefficient is:

$$r = \frac{\sum_{i=1}^{n}\left(x-\bar{x}\right)\left(y-\bar{y}\right)}{\sqrt{\sum\left(x-\bar{x}\right)^{2}\sum\left(y-\bar{y}\right)^{2}}} \qquad \text{(eq. 15)}$$

The best curve fit regression model was selected from models listed in equation (10) to (14). For this part the variable y and x represents stream flow (dependent) and rainfall (independent) respectively.

3.3.4. Household Respondents Data Analysis

Frequency and percent were computed in household respond data analysis. Mean of maximum and minimum of tomato and onion production of the sampled household was calculated and the difference between mean of maximum and minimum production. The difference between mean of maximum and minimum production over their sum was used to calculate percent of production reduction.

$$R = 100 * \left(\frac{Ma - \mathrm{Mi}}{Ma + \mathrm{Mi}}\right) \qquad \text{(eq. 16)}$$

Where; R is production reduction in percent;

Ma is mean of maximum production and Mi is mean of minimum production.

4. Result and Discussion

4.1. Rainfall Variability Estimation

Based on NMSA classification of rainfall variability the coefficient of variation < 20 is taken as low variability, between 20 to 30 to moderate variability, and >30 to high variability (Lemma ,1996).

4.1.1. Rainfall Variability Estimation at Each Station

The annual total rainfall at the stations varies from 457.40 mm at Bulbula to 1486.50 mm at Arsi Negele (Table 3). All rainfall stations used for Gedemso River catchment area rainfall calculation have high variability in rainfall during both Bega (October-January) and Belg (February-May) seasons except, Degage station which has the coefficient of variation 26.3 in Belg season (Table 3). The rainfall variability of *Kiremt* (Jun-September) season of four stations namely Arsi Negele, Bulbula, Kuyera and Langano categories under moderate variability.

While, Degage station falls under low variability during *Kiremt* season. The annual rainfall variability of A/negele, Bulbula and Langano station's characterized by moderate variability. The rest stations (Kuyera and Degage) have low annual rainfall variability.

In the year 1997, 1999-2000, 2002, 2004 and 2007 rainfall failed events observed in some stations commonly which the rainfall became below minus one standard deviation (Figure 4-8). On the other hand, the year 1996, 2001and 2003 show high rainfall (above plus one standard deviation) in some stations commonly. For instance the year 2003 *Kiremt* rainfall in Arsi Negele, Degaga and Bulbula shows above plus one standard deviation(Figure 8b, 7b and 4b) and the 1996 also show similar pattern for annual and *Kiremt* rainfall of Arsi Negele and Bulbula stations (Figure 8a, 8b, 4a and 4b).

In addition to inter annual and seasonal rainfall variation, Figure 4-8 and Table in Annex 1 show the rainfall trends at each station for the period of 1996-2007. And also the figures illustrate the year of highest and loWest rainfall accrues. The result of annex 1 shows the tests for existence of trend or not and with significance test at 5% level.

Table 3 Seasonal and Annual Indices description of RF at each station for the period 1996-2007

Indices	Season	Station				
		A/negele	Bulbula	Degaga	Kuyera	Langano
Mean	*Bega*	97.43	107.53	127.68	122.08	105.63
	Belg	350.42	181.50	301.25	294.76	189.78
	Kiremt	609.47	370.55	669.12	456.74	440.85
	Annual	1057.32	659.57	823.53	873.58	736.26
STD	*Bega*	51.07	71.03	57.29	78.07	93.87
	Belg	138.61	75.39	79.25	104.94	88.63
	Kiremt	183.31	91.23	101.74	93.42	129.49
	Annual	267.37	132.08	119.95	151.60	149.67
% CV	*Bega*	52.42	66.06	44.87	63.95	88.87
	Belg	39.55	41.54	26.31	35.60	46.70
	Kiremt	30.08	24.62	15.20	20.45	29.37
	Annual	25.29	20.03	14.57	17.35	20.33
Maximum	*Bega*	212.2	218.3	226.9	295.3	309.1
	Belg	594.4	307.7	424.8	537.1	392.9
	Kiremt	1001.0	506.1	852.4	707.2	725.5
	Annual	1486.5	872.4	1350.3	1129.0	973.8
Minimum	*Bega*	9.2	9.2	46.6	42.6	6.3
	Belg	192.1	69.9	181.8	150.8	112.5
	Kiremt	405.5	156.0	497.6	368.3	270.1
	Annual	746.8	457.4	821.4	663.6	536.9

The trend of rainfall in *Bega* (October-January) season for the period of 1996-2007 in Bulbula and Langano stations used for study show downward in rainfall with significant at 5% level (Figure 4d and 6d) and Annex 1. Annual trend of rainfall at Arsi Negele and

Kuyera show upward trend (Figure 8a and 5a); whereas, downward annual trend of rainfall at Langano station observed (Figure 6a).

For those observed within significant trends (annual rainfall of Arsi Negele, Lganoan and Kuyera; *Bega* rainfall of Langano and Bulbula), the model for curve fitting were selected based on the method described under section 3.3.2. By using standard error of estimates (SE) and residual of the mean squares (RMS) as tool for model selection, the model with loWest values of SE and RMS were selected. Power model was selected for Arsi Negele annual rainfall and *Bega* rainfall of Bulbula trend curve fitting. Whereas, exponential was selected as best model for curve fit of annual rainfall of Kuyera and for both annual and *Bega* Lganoan rainfall trends (see the table Annex 1b).

Note that: the model selected for one is not necessarily selected for others. Therefore, the selected model equation could be written using the general model equation 12 and 1 and the constants presented in annex 1b.

The power model equation for A/ Negele annual rainfall and *Bega* rainfall of Bulbula are:

For Arsi Negela annual rainfall: $y = 863.84x^{0.104}$ (eq. 17) (see Figure 8a)

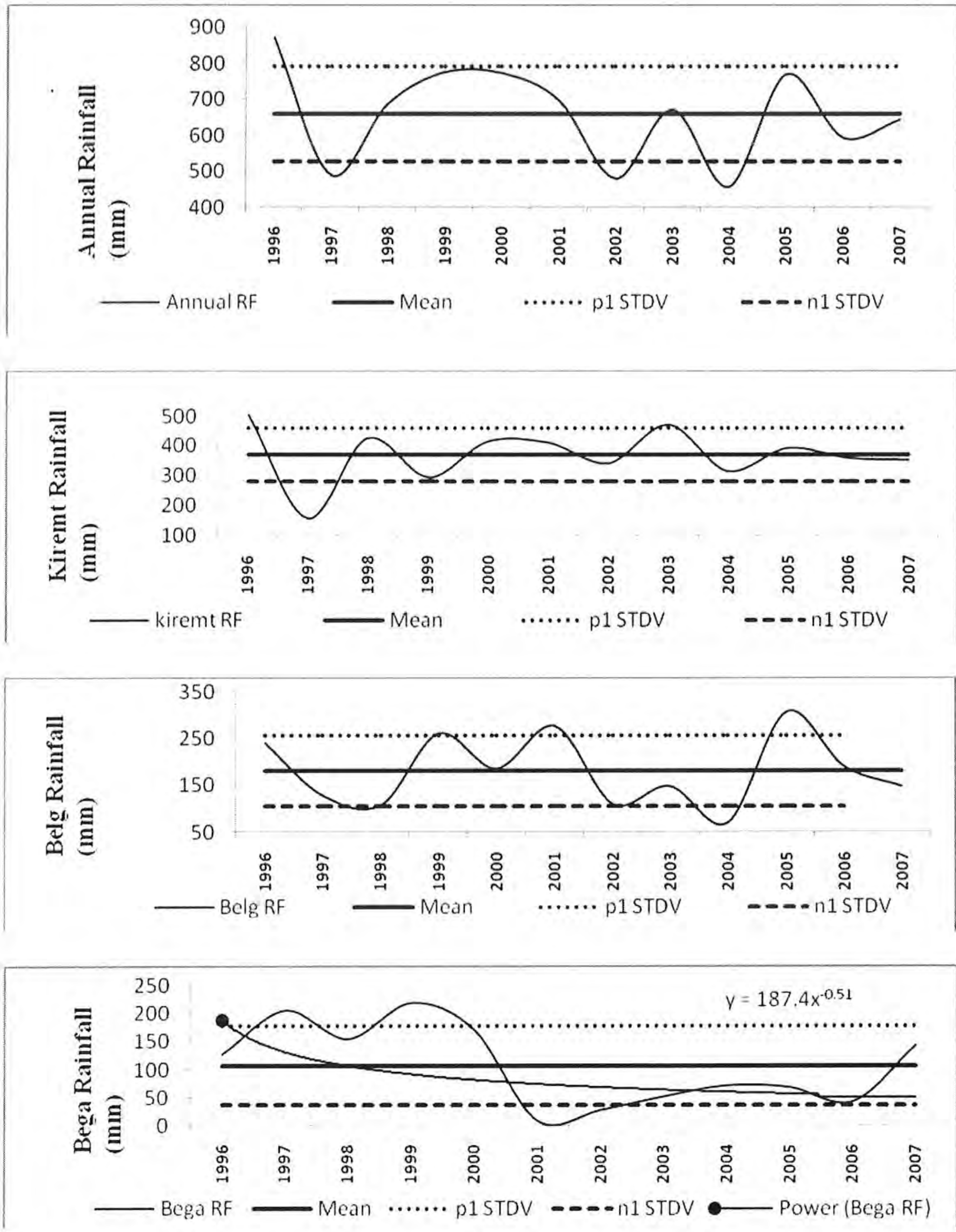
For Bulbula *bega* rainfall: $y = 187.4x^{-0.51}$ (eq. 18) (see Figure 4d)

The exponential model equation for annual rainfall of Kuyera and for both annual and *Bega* Lganoan rainfall are:

For Kuyera annual rainfall $y = 822.4e^{0.007x}$ (eq.19) (see Figure 5a)

For Langalo annual rainfall $y = 742.76e^{-0.004x}$ (eq.20) (see Figure 6a)

For Langalo *Bega* rainfall $y = 101.92e^{-0.061x}$ (eq. 21) (see Figure 6a)



(a) (b) (c) (d)

Figure 4 Seasonal and Annual RF Distribution of Bulbula Station

Figure 4 a, b, c and d show the twelve year (1996-2007) annual, *Kiremt* (June-September), *Belg* (February-May), and *Bega* (October-January) rainfall characters over Bulbula station respectively.

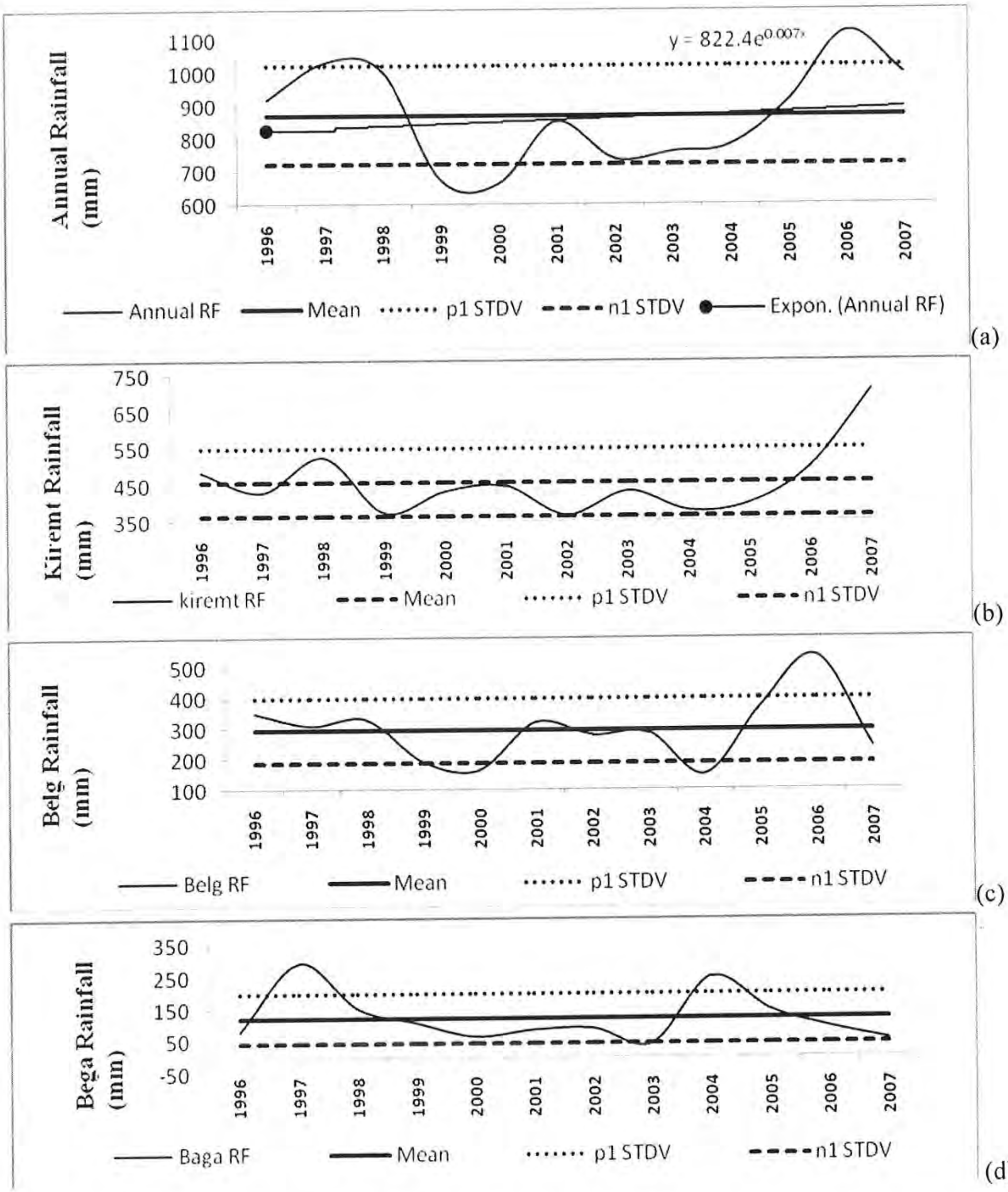


Figure 5 Seasonal and Annual RF Distributions at Kuyera Station

Figure 5 a, b, c and d show the twelve year (1996-2007) annual, *Kiremt* (June-September), *Belg* (February-May), and *Bega* (October-January) rainfall characters over Kuyera station respectively.

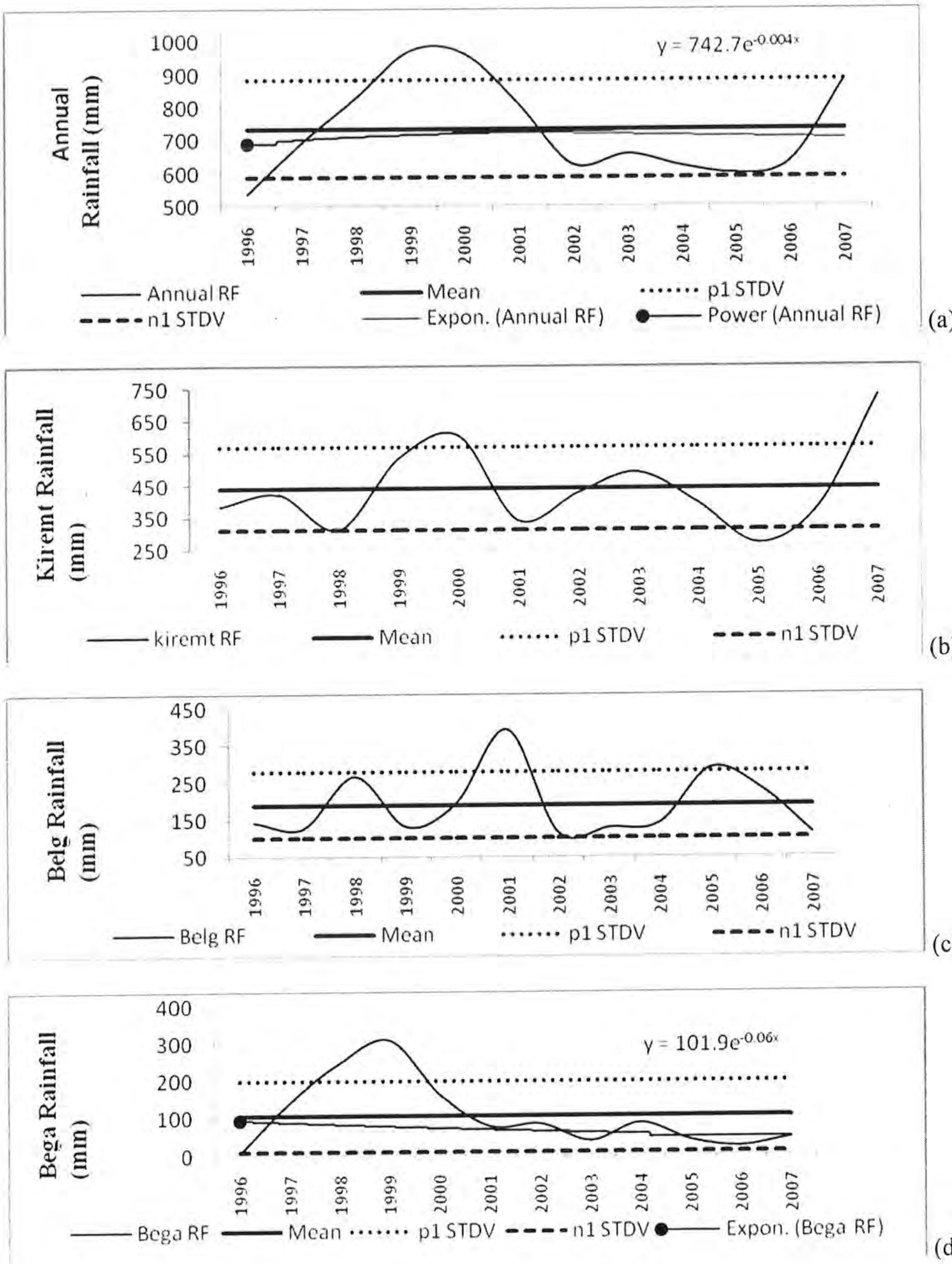


Figure 6 Seasonal and Annual RF Distribution at Langano Station

Figure 6 a, b, c and d show the twelve year (1996-2007) annual, *Kiremt* (June-September), *Belg* (February-May), and *Bega* (October-January) rainfall characters over Langano station respectively.

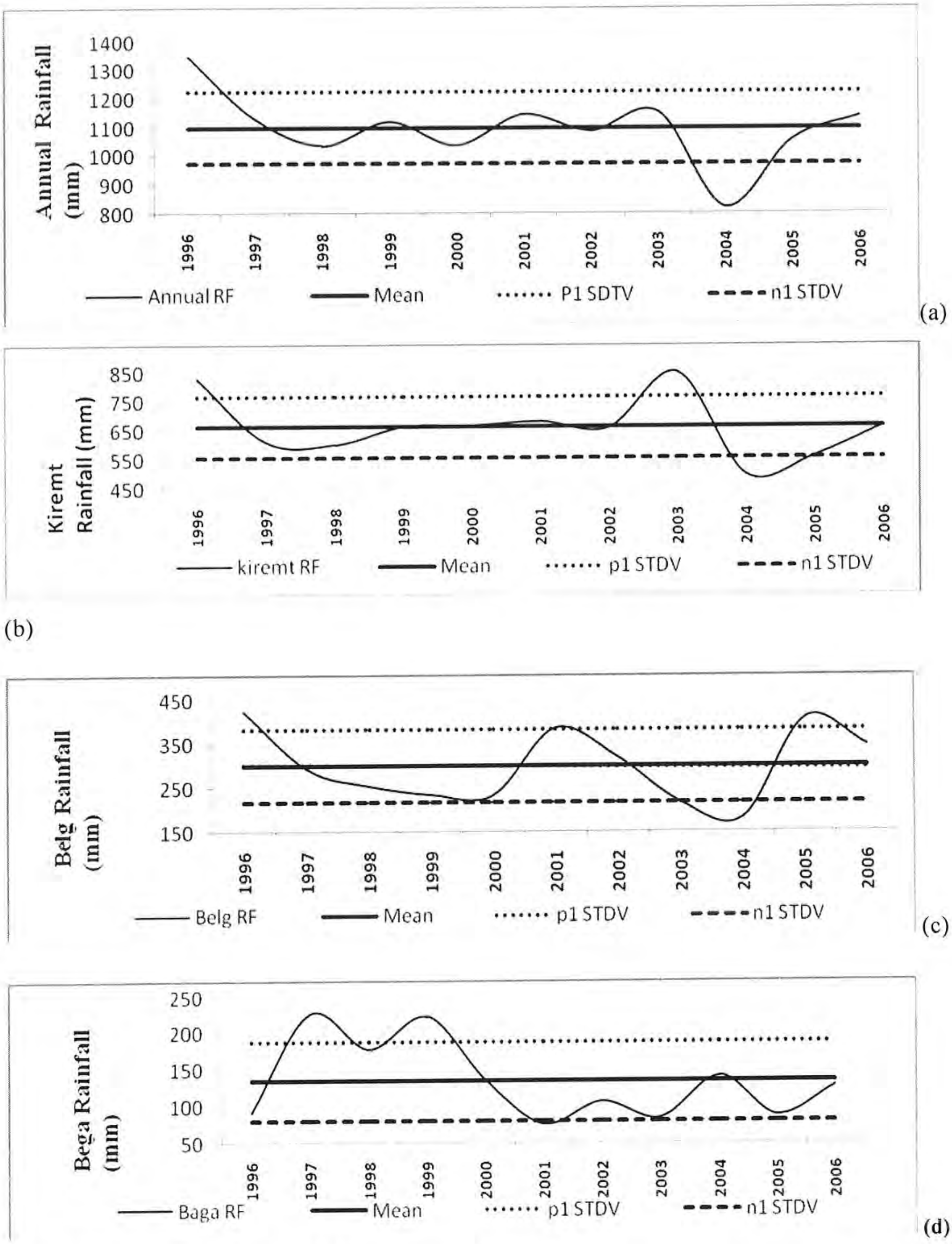


Figure 7 Seasonal and Annual RF Distribution of Degaga Station

Figure 7 a, b, c and d show the twelve year (1996-2007) annual, *Kiremt* (June-September), *Belg* (February-May), and *Bega* (October-January) rainfall characters over Dagaga station respectively.

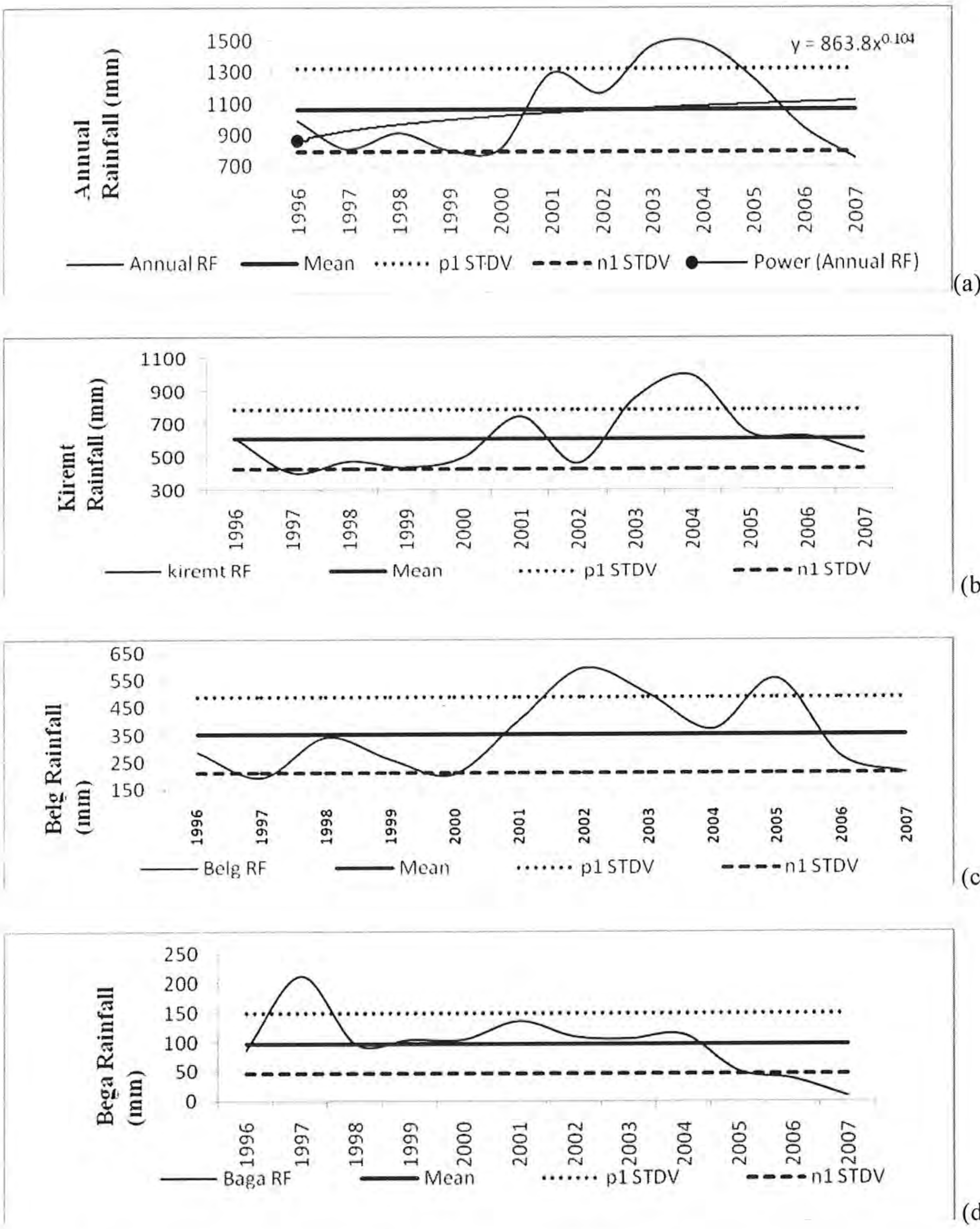


Figure 8 Seasonal and Annual RF Distribution of A/negele station

Figure 8 a, b, c and d show the twelve year (1996-2007) annual, *Kiremt* (June-September), *Belg* (February-May), and *Bega* (October-January) rainfall characters at A/negele station respectively.

4.1.2. Areal Rainfall

The rainfall over the catchment decreases from South-East toward North-West (Figure 10) which indicates that rainfall of the catchment is characterized by altitude. The altitude of the catchment decreases continuously in the in the direction of rainfall decreases (see Figure 3).

Since the standard deviation from the mean of the IDW methods is less than Arithmetic Mean (Table 4), in the study IDW methods was employed in the areal rainfall data analysis. The annual average areal rainfall in the Gedemso River catchment is 869.79 mm, with a standard deviation of 42.4 mm and coefficient of variability of 4.88%. The anomalies in the annual and seasonal areal rainfalls are shown in figure10. The rainfall in the region is characterized by alternation of wet years and dry years in a periodic pattern. Among the 12 years of observation, 7years (56.5%) recorded below the full observation years the average annual rainfall amount while 5 years recorded above average. The *Kiremt* season average areal rainfall of the catchment is 502 mm, with a standard deviation of 73.79 mm and coefficient of variability of 14.7%. Whereas, *Belg* and *Bega* average areal rainfall are 256.76 and 108.71mm with standard deviation of 70.59 mm and 60.06 mm and coefficient of variability of 27.49% and 55.25% respectively (Table 5).

Table 4 Comparison of Rainfall Interpolation using Spatial IDW and Arithmetic Mean (1996 – 2007)

Indices	IDW	Arithmetic Mean
Mean	869.79	884.96
STDV	42.40	46.73
% CV	4.88	5.28

Table 5 Indices of Areal Rainfall in Gedemso River Water Catchment using spatial interpolation (IDW) (1996-2007)

Indices	Mean	STDV	%CV
Annual	869.79	42.40	4.88
Kiremt	502.00	73.79	14.70
Belg	256.76	70.59	27.49
Bega	108.71	60.06	55.25

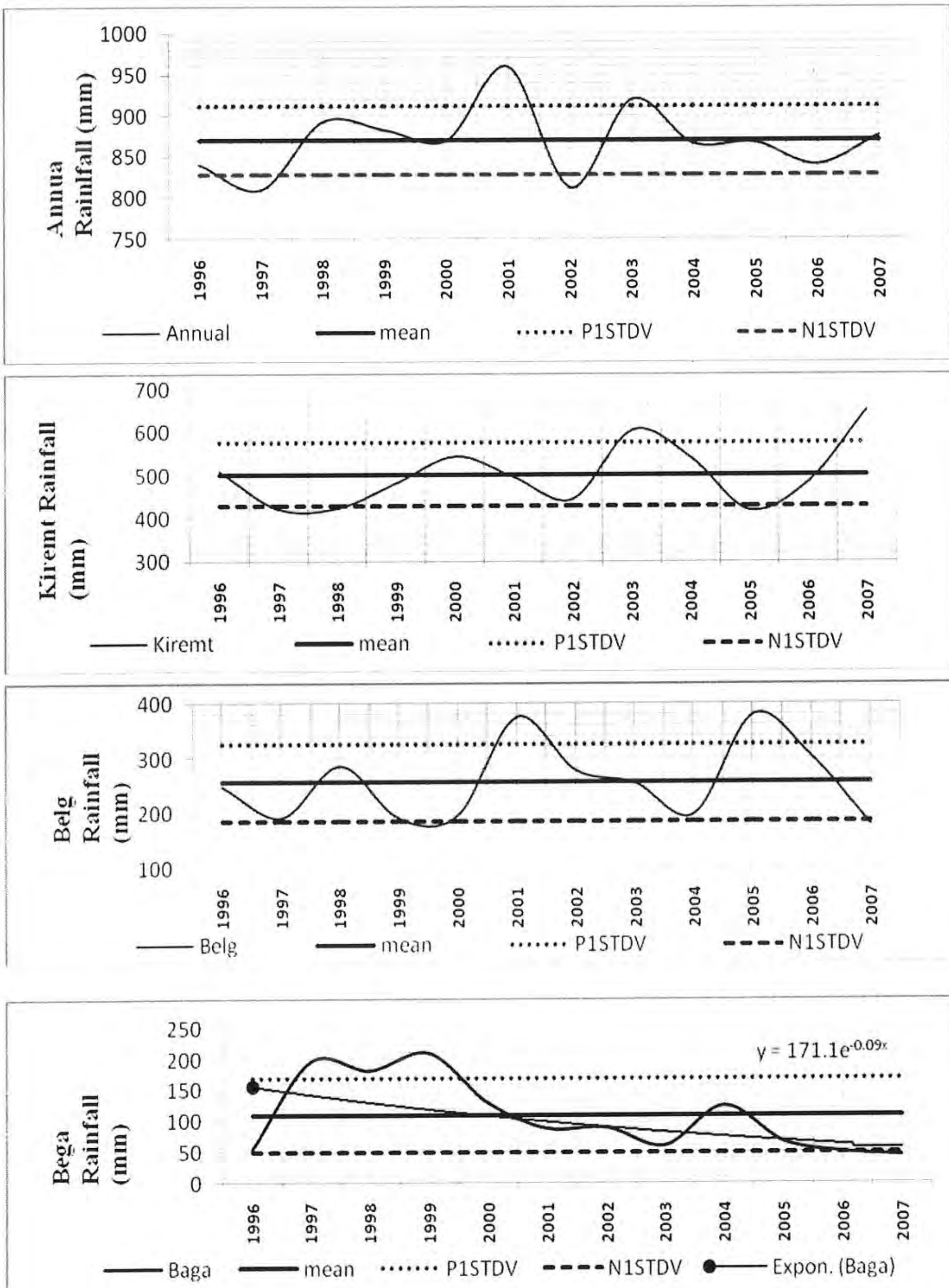
The rainfall variability over the catchment is greater during the *Bega* and *Belg* season than *Kiremt* season (Table 5). The years 1997 and 2002 the loWest rainfall recorded over the catchment both are below minus one standard deviation (Figure 9a). Whereas 2001 is the highest rainfall occurred year over the catchment. The years of 1997 and 2002 also indicated by Abebe, 2007 and Ahmed et. all 2011 as drought in Arsi and East Shewa zone.

The year 1999 and 2000 are the years in which the downstream rainfall stations (Langano and Bulbula) high rain fall recorded. For example figure 4a illustrate that, the1999 and 2000 rainfall at Bulbula station is approaches to plus one standard deviation. And annual rainfall of 1999 and 2000 are above plus one standard deviation at Langano station (Figure 6a). Whereas, at the upstream stations (Arsi Negele and Kuyera) rainfall recorded with below minus one standard deviation in both 1999 and 2000 year and 2000 is the lowest rainfall for Kuyera station (Figure 8a and 5a).

The time series trend of areal rainfall of twelve years was not significant at 5% level during *Kiremt* and *Belg* season and annual; whereas, the *Bega* season areal rainfall of the given period showed significant trend at 5% level with time series (see Annex 1). The *Bega* areal rainfall time series trend observed the downward trend (Figure 9d). The curve fit model for *Bega* areal rainfall trend was selected based on the tools used shown in annex 1b. Hence, the exponential model selected equation could be written as:

$$y = 822.4e^{-0.091x} \qquad \text{(eq.22)}$$

Figure 11, 12, 13 and 14 show the individual year of annual, *Kiremt, Belg* and *Bega* rainfall distribution over the catchment respectively. Annual area rainfall distribution over the catchment in each study year decreases almost in the same direction (SE to NW) except, the 1999 and 2000 which decreases in opposite direction (NW to SE) (figure 11). The detail discussions of areal catchment rainfall were made in the following sub topics (4.1.2.1 and 4.1.2.2).



(a)

(b)

(c)

(d)

Figure 9 Annual and Seasona Gedemso River Catchmen Areal RF (1996-2007)

Figure 9 a, b, c and d show the twelve year (1996-2007) annual, *kiremt* (June-September), *Belg* (February-May), and *Bega* (October-January) Gedemso River Catchmen Area rainfall (RF) variability respectively.

4.1.2.1. Annual Areal Rainfall Interpolation

The overall of Gedemso River stream flow catchment area rainfall interpolation were illustrated in Figure11 by using annual mean rainfall data of the period 1996-2007. The catchment area rainfall characterized by 903.77mm and 777.53mm high and low rainfall in the study period respectively.

The annual rainfall of each year over the catchment decreases from south East to North West except for the year 1999 and 2003 (Figure 11 d and e) which they were in opposite of the other ten years. The range between annual maximum and minimum over the catchment varies from 55.14mm in the year 2007 (Figure 11 L) to 267.43 mm in the year 1996 (Figure 11a). The year of largest the range between annual maximum and minimum rainfall value, the highest varies in rainfall distribution over the catchment. And the loWest value of range, relatively the normal rainfall distribution over the catchment. Therefore, the year 1996 was the highest varies in rainfall distribution over the catchment relative to the other years in the study period (Figure 11a) and in 2007 the rainfall distribution over the catchment relative to the other years was best normal distribution(Figure 11 L). The years 1997 and 2002-2006 also were varied in rainfall distribution over the catchment whereas the years 1998-2001 near normal distribution relatively. The peak of maximum rainfall over the catchment was observed in the year 2001 (Figure 11f) and the lowest minimum of annual rainfall recorded in the year 1996 (Figure 11a). From this discussion, it could be concluded that the year of high rainfall, the less variance over the catchment and also it is true, the less rainfall, high variance over the catchment.

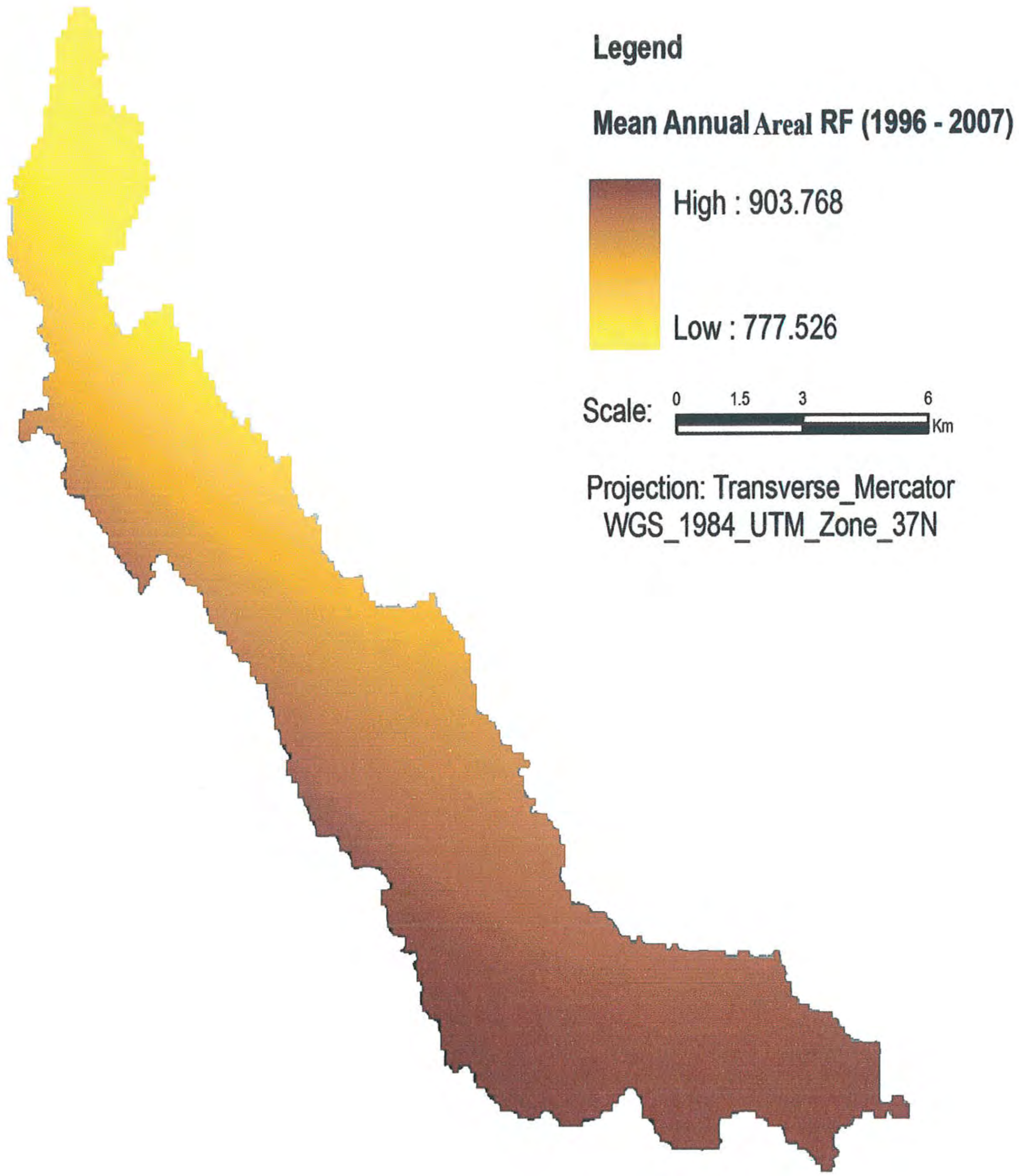


Figure 10 Mean Annual Rainfall Distributions over the Catchment (1996-2007)

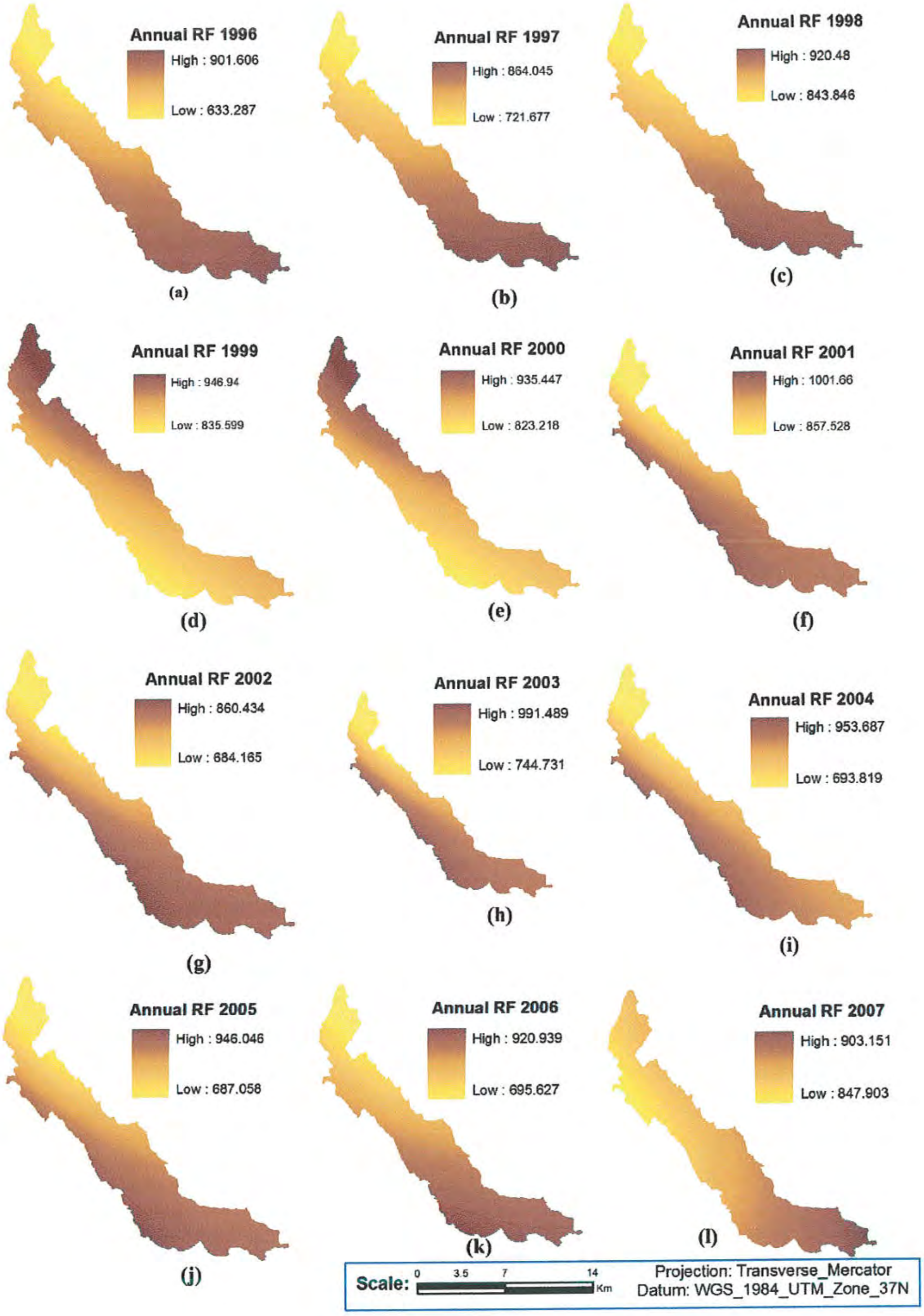


Figure 2 Annual RF distribution in each year of study over the Catchment

4.1.2.2. Seasonal Areal Rainfall Interpolation

The *Kiremt* rainfall of each year over the catchment decreases from south East to North West except for the year 1999, 2003 and 2007 (Figure 12 d, e and l) which they were in opposite of the other years. The range between *Kiremt* maximum and minimum over the catchment varies from 26.3mm in the year 1997 (Figure 12b) to 167mm in the year 2004 (Figure 12i). The year 2004 was the highest varies in rainfall distribution over the catchment relative to the other years in the study period (Figure 12i) and in 1997 the rainfall distribution over the catchment relative to the other years was best normal distribution (Figure 12b). The years 1998, 2001, 2003 2005 and 2007 also were varied in rainfall distribution over the catchment whereas the years 1996, 1999, 2000, 2002, and 2007 were near to normal distribution relatively. The peak of maximum rainfall over the catchment during *Kiremt* season was observed in the year 2007 (Figure 12 l) and the loWest minimum of *Kiremtl* rainfall recorded in the year 2005 (Figure 12j).

During *Belg* season rainfall decreases from South East to North West over the catchment in nine years among the twelve years of the study period (Figure 13); whereas, it decreases from North West to South East over the catchment in the years 2001. For the year 2000, Northern and small part of South Eastern part of the catchment got high rainfall relative to South Western part of it and in the year 2004 the rainfall distribution observed in opposite direction to the 2000 year (Figure 13e and i). The range between *Belg* season maximum and minimum rainfall over the catchment varies from 5mm in the year 2000 (Figure 13e) to 164.8mm in the year 2002 (Figure 13g). The year 2002 was the highest varies in rainfall distribution over the catchment relative to the other years in the study period (Figure 13g) and in 2000 the rainfall distribution over the catchment relative to the other years was best normal distribution (Figure 13e). The years 1997, 1998, and 2003 - 2007 also were varied in rainfall distribution over the catchment whereas the years 1996, 1999 and 2001 were near to normal distribution relatively. The peak of maximum rainfall over the catchment during *Belg* season was observed in the year 2005 (Figure 13j) and the lowest minimum of *Belg* rainfall recorded in the year 2007 (Figure 13l).

Bega rainfall decreases from South East to North West over the catchment for years 1996, 1997, and 2002-2006 (Figure 14); for the years 1998-2000 rainfall over the catchment was decreases from north east toward South West; from West South toward north East for the year 2001. For the year 2007, rainfall was decreases from both Northern and Southern parts of the catchment to the center of the catchment. The range between *Bega* season maximum and minimum rainfall over the catchment varies from 8mm in the year 2002 (Figure 14g) to 105.8mm in the year 1999 (Figure 14d). The year 1999 was the highest varies in rainfall distribution over the catchment relative to the other years in the study period and in 2002 the rainfall distribution over the catchment relative to the other years was best normal distribution. The years 1996-1998, 2000 and 2004 - 2006 also were varied in rainfall distribution over the catchment whereas the years 2001, 2003, and 2007 were near to normal distribution relatively. The peak of maximum rainfall over the catchment during the study period in *Bega* season was observed in the year1999 and the loWest minimum of *Bega* rainfall recorded in the year 1996.

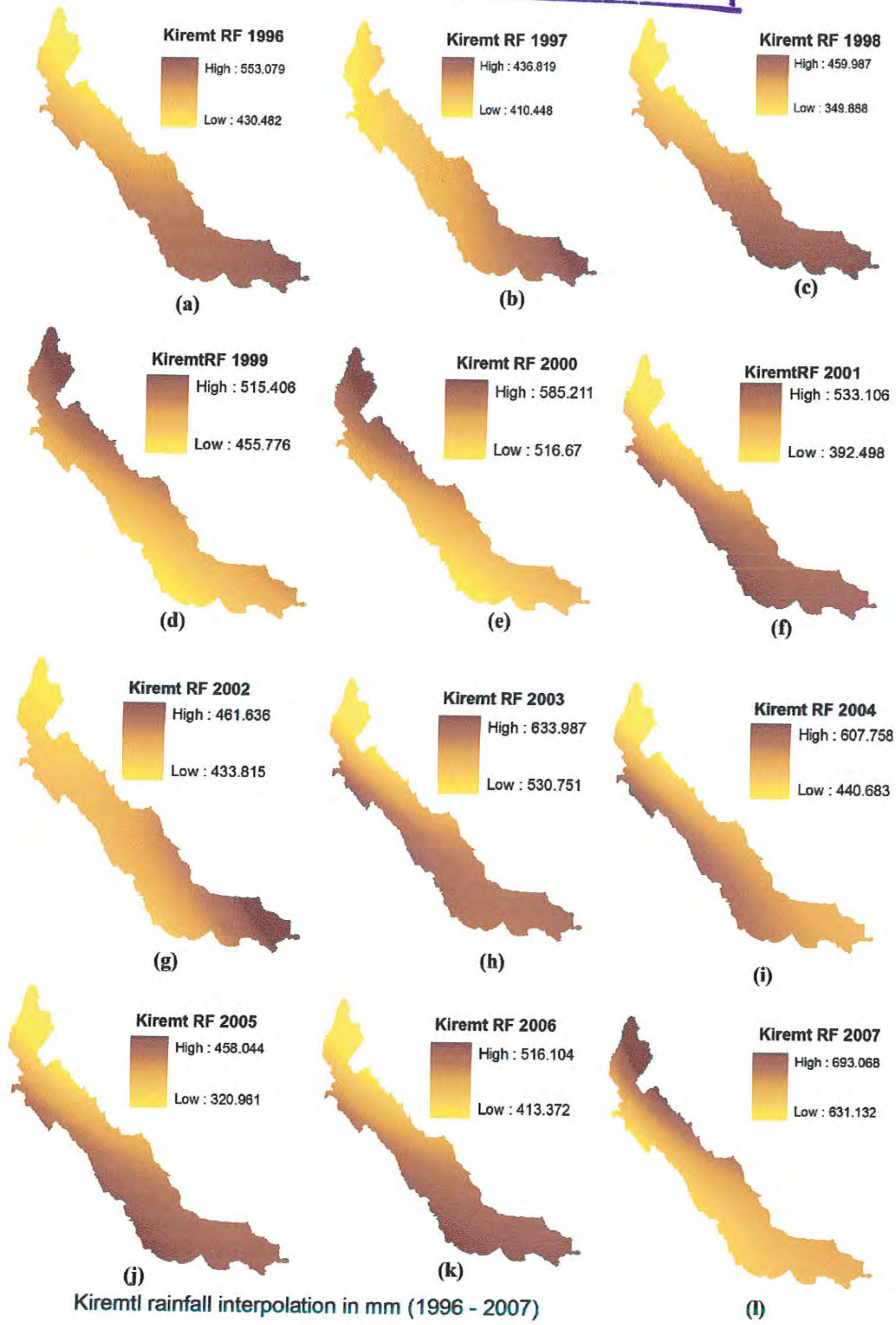


Figure 1 ***Kiremt*** **RF Distribution in each year of study over the Catchment**

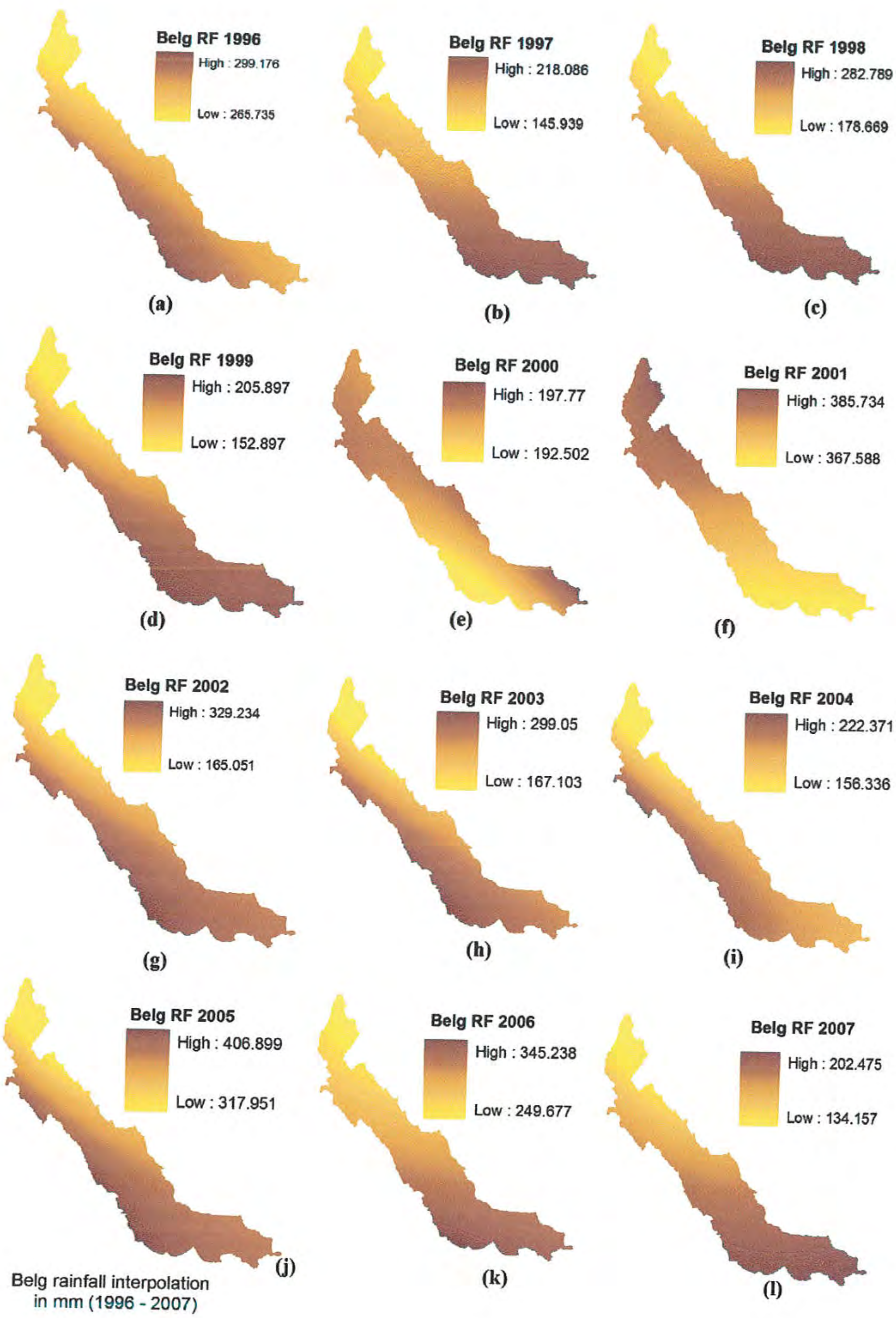


Figure 2 *Belg* RF Distribution in each year of study over the Catchment

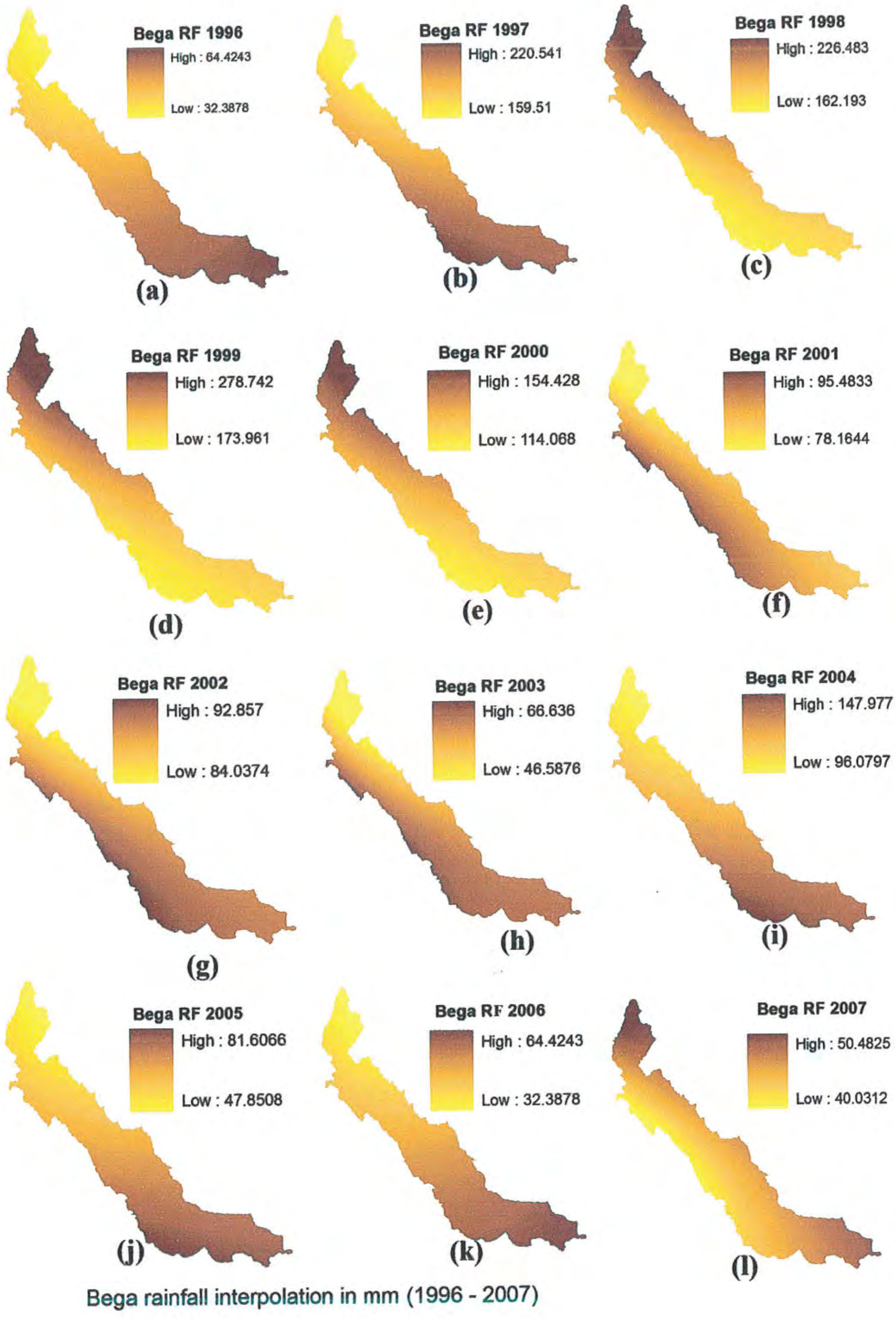


Figure 14 *Bega* RF Distribution in each year of study over the Catchment

4.2. Variability and Trends of Gedemso River Stream Flow

4.2.1. Annual and Seasonal Stream Flow Variability

Table 6 Indices of Gedemso River Stream Flow discharge (m^3/s) from the period of 1997-2006

Statistics	*Bega*	*Belg*	*Kiremt*	Annual
Mean	147.0942	60.5759	574.1398	781.8099
STDV	96.1867	19.02219	252.8874	306.1312
% CV	65.39123	31.40224	44.0463	39.15673

The stream flow coefficient of variability varies from 0.31 during *Belg* season to 0.65 in *Bega* season. The *Bega* stream flow amount is greater than the *Belg* season stream flow, which indicates that the *Kirem*t rainfall contributes for it. The investigated annual variability of the Gedemso River is on the subject of 39.15% (Table 6).

The year 1997 was the year of minimum stream flow (below its study period minus one standard deviation) recorded. Whereas the highest flow recorded was in the year 2000 except in *Belg* season (Figure 11). The highest Gedemso River stream flow found during 2006. About 60% years during study period the stream flow was below the study period mean flow and shows the decreasing trend during the *Bega* season (Figure 11a).

4.2.2.Trend and Model Test for Gedemso Stream Flow

For the Period 1997 to 2006, the Gedemso river stream flow trend was tested using parameters given in table 7 as indicated by Taffa Tulu (2003). And also the best model for those have significance trend, curve fitting was selected by comparing the standard error of estimates (SE) and residual of the mean squares (RMS) of the candidate models. Since the R^2 values in all data model were too small, it was not considered in model selection.

In annual and two seasons (*Belg* and *Kiremt*) stream flow, the ratio of mean square successive difference (Δ^2) to variance (s^2) is greater than critical point which indicates the existence of trends was not significant at 5% level. Whereas, the ratio of mean square successive difference (Δ^2) to variance (s^2) is less than critical point for *Bega* stream flow, which indicates the existence of trends was significant at 5% level (Table 7).

The critical point Cr obtained through the equation:

$$Cr = 2 - 2z * \sqrt{\frac{n-2}{(n-1)(n+1)}}$$

Where, n is number of observation and

z is standard normal variable (z= 1.645 at 5% level.

Then, the value of critical point (Cr) with number of observation (n=10) and the standard normal variable (z= 1.645) at 5% level is 1.065.

Due to shortage of long term stream flow gauged data and inconsistency of records, the study limited to only 10 years of flow data. This constrained the results of trend analysis and it could have resulted with insignificant trends at 5% level of significance.

Table 7 Test parameters for the significance of trends in stream flow of annual and seasons for the data series of 1997 to 2006

Season	**Δ^2**	**S^2**	**C**	**Remark**	**Sig at 5% level**
Bega	8940.64	8849.69	1.01	C<1.065	Significant
Belg	517.91	230.91	2.24	C>1.065	Not Significant
Kiremt	76393.43	56159.06	1.36	C>1.065	Not Significant
Annual	112607.72	87369.66	1.29	C>1.065	Not Significant

Note: Δ^2 = mean square successive difference; S^2 = variance; $C=\Delta^2 / S^2$ and Cr= critical point (for n=10, Cr is 1.065 at 5% significant level).

Among the three seasons and annual stream flow of ten years, the *Bega* season stream flow observed with significance at 5% level (Table 7). In order to select best model for time series and *Bega* season stream flow curve fit, the loWest value of standard error and residual mean square selected from the candidate models and the exponential is the best model for curve fitting (Table 8). The selected model equation can be written using the general model equation 12 and the value of the corresponding constant given in table 8.

Table 8 Statically parameters and constants of candidate models estimating using Microsoft Excel and SPSS program

	Candidate Models				
Constant	Linear	Logarithmic	Quadratic	Exponential	Power
SE	93.734	100.139	87.034	0.578	0.629
RME	8786.077	10027.72	7574.903	0.334	0.395
A	216.078	184.997	90.278	204.365	168.725
B	-12.542	-25.094	50.357	-0.091	-0.206
C			-5.718		

The exponential curve fitting for significant trend observed in *Bega* flow is down curve showed in figure 15a.

The trend line equation obtained from selected model (exponential) for *Bega* is:

$$y = 204.3e^{-0.09x} \qquad \text{(eq. 22)}$$

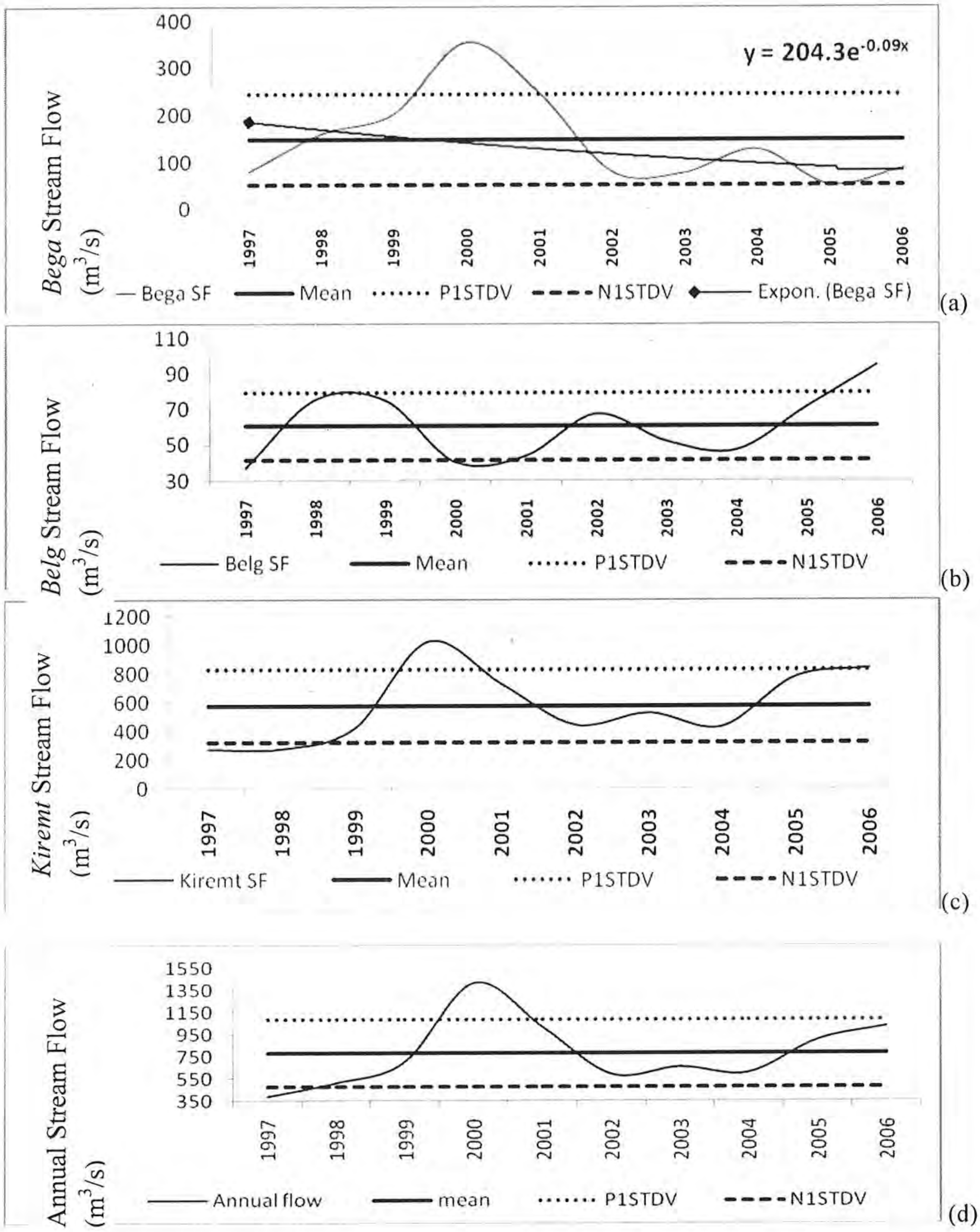


Figure 15 Variability of Annual and Seasonal Gedemso River Stream Flow

Figure 15 a, b, c anb d d show the *Bega* (October-January), *Belg* (February-May), *Kirem*t (June-September) and annual stream flow variability for the period of 1997-2006 respectively. In addition to variability, figure 15a shows the trend of *Bega* flow.

4.3. Relationship between Rainfall Variability and Stream Flow

The relationship between rainfall variability and stream flow was evaluated with bivariate of Pearson correlation coefficient. The correlation coefficien (r) between mean monthly rainfall and stream flow data during the periods of 1967-2006 was r = 0.718 which indicated that the two variabls were positively correlated with 0.01 significance level (Table 9) . The positive correlation coefficient indicates that, as one variable increases the other also increases and the opposite also is true.

Table 9 Correlation between mean monthly rainfall and stream flow (1997 - 2006)

		Rainfall	Stream flow
Rainfall	Pearson Correlation	1	.718**
	Sig. (2-tailed)		.009
Stream flow	Pearson Correlation	.718**	1
	Sig. (2-tailed)	.009	
**. Correlation is significant at the 0.01 level (2-tailed).			

The ten years mean monthly rainfall of the Gedemso River Catchment showed an increasing trend from February to July and later declined thoroughly up to December with a peak in July. Whereas the stream flow of Gedemso River also showed a similar trend with rainfall patterns with one month lag to have a peak stream flow in August (Figure 17a).

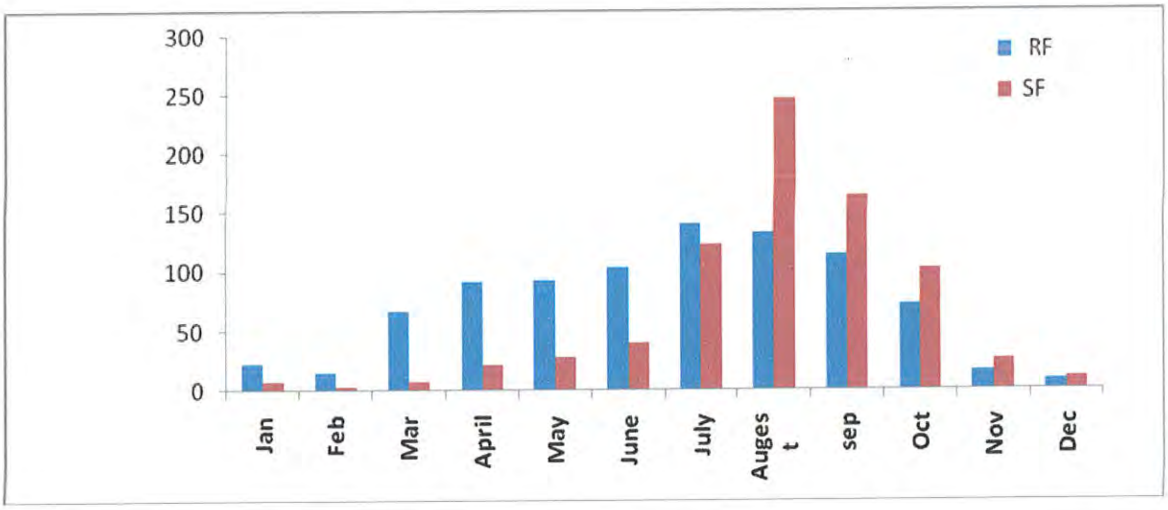
Table 10: Statistical parameters for model selection which best explain the relation between RF and SF

	Candidate Models				
Constant	Linear	Logarithmic	Quadratic	Exponential	Power
R^2	0.515	0.368	0.63	0.635	0.513
SE	56.791	64.842	52.316	0.873	1.008
RME	3225.195	4204.44	2736.997	0.762	1.016
A	1.169	48	0.016	5.619	1.004
B	-20.728	-125.108	-1.025	0.023	0.569
C			24.063		

The result of best selected exponential regration used to see in what direction and in what magnitude the two variables were correlated as illustrated below. Based on the hypothesis of the study, stream flow depends on rainfall. So, Rainfall (RF) is taken as independent variabe and Stream flow (SF) is taken as dependent variable. Then the best curve fit model was selected by comparing the candidate models using the R^2, SE and RME values (Figure 6b). The model with the loWest value of SE and RME and highest value of R^2 (Table 10) , which is exponetial model shown in equation 21 was developed to explain the reletionship between rainfall and stream flow.

$$SF = 5.619e^{0.023RF} \qquad \text{(eq. 23)}$$

The model's R^2 value clearly shows that 63.5% of stream flow explained by rainfall, which 36.5% stream flow explained by other factors. From the model produced here; it is possible to say that as rainfall increase by 1mm, the stream flow will increase by $5.619e^{0.023}$ m^3/s.



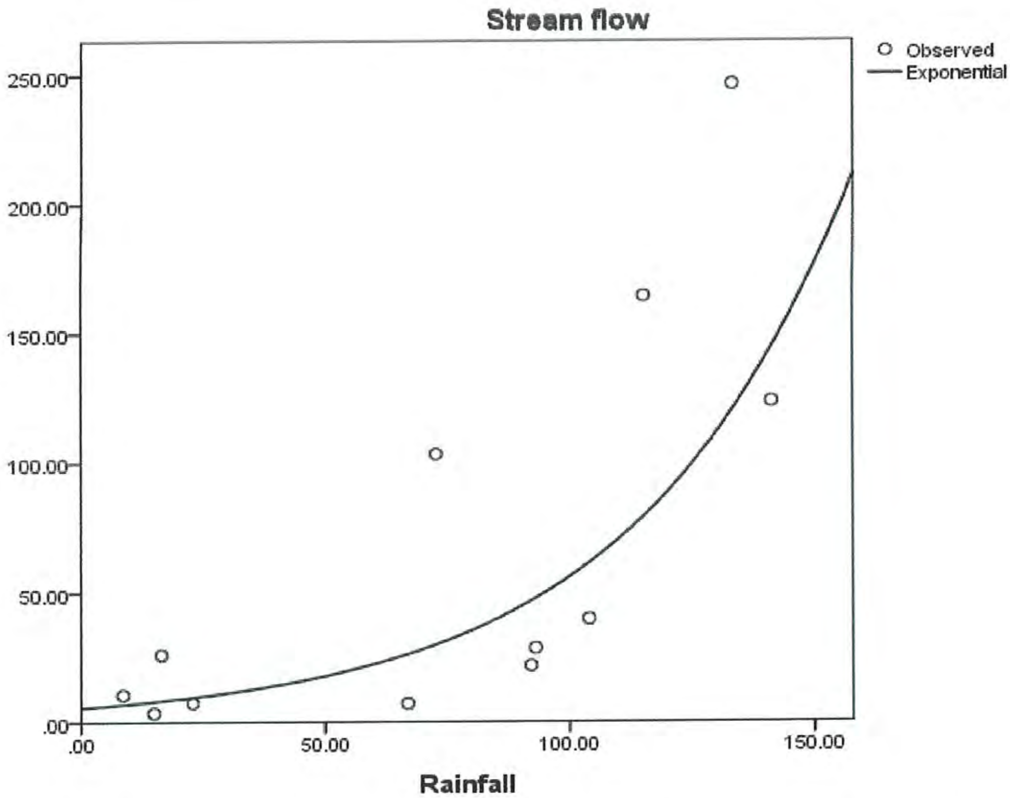


Figure 1 Comparison between mean monthly catchment-wide rainfall (mm) and stream flow (m^3/s) for the period of 1997–2006 in the Gedemso Catchment (a) and the selected model plotted curve

4.4. Impact of Rainfall variability on stream flow and its implication on irrigation production and water use

4.4.1. Impact of Rainfall variability on stream flow and its implication on irrigation production

In privies discussion (4.3) the relationship of rainfall and stream flow shows which they are highly correlated. In the time rainfall became decrease, low stream flow occurred. This event affects the availability of water used for irrigation and the irrigation production decrease both in quantity and quality. Other study also confirms that the temporal variability in rainfall and river flows and related water availability has strong implications for water and agricultural management (Meron and P. Willems, 2012).

The livelihood income of Gedemso SSI user farmers highly depend on irrigation product than rain-feed agricultural income. About 94% of sample household, their livelihood source covered from irrigation product is greater than 50% of their total annual income and 64% of sample household livelihood source covered from irrigation product is greater than 75% of their total annual income (Table 12).

Depending on sampled household respondent data collected in consideration of maximum production during abundant water available and minimum production due to water shortage in kg per hectare. Tomato and onion are the two cash crops produced with all framers commonly and frequently. During abundant water available for irrigation the mean of maximum production of tomato and onion are 17376.03 and 17461 kg per hectare respectively. The values 5433.01 and 7223.5 kg per hectare are the mean of minimum production of tomato and onion respectively in the time of water shortage. Therefore, reducing in water available in Gedemso River reduces the tomato and onion production by 11943.02 and 10237.5 kg per hectare respectively (Table 11).

From the observation data (Figure 17) in the Gedemso SSI schemes about 15 ha part of encompassed irrigation land observed with dry land due to water shortage. In the time stream flow decreases, the flow of canals become below the diversion point of water from the canal to irrigated farm land.

stream flow decreases, the flow of canals become below the diversion point of water from the canal to irrigated farm land.

The right hand side picture in Figure 18 shows the dry canal due to shortage of water in the Gedemso River and the left side once observed during February, 2013 shows the flow of canal become below diversion point of diversion to irrigated farm lands.

Figure 1 Effects of Water Shortage on Gedemso SSI Canal

4.4.2. Management Systems in Gedemso SSI Schemes

The Arsi Negele Woreda agricultural office and the Woreda water resource office have role in the provision of technical assistance for beneficiary farmers. The Woreda agriculture office, the irrigation team sub-division provides trainings and irrigation use awareness programs. Melkhasa Agricultural Research Institute is participating in introducing new technologies to beneficiary farmers.

Table 12 Frequency and percent description of Gedemso Scheme Irrigation User Household Respond

Questions	Respond option	Frequency	Percent
Water Resource Shared Fairly	Yes	7	14
	No	43	86
	Total	50	100
Gedemso stream Flow Fluctuation	Yes	50	100
	No	0	0
	Total	50	100
Government commitment in irrigation water management	Yes	40	80
	NO	10	20
	Total	50	100
livelihood source covered from irrigation product	25%- 50%	3	6
	50%- 75%	15	30
	75%-100%	32	64
	Total	50	100
Conflict Occurrence in Irrigation Water Use	Yes	48	96
	No	2	4
	Total	50	100

There are also Gedemso irrigation scheme has formed Association which attempt to assist the farmers through provision of input, administrate water use and conflict resolution mechanisms. It has rules, methods and sanctions for selecting executive committee, raising finances, setting disputes among irrigation water beneficiaries and supervising provision of the irrigation water service.

The Association has 165 members with 132 male and 33 and has an elected committee with 5 members with one-chair person, one-vice chairperson, one secretary, one cashier and one controller. The executive committee is an official link between irrigation water users and the government officials in Woreda.

According to discussions with elected committee, the principal duties of the executive committees include: enforcing the rules and regulations of the association and cleanse and maintenance of the main canal; collecting of annual cash contribution from each water user farmer; after negotiation with all water users and decide the water schedule for group user get the water and also listening any complaints and give resolutions.

But according to sample household respondent, the implementation of rule and regulation of the Association is weak. According to the rule, 0.5 ha per household has allowed to irrigate. While, the actual finding of the study shows the irrigation land holding size per household varies from 0.25ha to 2.25ha with an average of 0.53ha.

Table 12 shows 86% and 96 % of sample respondents agree that water resource in irrigation is not shared fairly and conflict in irrigation water use alloys occur respectively. 65% of sample respondents rase this problem commonly as due to weak management of the Association committee and water shortage. About 35% sample respondents also suggest selfishness and weak presumption of individual user in schedule irrigation water contributes to unfair water share and conflict occurrence.

Based on the observation data in the Gedemso SSI schemes (Figure 18) the wastage of water was highly observed. Since most of the canals in the Gedemso SSI scheme are not lined with stone pave and cement, the canals easily broken and the water resource became wasted. It is clear that the unlined canals prevent the speed of water in the canal and the water resource exposed to sink and evaporation. Unlined the canals also contributes for conflict occurrence since it is easily broken and divert by any users without permission. Soil siltation also observed as problem in the in the Gedemso SSI development. During the cleaning of the canal the canal becoming deep and deep and the water become below the diversion point to the irrigated land from the canal.

Figure 18 Effects of Canal structure Problems on Water Resource Managemen

In the Figure 18 above, the top right and left corner show broken of canal at not allowed point and soil siltation problem in Gedemso SSI reservoir respectively. Whereas the bottom right and left corners indicate the wastage of water due to broken of canals and become dipping of canals during the time of clean the canals respectively.

5. Conclusion and Recommendations

5.1. Conclusion

This paper has analyzed the impact of rainfall variability on stream flow fluctuation in Gedemso SSI schemes during the periods 1997-2006. Rainfall data of five stations near Gedemso water catchment were used for the analysis of existing trend and variability of rainfall over the area. On the other hand, about ten years Gedemso River flow gauged data and beneficiary household respondent's data collected using a questionnaire were used. The variability of rainfall was analyzed using both descriptive statistics and spatial interpolation. The impact of rainfall variability on stream flow fluctuations were analyzed using statistical techniques.

The findings of the paper showed that the Bega (October-February) and the Belg (February-May) rainfalls are much more variable than the Kiremt (main rainy season, June-September) rainfall. The annual total rainfall at the stations varies from 457.40 mm at Bulbula (downstream of the catchment) to 1486.50 mm at Arsi Negele (upperstrea of the catchment). Whereas catchment area rainfall varies from 777.53mm at south east part of the catchment to 903.77mm at North West of the catchment. The loWest rainfall occurs during the year 1997 and 2002 over the catchments which are the worst year of rainfall during the study period.

As concluded in previous paragraph, rainfall is decreasing from SE toward NW; but this is on the calculation of 1996-2007 period average over the catchment and the individual year's show similar distribution except the year 1999 and 2000. In these two years (1999 and 2000) rainfall is decrease from NW toward SE over the catchment (Figure 11) and it is also the years that highest stream flow recorded (Figure 15). The Langano rainfall station records highest rainfall which is above plus one standard deviation (figure 6a) in these two years whereas at Arsi Negele and Kuyera RF station loWest RF recorded relative to other years of study (Figure 7a and 6a). Therefore, among the five rainfalls station used, the Gedemso stream flow is more sensitive to Langano rainfall station.

The annual Gedemso stream flow variability over the period of 1997-2006 found 39.15%. The general result and discussion of stream flow of Gedemso River indicates; the trend is not significant at 5% level in ten years period; however, the inter annual and seasonal variability clearly observed. Standard error of estimates and residual of the mean squares are the best tools for curve fitting model selection. Exponential and power models are best model for this study.

The rainfall and stream flow variables have positive correlation. Both variables recorded below their minus one standard deviation during the year 1997. So 1997 is the worst year for the availability of water for irrigation in the study area. Since, the two variables have strong positive correlation, inter-annual and seasonal variability of rainfall is a major cause of fluctuations in stream flow. Then, it is clear that the temporal variability in rainfall and stream flows related water availability has strong implications for irrigation water use.

In the Gedemso SSI schemes the wastage of water were highly observed, while about 15 ha part of encompassed irrigation land observed with dry land. Therefore, the problem of water for irrigation purpose is not only the rainfall variability leads to stream flow fluctuation but also unlined structure and weak management.

Shortage of water for irrigation in Gedemso SSI brought reduction in production and conflicts between the users due to competition of the scarce water resource. The unlined canal structure of Gedemso SSI brought water wastage through the canal easily broken, sinking of water and decrease in speed which makes the water under exposure to evaporation. Lack of strong irrigation water use management causes unfair water resource share between the users and leads to conflicts.

In general conclusion, there are both rainfall and stream flows variation with positive correlation between them in the study area. The main products of the area, tomato and onion reduced on average by 11943.02kg and 10237.5kg per hectare respectively in the time of water shortage and due to the combination effects of discussed factors. The demand for irrigation and the water availability will be in question after few years in the future due to the climate change leads to affect rainfall in the area.

5.2. Recommendations

The search for solutions to the country's poverty and food insecurity problem requires efforts to reverse negative trends that have hitherto limited the impact of well meaning interventions. With this recognition, possible approaches that could be recommended are as follows:

- Water is an essential natural resource, but it is limited resource. Therefore, great management attention should be given how to use it effectively and efficiently.
- Selected technologies based on experiences of elsewhere should be introduced to overcome natural calamity due to climate change.
- Watershed management shall be structured to reduce sedimentation on the reservoir.
- Canal structure should be lined.
- Since more water is required during planting and flowering stage, the farmers should adjust their group schedules of planting time properly.
- Water reservoir / harvesting shall be practiced to argument water shortage.
- Further researches works have are required on other factors that affect the availability of water in the stream.

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Annex

Annex 1 Test parameters for the significance of trends in rainfall at station and over the catchment of annual and seasons for the data series of 1996 to 2007

		Δ^2	S^2	C	Remark	Sig at 5% level
Areal RF	Annual	4832.213	2015.971	2.396965	C>1.13	Not Significant
	Kiremt	8772.85	3392.894	2.585654	C>1.13	Not Significant
	Belg	11047.53	4440.612	2.487839	C>1.13	Not Significant
	Bega	3504.663	3239.504	1.081852	C<1.13	Significant
Degega station	Annual	24313.26	14379.53	1.690825	C>1.13	Not Significant
	Kiremt	21409.7	9967.361	2.147981	C>1.13	Not Significant
	Belg	10495.39	6275.818	1.672354	C>1.13	Not Significant
	Bega	4490.231	2683.935	1.673003	C>1.13	Not Significant
A/Negele Station	Annual	53534.81	62721.13	0.853537	C<1.13	Significant
	Kiremt	46709.98	32958.14	1.417252	C>1.13	Not Significant
	Belg	23490.27	17479.94	1.343841	C>1.13	Not Significant
	Bega	3223.043	1900.807	1.695618	C>1.13	Not Significant
Langano Station	Annual	17023.32	20394.82	0.834689	C<1.13	Significant
	Kiremt	27800.09	9401.88	2.956865	C>1.13	Not Significant
	Belg	18190.22	7312.957	2.487396	C>1.13	Not Significant
	Bega	6316.389	8496.066	0.743449	C<1.13	Significant
Bulbula Station	Annual	41590.89	17426.41	2.386659	C>1.13	Not Significant
	Kiremt	25369.88	8298.014	3.057344	C>1.13	Not Significant
	Belg	14273.45	5584.381	2.55596	C>1.13	Not Significant
	Bega	4814.945	4932.109	0.976245	C<1.13	Significant
Kuyera station	Annual	23269.58	21502.37	1.082187	C<1.13	Significant
	Kiremt	9672.906	3024.353	3.198339	C>1.13	Not Significant
	Belg	21041.51	10727.91	1.96138	C>1.13	Not Significant
	Bega	11906.72	5688.107	2.093266	C>1.13	Not Significant

(a)

Note: Δ^2 = mean square successive difference; S^2 = variance; $C=\Delta^2 / S^2$ and Cr= critical point (for n=12, Cr is 1.129983 at 5% significant level).

(b) Statically parameters and constants of candidate models estimating using Microsoft Excel and SPSS program

Model	Constant	Annual RF of A/Negele	Annual RF of Lganoan	*Bega* RF of L	Annual RF of Kuyera	*Bega* RF of Bulbula	*Bega* Areal Rainfall
Linear	SE	268.148	156.221	86.446	157.201	63.515	50.345
	RME	71903.195	24405.07	7472.933	24712.05	4034.18	2534.601
	a	21.697	-4.06	-12.456	6.303	-10.297	-10.014
	b	916.283	762.647	186.591	832.616	174.458	173.795
Logarithmic	SE	263.193	156.575	94.861	158.818	63.637	57.321
	RME	69270.444	24515.62	8998.532	25223.25	4049.703	3285.753
	a	122.075	14.112	-33.212	-9.512	-48.869	-32.962
	b	853.988	712.754	160.943	889.428	188.922	163.608
Quadratic	SE	239.171	160.813	84.876	113.2	61.672	50.278
	RME	57202.676	25860.97	7203.983	12814.27	3803.379	2527.896
	a	182.5	33.77	22.938	-122.879	-38.115	8.113
	b	-12.369	-2.91	-2.723	9.937	2.14	-1.394
	c	541.077	674.377	104.005	1134.041	239.367	131.499
Exponential	SE	0.25	0.208	1.115	0.182	0.927	0.465
	RME	0.063	0.043	1.243	0.033	0.86	0.217
	a	0.018	0.027	-0.061	0.007	-0.092	-0.091
	b	911.503	691.453	101.922	822.413	144.164	171.177
Power	SE	0.246	0.209	1.136	0.184	0.902	0.536
	RME	0.061	0.044	1.29	0.034	0.813	0.288
	a	0.104	-0.004	0.096	-0.013	-0.517	-0.277
	b	863.844	742.758	58.459	879.985	187.469	150.001

Annex 2 Questionnaires for household survey
Dear sir/ madam,

Mulugeta Bekele, a postgraduate student at Addis Ababa University, is conducting a study entitled "**Effects of Rainfall Variability on Stream Flow and Its Impact on Small Scale Irrigation: The Case of Gedemso River, Central Rift Valley of Ethiopia**" for the Partial fulfillments of Masters Degree in Water and Development with Specialization of Water Resources Planning and Management. Therefore, the researcher is kindly requesting you to answer the questions with great concern for viability of the outcomes of the study. The researcher would like to confirm you that the answers you provided will be used in secret only for research purpose.

A. General information

Sample number/code_________ sex _______ Age _________ Irrigation scheme__________

Marital status: A) married B) single C) divorce D) other____________

Family size: Male: ____, Female_______, Total_____

How long do you work in the irrigation scheme? ____________________

B. Questions

1. List the crop and vegetation types you plant in rank order. ________, ________, _________, __________
2. How much hectare irrigation land do you have? _________________
3. How much times you have irrigation annually? _____________

3.1. Put your irrigation work calendar.

Activities	Phase I	Phase II	Phase III
Land preparation			
Planting			
Harvesting			

4. The total of your livelihood source covered from irrigation product is;

A) 75% - 100% B) 50% - 75% C) 25% -50% D) less than 25%

5. Is there the stream flow fluctuation? A) Yes B. No

6. If your answer is yes for Q5,

6.1. What do you think are the causes?

____

____

____

6.2. Tick which phase and stage of your irrigation most of the time faced to water shortage?

First phase planting stage _______, First phase flowering stage _______,

Second phase planting stage _______, Second phase flowering stage _______,

6.3. What are the effects on your irrigation products?

____

____

____

7. Please put your land irrigated in hectare or Timad (1timad=0.25ha) and your irrigation product produced in Kuntal or kg (1ku=100kg) both in the years of maximum and minimum stream flow you remember.

During Maximum flow(Enough water available)			During minimum flow(water shotage)		
Years	Land irrigated (ha) or Timad	Production type in Kuntal or kg	years	Land irrigated (ha) or Timad	Production type in Kuntal or kg

8. Did you get conflict in water use for irrigation with others users? A) Yes B) no

8.1. If so what was the main cause for the conflict?

____

____

____

9. Did the beneficiaries of the irrigation share water resources fairly? A) Yes B) no

9.1. If not what are the causes?

____

____

____

____

10. Are there rules and regulations in irrigation water use in your irrigation? A) Yes B) no

11. Did the local government are committed for irrigation water management? A) Yes B) no

11.1. If you say no for Q11, what are the failures?

____

____

General comment

Please put your comment on overall effects of stream flow fluctuation on your irrigation development.

____

____

____

____

____

____

Declaration

This thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for the thesis has been duly acknowledged.

Name: Mulugeta Bekele

Signature: