ASSESSMENT OF WATER RESOURCES IN UNGAUGED CATCHMENTS, KERALA

A DISSERTATION

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By

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CANDIDATE DECLARATION

I hereby certify that the dissertation titled "**Assessment of water resources in ungauged catchment, Kerala**" being submitted by me in fulfilment for the award of the Degree of Master of Technology in Hydrology in Department of Hydrology, Indian Institute of Technology Roorkee, is a bonafide study carried by me except where otherwise acknowledged, under the supervision of Dr. D. S. Arya, Professor, Department of Hydrology, Indian Institute of Technology Roorkee. Any materials from the work of others are acknowledged herein by referencing to the sources as appeared throughout the text and list of references.

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ABSTRACT

Streamflow estimation is a crucial challenge required in assessments of water resources, planning, decision-making and improvement. Tools and data needed to carry out such assessments are often limited, especially in developing countries having limited technical capacity and funding. Due to this, there is a need to develop methods, techniques and tools for assessing water resources that works with limited data or in ungauged catchments. Hence, the objectives of this study are (a) to assess the catchment characteristics of gauged catchments, (b) to estimate the flow quantiles to establish flow duration curve of gauged catchments, and (c) to regionalize the information obtained from gauged catchments to estimate flow characteristics of ungauged catchments. The study uses 19 gauged catchment data and in 110 ungauged catchments located in Kerala, India.

ALOS DEM was used to obtained various geomorphological characteristics and delineation of catchments. Precipitation data was obtained from IMD. Temperature, relative humidity and wind data was obtained from Global weather data provided by Climate Forecast System Reanalysis (CFSR) data. FAO Local Climate Estimator (New_LocClim) was used to obtained sunshine hours. The discharge data of gauged catchments was obtained from Central Water Commission portal i.e. WRIS. With MODIS land cover data, crop coefficient (Kc) values were calculated based on FAO guidelines. CROPWAT was used to get potential evapotranspiration. A climatic classification based on Budyko curve was used and it was found that 19 gauged catchments fall in the wet category with aridity index values between 0.38 and 0.69. They also have comparable evaporative indices (between 0.24 and 0.64) for regionalization of the catchments. The gauged catchments were then used as the donor catchments.

Regression models were developed for all parameter using a forward stepwise-regression considering non-transformed and log-transformed data. Leave-one-out cross validation was utilized as the basic criteria for selecting the best performing models. The results showed that the log-transformed models outperformed the non-transformed ones. For high flows (q_5), it was observed that precipitation (PREC), potential evapotranspiration (ET_{pot}), drainage density(D), catchment area (C_A) and percent of urban (L_U) area are the explanatory variables. For median flow (q_{50}), precipitation (PREC), minimum elevation (H^-), percent of grasses/crop cover (L_{GC}), catchment area (C_A) and drainage density(D) were observed as the dominant explanatory variables. For low flows (q_{90}) prediction, precipitation (PREC), percent of water bodies (L_W), minimum elevation (H^-), potential evapotranspiration (ET_{pot}), percent of

evergreen needle leaf forest (L_{EN}) and maximum elevation (H^+) appears in the stepwise model. And for low flows (q_{95}), precipitation (PREC), percent of water bodies (L_W), minimum elevation (H^-), potential evapotranspiration (ET_{pot}) and percent of evergreen needle leaf forest (L_{EN}) are the dominant explanatory variables. The identified most substantial variables for the regionalization of FDC_{slp} are elevation range (H_R), percentage of broadleaf forest (L_B) and waterbodies (L_W), drainage density (D), catchment perimeter (Cp) and potential evapotranspiration (ET_{pot}).

The assessment of q_5 and q_{50} in ungauged catchments shows that a larger predicted value found along the coastal area mostly draining in to the Arabian sea. The spatial pattern of low flows i.e. q_{90} and q_{95} demonstrates a decreasing trend alongside the eastern parts which is mostly mountainous. FDC_{slp} is higher in the south eastern catchments demonstrating a high variable streamflow owing to direct runoff. The lower values of FDC_{slp} are found in the western catchments or along the coastal area indicating higher contribution and presence of groundwater in these catchments.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations & Symbols	**Description**
AIC	Akaike Information Criterion
AICc	Corrected Akaike information criterion
ALOS	Advanced Land Observation Satellite
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CFSR	Climate Forecast System Reanalysis
CWC	Central Water Commission
DEM	Digital Elevation Model
ET_A	Actual evapotranspiration
ET_o	Potential evapotranspiration
EOSDIS	Earth Observing System Data and Information System
FAO	Food and Agriculture Organization
FDC	Flow Duration Curve
IAHS	International Association of Hydrological Sciences
IDW	Inverse Distance Weighting
IMD	India Meteorological Department
JAXA	Japan Aerospace Exploration Agency
Kc	Crop Coefficient
km	Kilometer
l	litre
LPDAAC	Land Processes Distributed Active Archive Center
LOOCV	Leave-one-out cross-validation
MAE	Mean Absolute Error
m	meter
mm	millimeter
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction
NSE	Nash-Sutcliffe Efficiency
PUB	Prediction of Ungauged Basins
q	flow quantile
RMSE	Root Mean Square Error
s	second
USGS	United States Geological Survey

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Chapter 1

Introduction

1.1 General

Sustainable water resources planning and management requires data for assessing water quantity and quality. Information related to the rates of transfers and storage of water within a catchment is required for optimal management of water resources in catchments. The vagueness in the design of hydraulic structures and management of water resources are due to insufficient hydrological records. Due to poor hydrologic or no records, most of the developing regions has inaccurate estimation about the available water resources and water demand (*McNulty et al., 2016*). The main causes of water scarcity are the fast-growing population attributed to the increasing water demand for domestic, agricultural, electricity generation, agro-based industrial uses and industrial purposes. The magnitude of this shortage and its spatiotemporal variation remain unanalyzed due to lack of hydrological records.

The degradation of catchment in various forms continues without effective control measures due to lack of the data adversely effecting assessment of water resources. This uncertainty also emerges from inadequate hydrological information that should enable quantification of effects of specific land use practices on quantity and quality of water resources. Floods and drought happen likewise, with frequencies and magnitude that are inadequately defined in the area due to the absence of relevant hydrological information. This leads to major social, economic and environmental misfortunes every year.

Limited information about water resources regarding the quantity and quality arises from a poor hydrological network. Water resources assessment is of an incredible worth for national economy, advancement and stability. In such case, instruments and information which is important to do such evaluations are often restricted or lacking, particularly in developing nations (*McNulty et al., 2016*). It is experienced that it takes not less than 30 years before adequate data are collected if the resources, finance as well as technical, are made available for the establishment and expansion of hydrometric networks. An ideal network is also difficult to set up as some sites are not inaccessible. Furthermore, some present or existing monitoring sites have already been affected by anthropogenic influences such as upstream abstractions and impoundments on rivers that provide the information collected unsuitable for long-term planning (*Sivapalan et al., 2003*). The International Association of Hydrological Sciences (IAHS) recognized this need in 2002, and adopted the Prediction of Ungauged Basins (PUB) as a research agenda for the coming decade (*Sivapalan et al., 2003*). Hence, there is a need to develop methods for assessing water resources in ungauged catchments. Keeping in view of the above, a study is proposed for the assessment of hydrological estimates in ungauged catchment of Kerala State, India.

1.2 Research objectives

The objectives of this study are

i. to assess the geomorphological characteristics of gauged and ungauged catchments.
ii. to estimate flow quantiles (q_5, q_{50}, q_{90} and q_{95}) and characteristics of flow duration curve of gauged catchments.
iii. to regionalize the information obtained from gauged catchments to estimate flow characteristics of the ungauged catchments.

This study addresses (1) the degree to which prediction correspond with climate and catchment characteristics, (2) which kind of stepwise-parameter regression performs better (non-transformed or log-transformed regression), (3) how hydrologically important informative factors or explanatory variables are chosen by using the forward stepwise regression procedure, and (4) how model unpredictability affects the performance.

1.3 Thesis outline

This thesis is divided into five chapters starting from general introduction and objectives of the study as presented in this Chapter. The rest of the chapters are structured as below:

Chapter 2 is a review of common statistical methods of prediction, catchment similarity, parameter regression and conclusion of the review. The review is developed based on international literature.

Chapter 3 describes the study area and methodology used for this study. This chapter describe the study area, preparation of data and analyzing which method is useful for developing understanding of the linkage between catchment properties and hydrological response and interpreting regionalization results. Flow quantiles and slope of flow duration curve of the gauged catchment estimation for stepwise regression analysis and selection of best performing model.

Chapter 4 shows results and discussion of the models. The performance of non-transformed and log transformed model are compared. The best performing model are discussed in details.

Chapter 5 is the conclusion of major findings, limitations and future scope of work that could contribute to the advancement in prediction in ungauged catchments.

Chapter 2
Literature Review

2.1 General

“Falkenmark and Chapman (1989, p. 12) coined ‘comparative hydrology’ approach to describe the study of the character of hydrological processes as influenced by climate and the nature of the earth’s surface and subsurface”. An importance is given on understanding the interactions between hydrology and the ecosystem, and deciding to what extent hydrological predictions may additionally be transferred from one region to another. The accomplishment of the comparative hydrology strategy depends on the ideas of similarity and dissimilarity. Climate classification schemes such as those by *Köppen (1936) and Thornthwaite (1931)* define regions through a combination of mean annual precipitation, air temperature and their seasonal variability. *Budyko (1974) and L’vovich (1979)* developed long-term average relationships between measures of water and energy availability in various regions.

2.2 Definition of terms

2.2.1 Ungauged catchments

According to *Sivapalan et al. (2003)*, an ungauged catchment is one with inadequate records (in terms of both data quantity and quality) of hydrological observations to enable computation of hydrological variables of interest (both water quantity and/or quality) at the appropriate spatial and temporal scales, and to the accuracy acceptable for practical applications. An ungauged catchment is therefore not necessarily completely ungauged and, in many cases, it refers to a poorly-gauged catchment. The hydrological variables mentioned in this context would include, for example, rainfall, runoff, erosion rates, sediment concentrations in flow (*Makungo et al. 2010*). The ungauged catchment problem (*Beven, 2001*) is common, especially in the developing countries (*Schreider et al. 2002, Singhrattna et al. 2005, Lee 2006, Buytaert and Beven 2009, Piman and Babel 2013*).

2.2.2 Regionalization

Depending on the contexts and focuses of the studies concerned, various definitions of regionalization have been used in the literature. A sequential review of the definition of regionalization provided by *He et al. (2011),* stated that the following: regionalization refers to a technique of transferring hydrological information from gauged to ungauged or poorly gauged catchments to estimate the streamflow. Several regionalization approaches ranging from the simplest to the most sophisticated techniques have been used for predictions in ungauged catchments (*He et al. 2011, Parajka et al. 2013b, Savenije and Sivapalan 2013*)

2.3 Statistical methods of predictions in ungauged basins

2.3.1 Regression methods

In a regression method, the runoff signature $\hat{y}$ of interest (for example, the flood discharge of a given probability) is estimated from catchment and/or climate characteristics x_i with sampling error ε:

$$\hat{y} = \beta_0 + \sum_{i=1}^{p} \beta_i x_i + \varepsilon + \eta \tag{2.1}$$

where there are i different characteristics, β_i - model parameters (i.e., regression coefficients)
η - model error

2.3.2 Index methods

Index techniques rely on some scaled normal for the catchment. An example is the Budyko curve technique, where the percentage of mean annual actual evaporation to mean annual precipitation is communicated as a characteristic of the aridity index, the ratio of mean annual potential evaporation and mean annual precipitation. The index techniques replicate some foremost hydrological rule that is not derived from the information yet from hydrological reasoning.

2.3.3 Geostatistical methods

The geostatistical methods make use of the correlation of runoff signatures in space. In the geostatistical approach, the runoff signature of activity in the ungauged catchment is presumed to be a weighted imply of the runoff signatures in the neighboring catchments. On the basis of the spatial correlations of the runoff signatures and the relative locations of the catchments and/or the stream network, the weights are estimated. The geostatistical approach as they account for spatial correlations that will vary between methods and regions, goes beyond simple spatial distance measures (e.g., longer spatial distances for low flows than for floods), and the so-called declustering property of geostatistics, i.e., the potential to provide less weight to observations that are close to each other due to the fact they are correlated, so include less information about the random variable.

2.3.4 Estimation from short runoff records

The record may be not enough to estimate the runoff signatures to a level of accuracy that is sufficient for the problem at hand. However, with the information from other catchments in the region and the use of regionalization methods together, it may be possible to utilize the information that is contained in the short runoff records. Runoff information from a neighboring catchment is usually used to account for the temporal variability in the runoff signatures in the poorly gauged catchment of interest as a result of the runoff records in that catchment being insufficient.

2.4 Catchment similarity

The assumption by the spatial proximity method is that the catchment characteristics and climate contrast smoothly in space. Thus, spatial proximity, which is normally characterized dependent on the separations between the catchment centroids or catchment outlets, would possibly be an appropriate measure of closeness between the catchments while selecting the donor catchment (*Li et al., 2009; Randrianasolo et al., 2011*). A donor catchment is a catchment that is most comparative as far as its physiographic attributes to the catchment of activity (*Parajka et al., 2005*). So as to represent nested catchments, geostatistical distances can be utilized (*Skoien et al., 2006; Skoien and Blöschl, 2007*). Similarity of catchment traits and climate, as an elective technique, chooses the donor catchment(s) in light of the closeness of the catchment traits and local weather in the catchments. Similarity is decided by way of the root mean square differences of all the characteristics in a couple of catchments (*Blöschl et al., 2013*). So as to make it comparable, the characteristics are usually standardized. Kokkonen et al. (2003) relocate the total set of parameters from the catchment which has the most indistinguishable elevation to that of the catchment outlet even as McIntyre et al. (2004) characterized the most homogenous catchment primarily based on the catchment area, standardizes annual mean precipitation and base-flow index. A few investigations (*Parajka et al., 2005; Zhang and Chiew, 2009*) utilized a massive range of catchment characteristics, others used fewer, yet more relevant catchment characteristics (e.g., *Oudin et al., 2010*). The model averaging method utilizes a weighted combination of the parameter units from more than one donor catchment, where the catchments are select either dependent on spatial proximity, catchment characteristics or both (*Seibert and Beven, 2009*). Every catchment can either be assigned to its very own group of donor catchments or, alternatively, the area can be isolated into groups of catchments (*Burn and Boorman, 1993*).

2.5 Parameter regression/ Stepwise regression

Parameter regression is the comprehensively utilized technique for rainfall-runoff model regionalization (*McIntyre et al., 2004*). This technique associates with the model parameters explanatorily to physiographic characteristics in the gauged catchments through empirical equations which would then be able to be utilized to foresee the model parameters in the ungauged catchments (*Merz and Blöschl, 2004; Mazvimavi et al., 2004, 2005; Wagener and Wheater, 2006; Young, 2006; Parajka et al., 2013*). Stepwise-multiple regressions was utilized by *Laaha and Blöschl (2006, 2007*) to examine the estimation of regularity indices for regionalizing low flows, in light of physical catchment attributes and consistent records to make regionalization models. The estimation of various models was evaluated to consolidate regularity by various methodologies so as to foresee low streams in ungauged catchments utilizing cross-validation. They looked at the models for the 95% quantile of particular discharges and moreover considered the precise low stream flow discharges of the summer season and winter periods ($q_{95}s$, $q_{95}w$). They saw from their consequences that gathering the study location into a range of areas and separate regressions in each locale offers the satisfactory model performance. As indicated with the aid of Laaha and Blöschl (2006, 2007), the lowest overall performance was yielded through a global regression model and performs marginally higher when makes use of regional calibration coefficients. They supported that an outstanding regression models in every one of the locales are to be chosen over a global model so as to communicate to differentiate in the manner in which catchment characters are recognized with low streams flows.

It is preferable to make reliable forecasts in ungauged basin, the conditions which relate the model parameters and the catchment characteristics ought to be hydrologically logical. In any case, this isn't constantly conceivable as indicated by Sefton and Howarth (1998), as the clarification of the regression equations is many times not simple by reason of unrepresentative of catchment characteristics and moreover problems recognized with the determination of model parameters (*Blöschl, 2005*). Kokkonen et al. (2003) noticed that high magnitude of regression models does no longer really provide a lot of parameters with a properly predictive power. Consequently, illustrating the physical importance of regression relationships among model parameters and attributes needs cautious consideration. Model averaging and parameter regression can likewise be linked concurrently by way of adjusting the coefficients of these relationships as a replacement to first evaluating model parameters at each gauged catchment and afterward interface them to the catchment traits by way of an empirical equation. This lets in the discovering of progressively dependable parameters contrasted with just aligning the model parameters themselves and blueprint on the spatial information suit inside the catchment characteristics (*Parajka et al., 2013*). Rather than using only a single strategy, a few investigations analyze regionalization techniques for assessing the model parameters in ungauged catchments (*Merz and Blöschl, 2004*).

A regression model is able to show an explicit link between the predictors and predicted variables as well as the contribution of each predictor to the predicted variables. It is easy to implement using automated procedures available in software such as MATLAB, R and SPSS. However, disadvantages of the regression model are that it could be highly influenced by outliers and produces erroneous regression equations that are not obviously illogical. When an outlier is included in the analysis, it pulls the regression line towards itself resulting in overfitting which is the problem of the regression model representing random error rather than the underlying relationship between the predictors and predicted variables. The regression is not robust to variations in the data. Rather, it depends on the algorithms used for selecting the predictors (forward selection, backward elimination or forward/backward stepwise) (*Whittingham et al. 2006, Lark et al. 2007*). The stepwise selection algorithm relies on the calculation of marginal statistics, i.e. entrance and exit p-value tolerances and r^2, and may result in the exclusion of predictors that are highly correlated with the predicted variables because of multi-collinearity problem. The number of input predictors and sample sizes has also been found to affect the final regression model (*Derksen and Keselman 1992, Graham 2003, Chong and Jun 2005, Basagaña et al. 2012*). While having the above-mentioned issues, the stepwise regression has widely been used in many disciplines such as environmental science (*e.g. Hauser 1974, Geladi et al. 1999, Lark et al. 2007, Minasny and Hartemin 2011*), medical science (*e.g. Bagley et al. 2001, Phillip and James 2012, Sainani 2013*) and social science (*e.g. Fox 1997, Osborne and Elaine 2002, Ron 2002, Hinkle et al. 2003*). Transformations of variables, for example using the logarithm, square, square root or cube root, have been used to move the variables towards normal distributions and to alleviate the likelihood that the value for a case will be characterized as an outlier (*Kim and Hill 1993, Geladi et al. 1999, Kjeldsen and Jones 2009, Liu et al. 2009, Haddad and Rahman 2012*). Incorporating expert knowledge throughout the model development process could shape the regression model into a more meaningful representation of the relationship between the predictors and predicted variables (*Lark et al. 2007, Basagaña, et al. 2012, Sainani 2013*).

2.6 Conclusions

The regression method is the most widely used method for regionalizing flow responses. The advantage of the regression method is the explicit relationships between catchment properties and information about flow responses which may offer improved understanding of dominant processes in tropical catchments. The regression method may be useful for predicting the effect of non-stationarity on catchment hydrology although it may incur significantly more uncertainty caused by changes in the regression relationships when moving beyond the period of modelling. Furthermore, the regression method is the only method from which the estimation of uncertainty can be directly obtained from analyzing the residuals. In this sense, the regression method may be the most suitable choice for addressing the problem of predicting flows in Kerala ungauged catchments. The intended contribution of this thesis is to identify the potential value and to expand the knowledge of the prediction of ungauged catchments using an established regionalization method for predicting flow in humid tropical wet catchments. However, ample examining whether or not the option of extra variables improves the predictive overall performance of the regression models was not clearly explained from various studies which additionally make a contribution to discover the use of LOOCV using a case study of the nineteen gauged and 110 ungauged catchments in this thesis.

Chapter 3
Study Area and Methodology

3.1 Description of Study Area

3.1.1 Location

Kerala lies on the south western coastal region of India which lies in the middle of scopes 8°17' and 12° 47' North and longitudes 74° 52' and 77° 24' East, spread out over a territory of 38,863 km², extending a length of 580 km and width of 30 to 130 km. It covers about 1.2% of geographical region of India. The location of the state is shown in Figure 3.1.

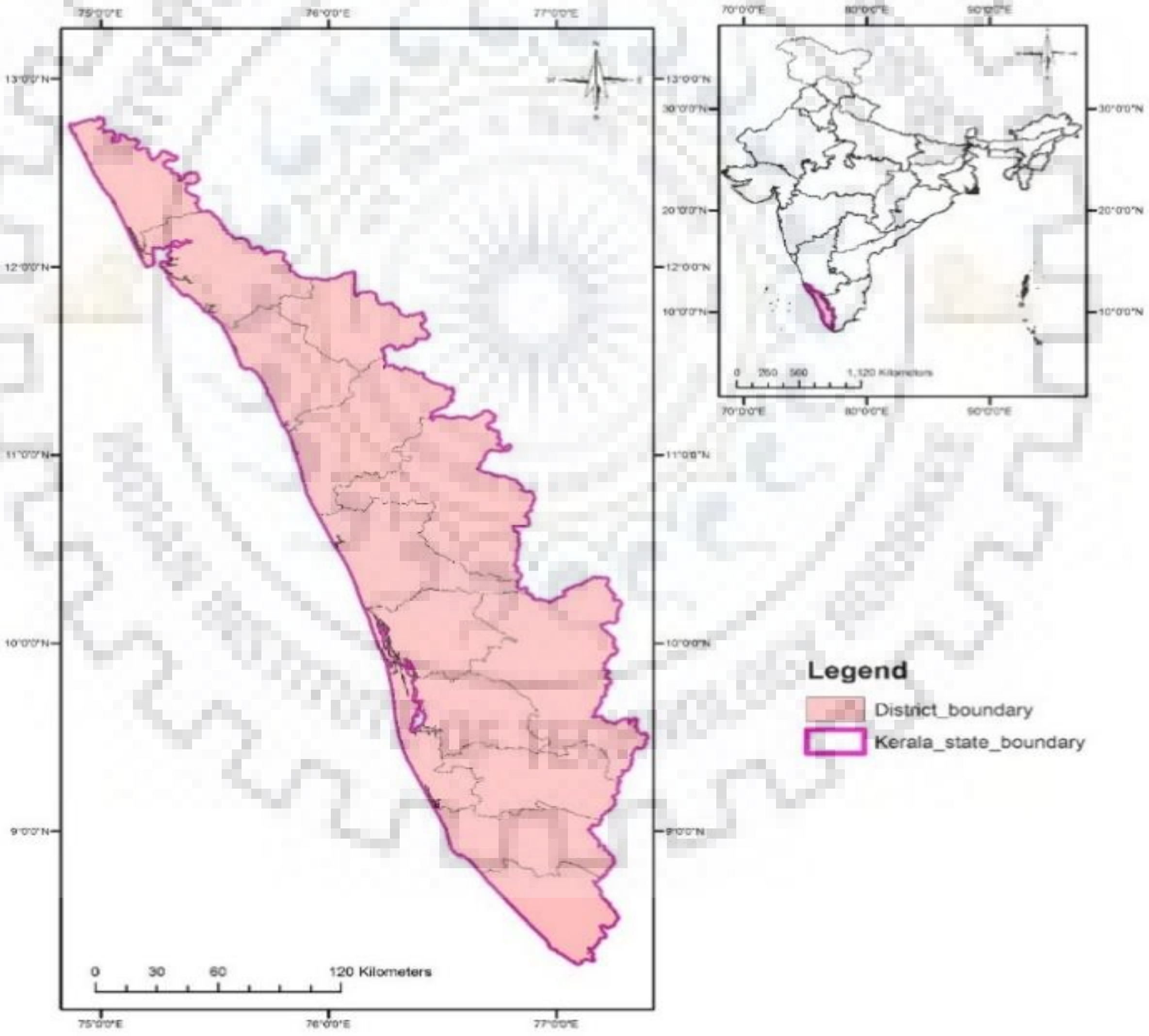

Figure 3.1 Location Map of Kerala

3.1.2 Population

As per Census 2011, the state's population is 33.3 million which represents 3.01 percent of India's population. It has one of the most noteworthy population densities of the state in the nation representing 859 people for every square km. In addition, the population is spreading over the State. The biggest city, Kochi has a population of about 0.27 million. The total population of consists 16,021,290 and 17,366,387 male and female respectively.

3.1.3 Climate

Kerala encounters a tropical rainstorm atmosphere with regularly unreasonable precipitation and sweltering summer*. The Western Ghats plays a noteworthy obligation to the climatic conditions across the state. Seasons are separated into four period, the hot season March as far as possible of May, trailed by South West Monsoon season that proceeded till the start of October, October to December is the North East Monsoon season and January and February, are the winter season. The state has a wonderful atmosphere from September to February. The yearly precipitation of the state varies between 100 cm to 500 cm with a normal of around 300 cm. The long stretch of March to May is the hottest time and the minimum is achieved amid December to January. Winds are seasonal over the state; variation during the day is felt owing to the coastal effect. The annual relative humidity is generally high and varies between 73 – 80%.

3.1.4 Water Resources

The quick falling territory, substantial precipitation and the restricted width of the state have offered ascend to various waterways. There are 44 waterways, in which the majority of them have their source in the Western Ghats and drains into the Arabian Sea. The important rivers from north to south are; Valapattanam river (110 km), Chaliar (69 km), Kadalundipuzha (130 km), Bharathapuzha (209 km), Chalakudy river (130 km), Periyar (244 km), Pamba (176 km), Achancoil (128 km) and Kalladayar (121 km). Other than these, there are 35 small rivers and rivulets flowing down from the Ghats. The three rivers namely, Kabani, Bhavani and Pambar flows towards East joining the Bay of Bengal**.

State Environment Report, 2007

****Resource Atlas of India, Centre for Earth Science Studie,1984, Thiruvananthapuram***

3.2 Data Used in the studies

3.2.1 Stream discharge

The observation parameters such as gauge (river water level), discharge (amount of water released from a cross section in the river in a given time period) and sediment (concentration of solid particles in water) observing stations of CWC (Central Water Commission) were obtained from http://india-wris.nrsc.gov.in. The details are shown in Table 3.1.

Table 3.1 Summary of Discharge gauging stations of CWC

Station Name	Latitude (DMS)	Longitude (DMS)	Start Record	End Record	Period Record (years)
Vandiperiyar	9°34'26" N	77°05'22" E	1/6/2000	31/5/2017	17
Thumpamon	9°13'30" N	76°42'53" E	21/12/1977	31/5/2017	40
Ramamangalam	9°56'26" N	76°28'28" E	25/4/1978	31/5/2017	39
Pudur	10°46'40" N	76°34'29" E	2/9/1985	31/5/2017	32
Perumannu	11°58'52" N	75°35'29" E	24/5/1984	31/5/2017	33
Neeleswaram	10°10'59" N	76°29'51" E	1/6/1971	31/5/2017	46
Muthankera	11°50'49" N	76°07'15" E	1/6/1973	31/5/2017	44
Mankara	10°45'44" N	76°29'12" E	21/6/1985	31/5/2017	32
Malakkara	9°19'56" N	76°39'50" E	19/6/1985	31/5/2017	32
Kuttyadi	11°38'42" N	75°45'58" E	1/6/2000	31/5/2017	17
Kuniyil	11°14'28" N	76°01'28" E	2/6/1979	31/5/2017	38
Kumbidi	10°50'38" N	76°01'17" E	2/6/1979	31/5/2017	38
Kidangoor	9°40'32" N	76°36'21" E	2/7/1985	31/5/2017	32
Karathodu	11°03'23" N	76°02'23" E	20/6/1986	31/5/2017	31
Kalampur	9°59'27" N	76°37'50" E	23/6/1986	31/5/2017	31
Erinjipuzha	12°29'37" N	75°09'23" E	25/6/1985	31/5/2017	32
Ayilam	8°43'23" N	76°51'34" E	2/6/1978	30/11/2016	38
Kallooppara	9°24'08" N	76°39'10" E	19/6/1985	31/5/2017	32
Arangaly	10°16'53" N	76°18'51" E	27/4/1978	31/5/2017	39

3.2.2 Kerala DEM (Digital Elevation Model)

The Japan Aerospace Exploration Agency (JAXA) released "ALOS World 3D – 30m (AW3D30)", the global digital surface model (DSM) with a horizontal resolution of approx. 30-meter mesh (1×1 arc second) in May 2015. This DEM was used to delineate the catchment area of gauged and ungauged catchment, perimeter, drainage density and slope. ASTER DEM downloaded from USGS Earth Explorer (https://earthexplorer.usgs.gov/) and ALOS DEM (http://www.eorc.jaxa.jp/ALOS/en/aw3d30/data/index.htm) were used for delineation of catchment. The area obtained by ASTER DEM catchment delineation gives an unacceptable difference with the area given by CWC in some catchment. Therefore, ALOS DEM was used for the studies. The DEM data was processed using ArcGIS 10.4.

3.2.3 Land Cover

The Terra and Aqua combined Moderate Resolution Imaging Spectroradiometer (MODIS) Land cover type (MCD12Q1) Yearly L3 Global 500m SIN Grid V051 data of Kerala from 2014 was obtained from https://lpdaac.usgs.gov/. The Land Cover layer was set at Land Cover Type 3 (LAI/fPAR) classification schemes and processed using ArcGIS 10.4.

3.2.4 Precipitation

A daily gridded rainfall data set (IMD) was used. This data set is a very high spatial resolution (0.25° × 0.25°, latitude × longitude) covering a long period of 1901-2013. A daily rainfall records from 6995 rain gauge stations from the nation were utilized for the improvement of IMD gridded informational index for the period 1901-2010 sourced from the IMD archive. It is the most noteworthy ever number of stations over Indian terrain utilized by any investigations so far to get ready gridded precipitation over the locale. Around 3500 stations on a normal that fluctuated between 1450 and 3900 mm were utilized for the planning of the gridded information on daily basis. Different standard quality checking tests were applied on the information before the addition of the station precipitation information on fixed spatial grid points. For this, IMD utilized the well tested inverse distance weighted interpolation (IDW) scheme of Shepard (1968).

The Thiessen polygon method and the inverse distance weighting (IDW) were used for obtaining rainfall for each of the catchment area.

3.2.4.1 The Thiessen polygon method

The Thiessen polygon method (*Thiessen, 1911*) performs the interpolation by creating a zone of influence, which is the area surrounded by perpendicular bisectors lines connecting rain gauges, around a rain gauge. Any point within the zone of influence is assumed to have rainfall equal to the rainfall from rain gauge located within the zone of influence. The rainfall over a catchment area is calculated from weighted average values of rainfall from each rain gauge in direct proportion to the total catchment area it represents. The Thiessen polygon method is simple but, in principle, not appropriate for estimating rainfall over mountainous or monsoon-dominated catchments due to the assumption that a rain gauge is representative of a potentially large area around it.

3.2.4.2 Inverse Distance Weighting (IDW)

Rainfall values at an ungauged point derived from the IDW method are calculated from weighted average values of rainfall from a number of surrounding rain gauges using a weighting function represented by the inverse distance between each rain gauge and the ungauged point as shown in the equation below:

$$R = \frac{\sum_{i=1}^{n} R_i (1/d_i)^p}{\sum_{i=1}^{n} (1/d_i)^p} \tag{3.1}$$

where R is interpolated rainfall at ungauged point

Ri is observed rainfall at surrounding gauge i

di is the distance between the surrounding gauge i and ungauged point

p is power of distance

n is numbers of surrounding gauges

The closer the distance between the rain gauge and ungauged point, the more the influence of the rain gauge. Beyond a radius of influence, the gauge may be ignored. The weighting functions are adjustable by using different p values and different radii of influence, thus allowing flexibility for obtaining sensible local values. While the p values and radii of influence can be optimized for any gauge and time period, the same values are generally applied to all gauges in the regions throughout the period of interpolation. However, as there is no physical basis and it is difficult to identify optimal values for weighting functions, the adjustments are usually arbitrary (*Babak and Deutsch 2009, Tobin et al. 2011*). The IDW method assumes that the distance between rain gauges and ungauged point is the only factor characterizing the spatial distribution of rainfall and others are ignored. The IDW is a simple method which has been demonstrated efficient and reliable in many rainfall studies, e.g. *Tabios and Salas (1985), Garcia et al. (2008), Ly et al. (2011), Chen (2012)*. A major weakness of the IDW method is inability to account for the effect of topography on rainfall

3.2.5 Weather data [Temperature (Max and Min), Relative humidity, Sunshine hours, Wind]

Global Weather Data for SWAT was downloaded from http://globalweather.tamu.edu/ for the period of 1979 to 2014. The National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) was accomplished over the 36-year period (1979 through 2014). CFSR data depends on both historical and operational archives of observations and newly reprocessed sets of observations produced at meteorological research centers around the world. The CFSR was designed and executed as a global, high resolution, coupled atmosphere-ocean-land surface-sea ice system for providing the best estimate of the state of these coupled domains over this period. The data were extracted using ArcGIS 10.4. FAO Local Climate Estimator (New_LocClim) which was once advanced to provide an estimate of climatic prerequisites at areas for which no perceptions are reachable had been utilized to obtained sunshine hours.

3.3 Catchment Selection

The essential scrutiny in deciding on catchments for inclusion in this study is the availability of flow information on gauging catchment in order to allow correct estimation of flow statistics. A minimum of 10 years of flow information offers a sensible estimation of most flow records (*Searcy*, *1959*). This criterion is used for selecting catchments to be contain in this study. The CWC discharge data obtained meets this requirement. Out of 21 gauging site, 19 gauging sites are selected as shown in Figure 3.2. Three are excluded because the catchment area delineated using DEM obtained from ASTERDEM and ALOSDEM give unacceptable percent difference of catchment area with the catchment area given by CWC and the other one of the same catchment regions. The other set was of 110 Ungauged catchments as shown in Figure 3.3.

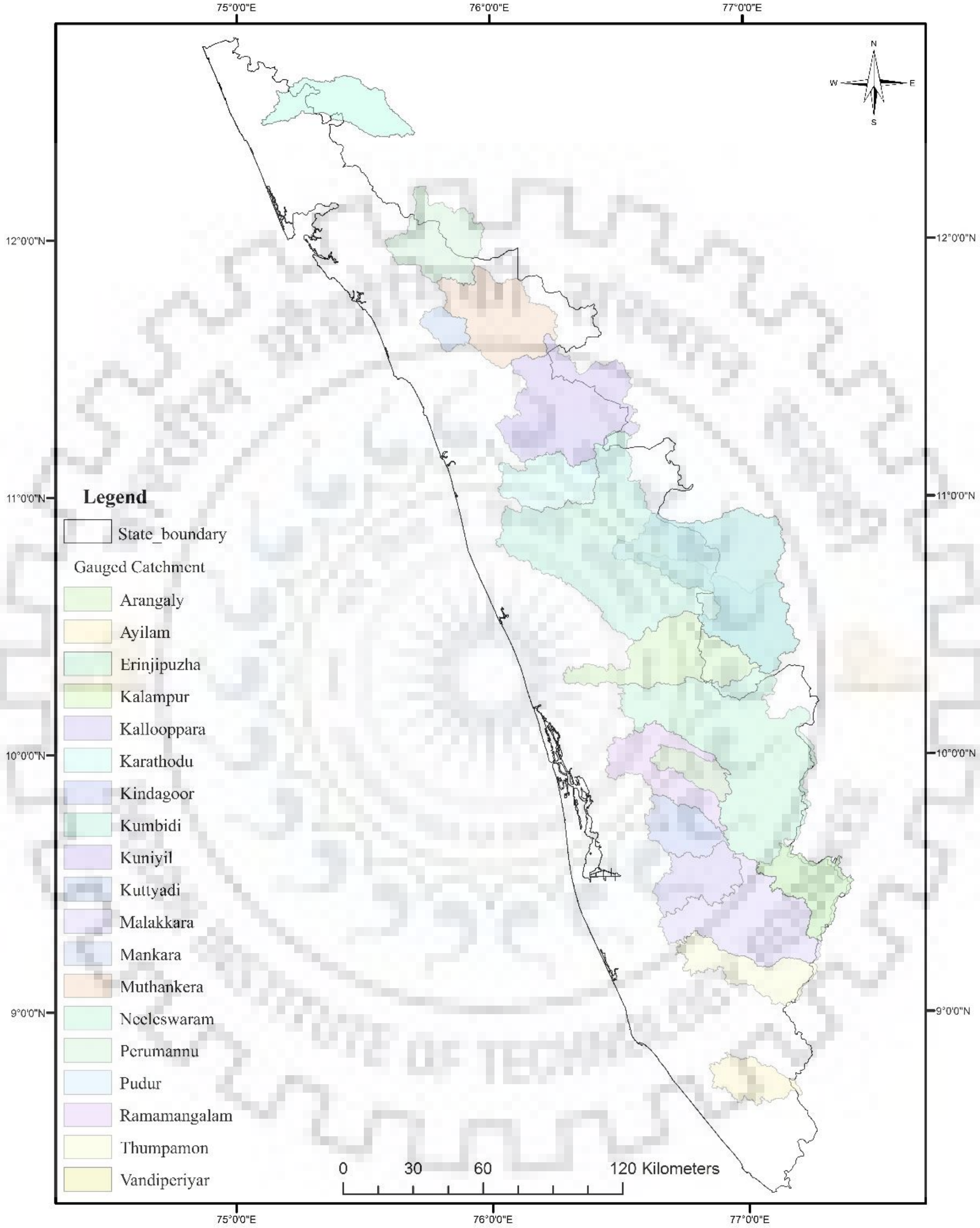

Figure 3.2 Selected gauged catchment map in study area

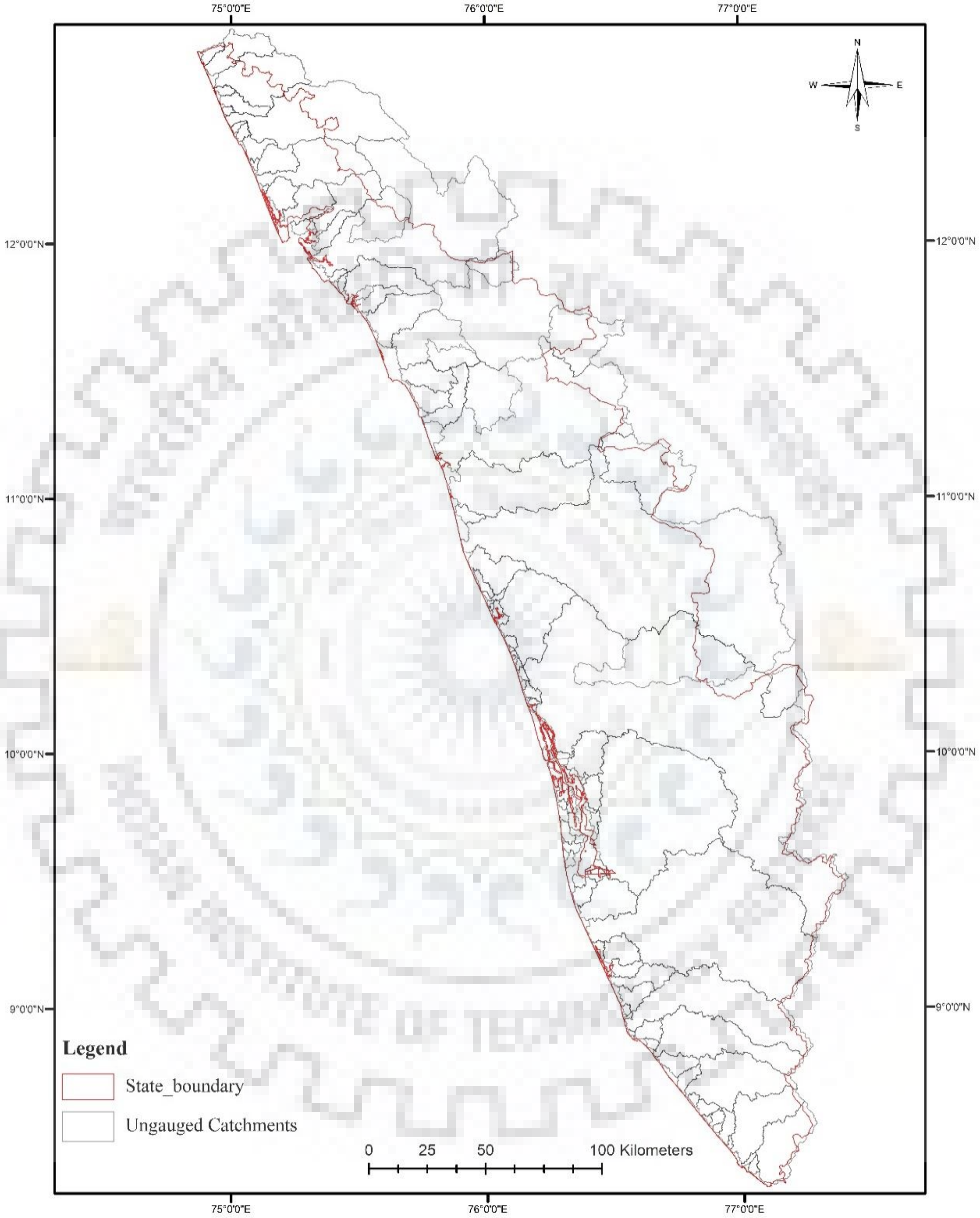

Figure 3.3 Selected Ungauged catchment map in study area

3.4 Catchment Characteristics

Selected catchment characteristics are elevation, drainage density, slope, land cover, precipitation, temperature, humidity, wind and solar as shown in Table 3.2.

Table 3.2 Selected catchment characteristics for use in the study

Catchment characteristics	**Description and Data source**
Catchment Elevation (Max., Min., Mean and Range)	Derived from a digital elevation model (DEM) having a geographic projection of 30 Arc seconds
Drainage density	Derived from a digital elevation model (DEM) and streams are assumed to represent by blue lines on these maps.
Slope	Estimated from a DEM
Land Cover type	Determined from the 1:500 000 (MODIS) Land cover type (MCD12Q1) Yearly L3 Global 500m SIN Grid V051
Precipitation,	IMD gridded dataset (0.25° x 0.25°)
Temperature, Humidity, wind, Solar	CFSR data over the 36-year period

The study area elevation map, drainage map of gauged and ungauged catchments, and land cover map are shown in Figure 3.4, 3.5, 3.6 and 3.7 respectively.

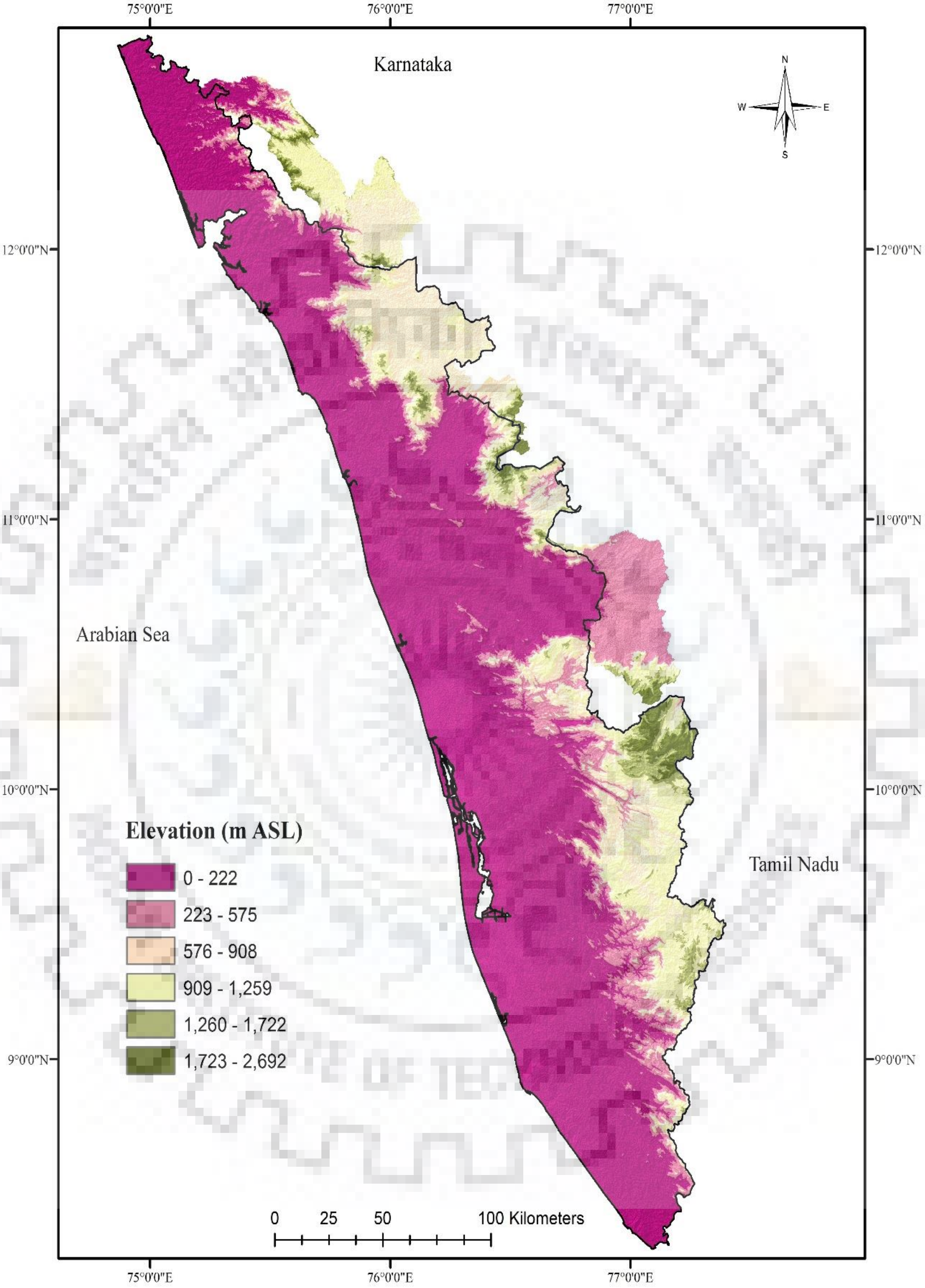

Figure 3.4 Elevation map of study area

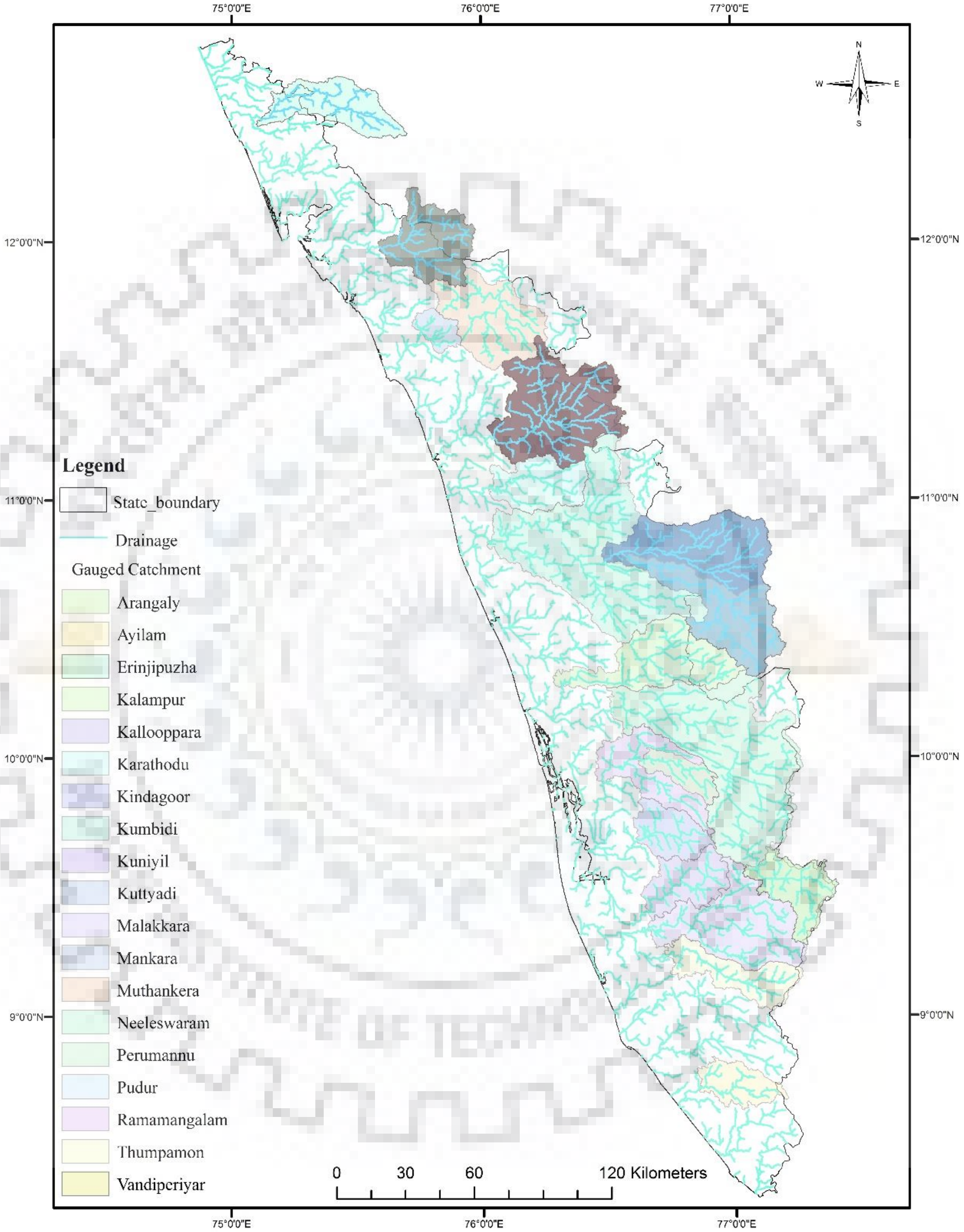

Figure 3.5 Drainage map of Gauged catchment

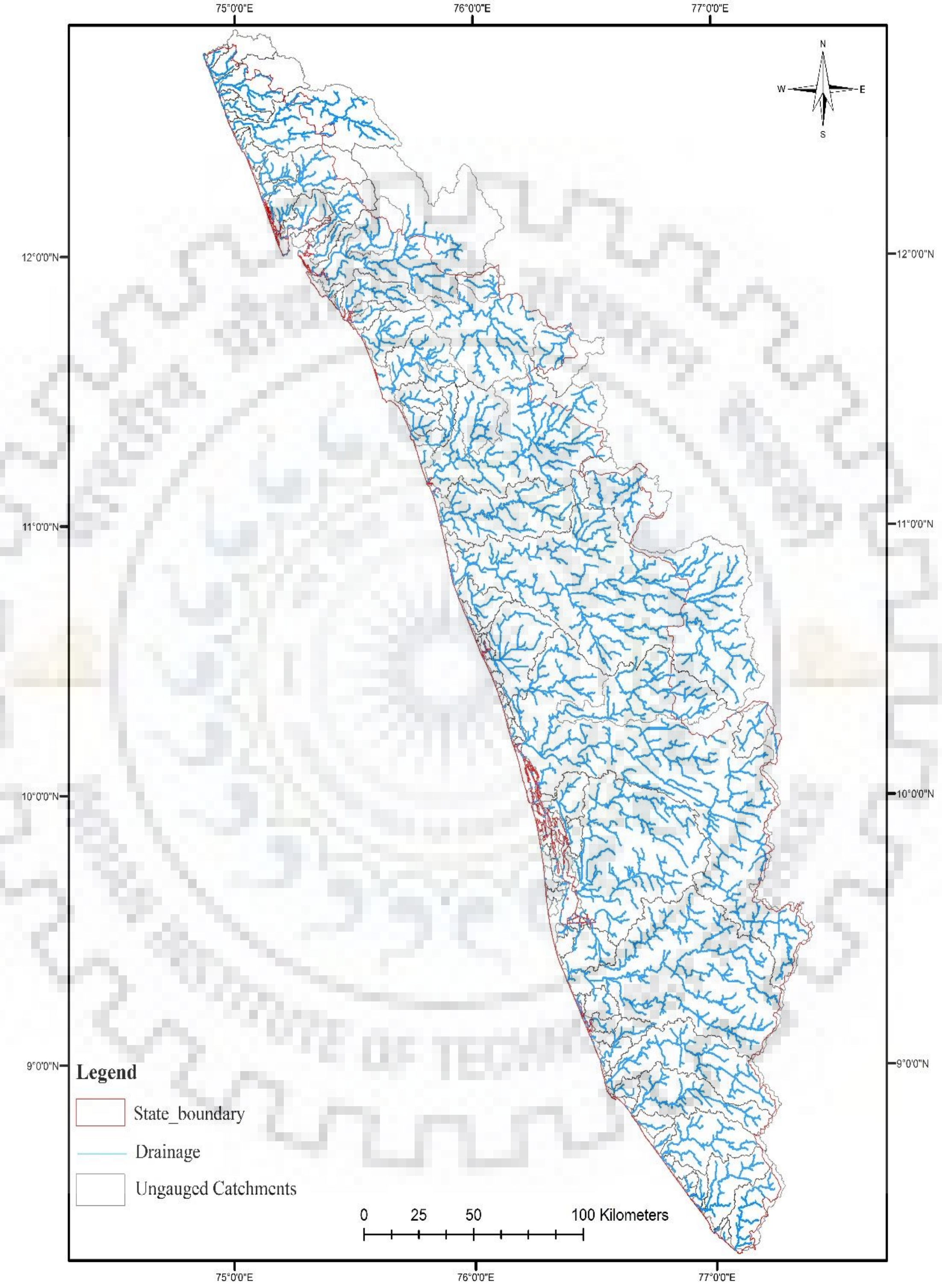

Figure 3.6 Drainage map of Ungauged catchment

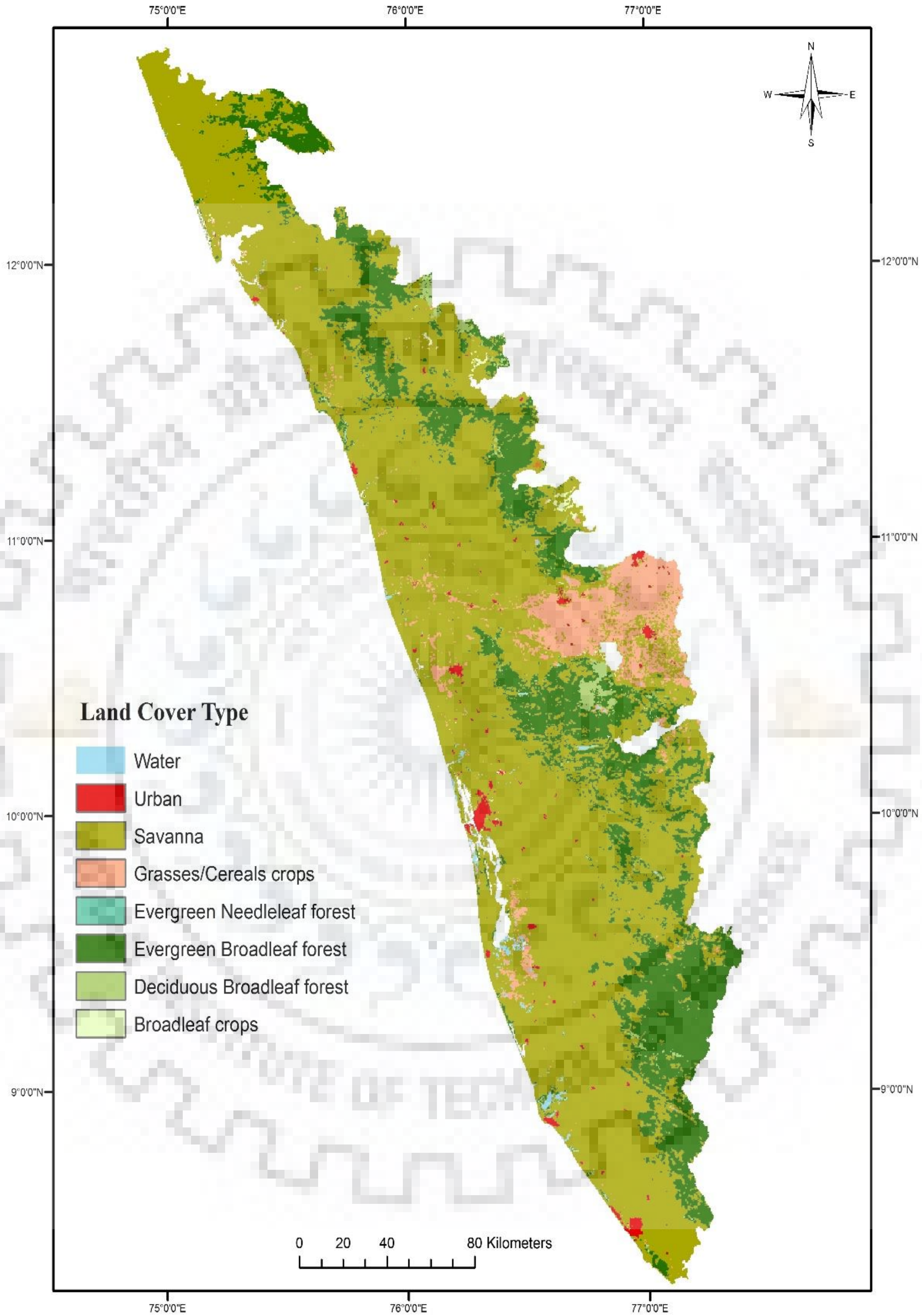

Figure 3.7 Land cover (MODIS Type 3) map of Study area

3.5 Evapotranspiration (Potential and Actual)

The National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) data like maximum and minimum temperature, humidity and wind for the period of 1979 to 2014 were used as input data to calculate potential evapotranspiration. CROPWAT 8.0 model provided by the United Nations Food and Agriculture Organization (FAO) that gives the ET and irrigation water requirements of crops was used. Penman-Monteith approach was used in this study to calculate potential evapotranspiration. As mentioned earlier, MODIS land cover data Type 3 classification scheme were used. The crop coefficient (Kc) value are taken from '*Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56*'.

The average crop coefficient calculated for each land cover was determined and using weighted average method to get crop coefficient value for each catchment. Actual evapotranspiration is calculated using the equation:

$$ET_a = K_c * ET_o \tag{3.2}$$

Where, ET_a = Actual evapotranspiration,

K_c = Crop Coefficient

ET_o = Potential evapotranspiration

Potential evapotranspiration (ET_o), crop coefficient (Kc), actual evapotranspiration (ETa) for 19 gauged catchments are shown in **Appendices A.1**.

3.6 Climatic Classification

Using gauged catchment, climatic classification was conducted primarily based on the hydro-climatic place in the catchment. Budyko curve approach is used for developing climate classification scheme which is used to anticipate evaporation as a component of dryness index. Budyko curve is a plot of the proportion of normal actual annual evapotranspiration to mean annual precipitation which is a component of dryness index. Three climatic limits i.e., dryness index between zero and 0.7 used to be considered as wet, between 1.3 and infinity was seen as dry and between 0.7 and 1.3 have been seen as medium classification (i.e. not too moist nor too dry) (*Abimbola et al., 2017*).

A number of studies have been done on finding this relation. Classical studies were done by Schreiber [1904], Ol'dekop [1911], Budyko [1974], Turc [1954], and Pike [1964]. Schreiber [1904], Pike [1964] and Budyko [1974] are used in this study and their equations are summarized in Table 3.

Table 3.3 Different Budyko curves as a function of the Aridity Index ϕ

Equation	Reference
$\frac{E_a}{P} = 1 - exp^{-\emptyset}$	Schreiber (1904)
$\frac{E_a}{P} = \frac{1}{\sqrt{1 + (\frac{1}{\emptyset})^2}}$	Pike (1964)
$\frac{E_a}{P} = [\emptyset \tanh(\frac{1}{\emptyset})(exp^{-\emptyset})]^{0.5}$	Budyko (1974)

A climatic classification based on the observation i.e. the ratio of ETo/PREC and ETa/PREC are calculated and plotted as shown in Figure 3.8. It tends to be viewed from the anticipate that all the gauged catchments are in the moist category with dry report in the range of 0.38 and 0.69. Regardless of the way that each of the nineteen gauged catchments fall inside the moist classification, they have been simply utilized in one pool for regionalization investigation on account that they have virtually equal to evaporative records (somewhere in the range of 0.20 and 0.64). This verifiable the likeness of atmosphere in the catchments with respect to relative water and energy accessibility and consequently utilized of different local conditions to demonstrate parameters for medium and dry catchments isn't required. Subsequently, each one of the nineteen gauged catchments had been chosen as donor catchments and the total parameter set had been used to be migrated from these catchments to the ungauged catchments. The 1:1 line elucidate the available energy limit to evapotranspiration (ETo/ PREC), while the horizontal line elucidate the available water limit (ETa / PREC).

ETo/ PREC and ETa / PREC for 19 gauged catchments are shown in **Appendices A.1**.

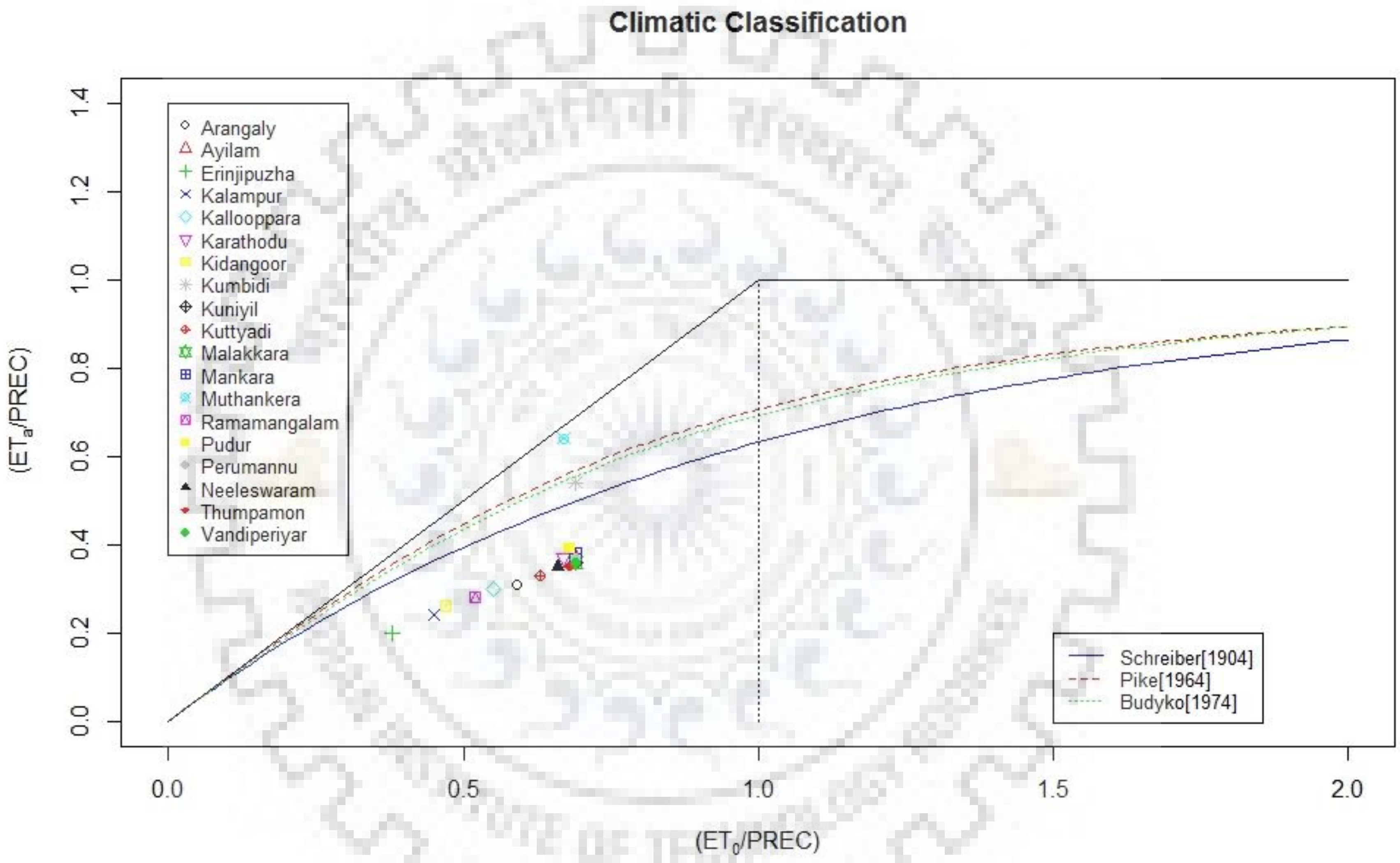

Figure 3.8 Climatic classification based on observation from gauged catchments

3.7 Summary and abbreviations of catchment characteristics

The catchments characteristics of gauged and ungauged catchments were computed using a DEM. These are summarized in Table 3.6.

Table 3.6 Summary of catchments characteristics of gauged and ungauged catchments

	Gauged			Ungauged		
	Min	Mean	Max	Min	Mean	Max
Area (km²)	242	1537.15	5949	2	379.35	7224
Perimeter (km)	83	269.36	609	7	105	823
Mean Elevation (m)	111.08	451.052	1127.04	0.088	77.96	1441.73
Minimum Elevation (m)	2	81.579	772	0	2.509	800
Maximum Elevation (m)	1137	1963.84	2692	1	455.28	2692
Range Elevation (m)	1134	1882.26	2688	1	452.77	2690
Slope (%)	0.007	18.28	47.31	0.008	9.162	72.76
Precipitation (mm)	921.46	2102.44	4062.12	2406.3	4058.9	5021.55
ETpot (mm)	79.36	124.74	184.14	80.6	128.07	184.45
River Density (km/km²)	1.433	3.187	3.428	1.117	3.212	5
Water bodies (%)	0	0.076	0.352	0.037	2.953	33.566
Grasses/Cereal Crops (%)	0	7.338	55.484	0.063	2.953	34.234
Broadleaf Crops (%)	0	0.07	0.711	0.032	0.088	8.786
Savanna (%)	30.306	62.051	97.973	10.101	78.756	100
Evergreen Broadleaf forest (%)	1.88	29.124	68.443	0.14	7.644	59.091
Decidous Broadleaf forest (%)	0	1.019	10.234	0.333	0.176	27.429
Evergreen Needleleaf forest (%)	0	0.002	0.039	0.017	0	0.017

The details of gauged and ungauged catchments characteristics are shown in **Appendices A.3 & A.4**.

The abbreviations and units used for catchment characteristics for multiple regressions analysis are shown in Table 3.7.

Table 3.7 Abbreviations and units of all catchment characteristics for multiple regressions

Symbols	Characteristic description	Unit
Physiographic		
A	Catchment area	km²
C_p	Catchment perimeter	km
D	Drainage Density	km/km²
H^-	Minimum catchment elevation	m
H^+	Maximum catchment elevation	m
H_m	Mean catchment elevation	m
H_R	Range of catchment elevation	m
C_S	Mean catchment slope	%
Climatic		
PREC	Mean annual precipitation	
ET_{pot}	Mean annual potential evapotranspiration	
Hydrologic		
q_p	Streamflow (p=5%, 50%, 90% and 95%)	l/s km²
FDC_{slp}	Slope of flow duration curve	(-)
Land cover		
L_W	Percent of water bodies	%
L_{GC}	Percent of Grasses/Cereal crops	%
L_{BC}	Percent of Broadleaf crops	%
L_S	Percent of Savanna	%
L_{EB}	Percent of Evergreen Broadleaf forest	%
L_{DB}	Percent of Deciduous Broadleaf forest	%
L_{EN}	Percent of Evergreen Needleleaf forest	%
L_U	Percent of Urban	%

3.8 Flow quantiles

For predicting flow magnitude in ungauged catchment, 5, 50, 90 and 95 percent flow duration i.e., q_5, q_{50}, q_{90} and q_{95}, and also with the flow duration curve (FDC_{slp}) of the nineteen gauged catchments were estimated. The observed stream flows were arranged in descending order and then ranked accordingly. The exceedance of probability was calculated by $P = m/(n+1)$, where 'P' is the probability of exceedance, 'm' is the rank and 'n' is the number of observations. The discharge, q (m^3/sec) was standardized to discharge q (l/s/km^2) with each corresponding catchment areas to make the flow quantile more comparable. The flow quantile(s) (q_5, q_{50}, q_{90} and q_{95}) was calculated and shown in the Table 3.8.

Table 3.8 Flow quantiles of gauged catchments

Location	**q_5 (l/s / km²)**	**q_{50} (l/s / km²)**	**q_{90} (l/s / km²)**	**q_{95} (l/s / km²)**
Vandiperiyar	39.70	6.42	1.17	0.47
Thumpamon	208.37	50.77	11.82	7.90
Ramamangalam	3.22	1.37	0.67	0.57
Pudur	40.52	4.57	0.70	0.46
Perumannu	673.25	91.99	2.48	1.08
Neeleswaram	200.17	60.48	14.00	7.36
Muthankera	333.65	46.63	2.86	1.64
Mankara	45.70	4.37	0.38	0.16
Malakkara	307.21	85.74	29.65	22.95
Kuttyadi	728.31	144.45	9.14	7.69
Kuniyil	422.24	77.45	27.52	18.85
Kumbidi	133.30	21.08	1.36	0.53
Kidangoor	457.80	95.55	12.90	6.41
Karathodu	348.31	75.98	20.76	12.96
Kalampur	478.28	132.18	31.15	19.30
Erinjipuzha	437.94	75.23	5.79	2.09
Ayilam	191.79	48.18	16.36	12.15
Kallooppara	371.96	83.53	13.50	7.37
Arangaly	231.94	50.06	13.92	5.10

3.9 Flow Duration Curves

An empirical long-term flow-duration curve (FDC) is the tribute of the empirical cumulative distribution function of daily stream flows established on the complete streamflow record available for the catchment of interest. Flow Duration Curves was constructed by plotting (plot in log-normal scale) each ordered observation versus its corresponding probability of exceedance, which is generally dimensionless. The duration of the ith observation in the ordered discharge coincides with an estimate of the exceedance probability of the observation. Then FDC_{slp} were plotted and the slope of each flow duration curve was fitted with exponential trend line for each gauged catchment (**Appendices A.2**) and summarized in Table

3.9. FDC_{slp} for the nineteen gauged catchments are summarized in Figure 3.9 (a & b). The shape of a flow duration curve gives a measurement of fluctuation and is dictated by hydrologic and geologic attributes of the gauged catchment.

Table 3.9 Flow duration curve (slope) of gauged catchments

Location	**FDC_{slp} (−)**
Vandiperiyar	4.20
Thumpamon	3.39
Ramamangalam	1.78
Pudur	4.87
Perumannu	6.99
Neeleswaram	3.16
Muthankera	5.38
Mankara	5.59
Malakkara	2.66
Kuttyadi	4.88
Kuniyil	3.01
Kumbidi	5.33
Kidangoor	4.26
Karathodu	3.53
Kalampur	3.21
Erinjipuzha	5.26
Ayilam	2.94
Kallooppara	3.95
Arangaly	3.14

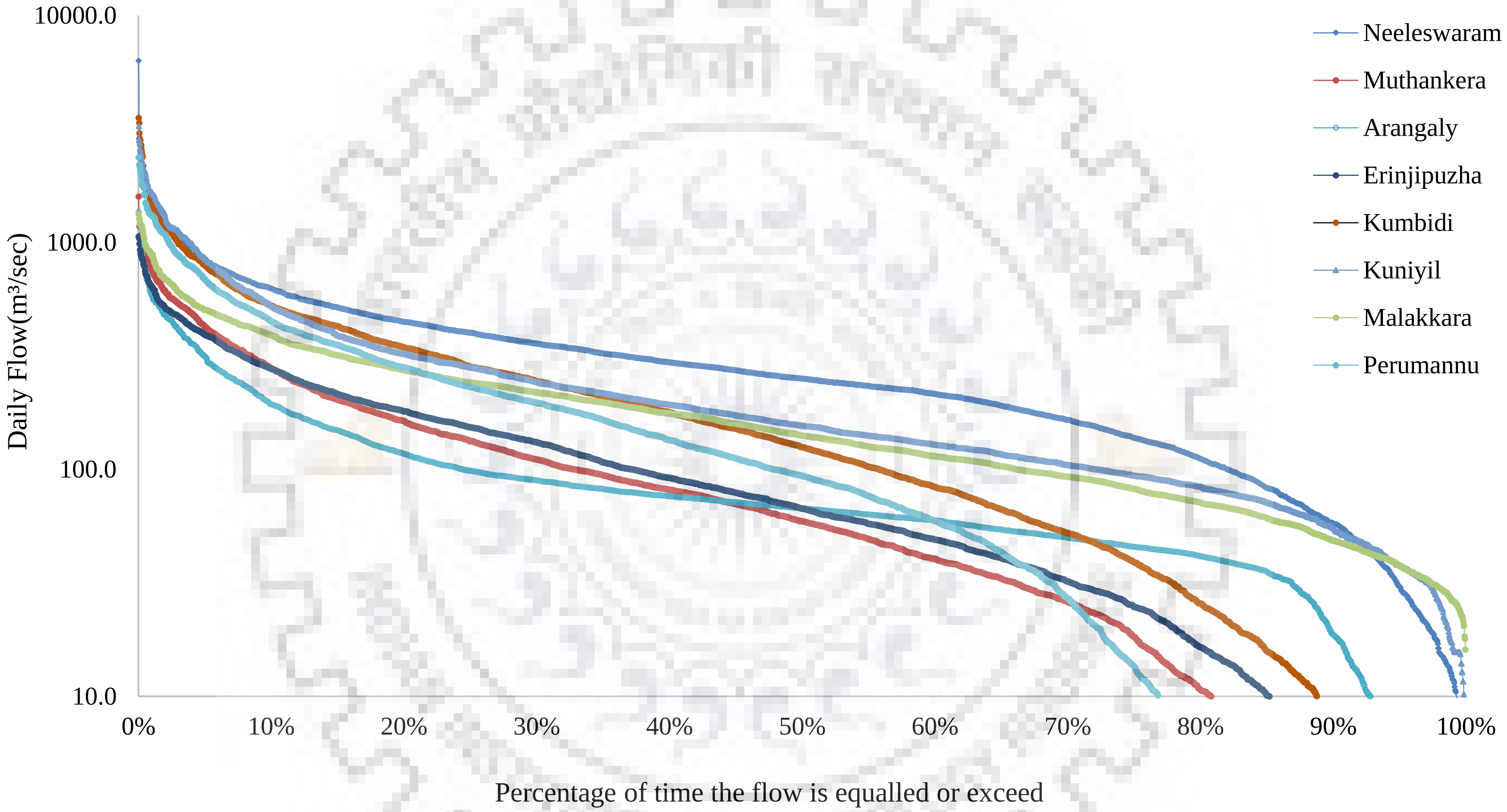

Figure 3.9 (a) Flow duration curves for nineteen gauged catchments

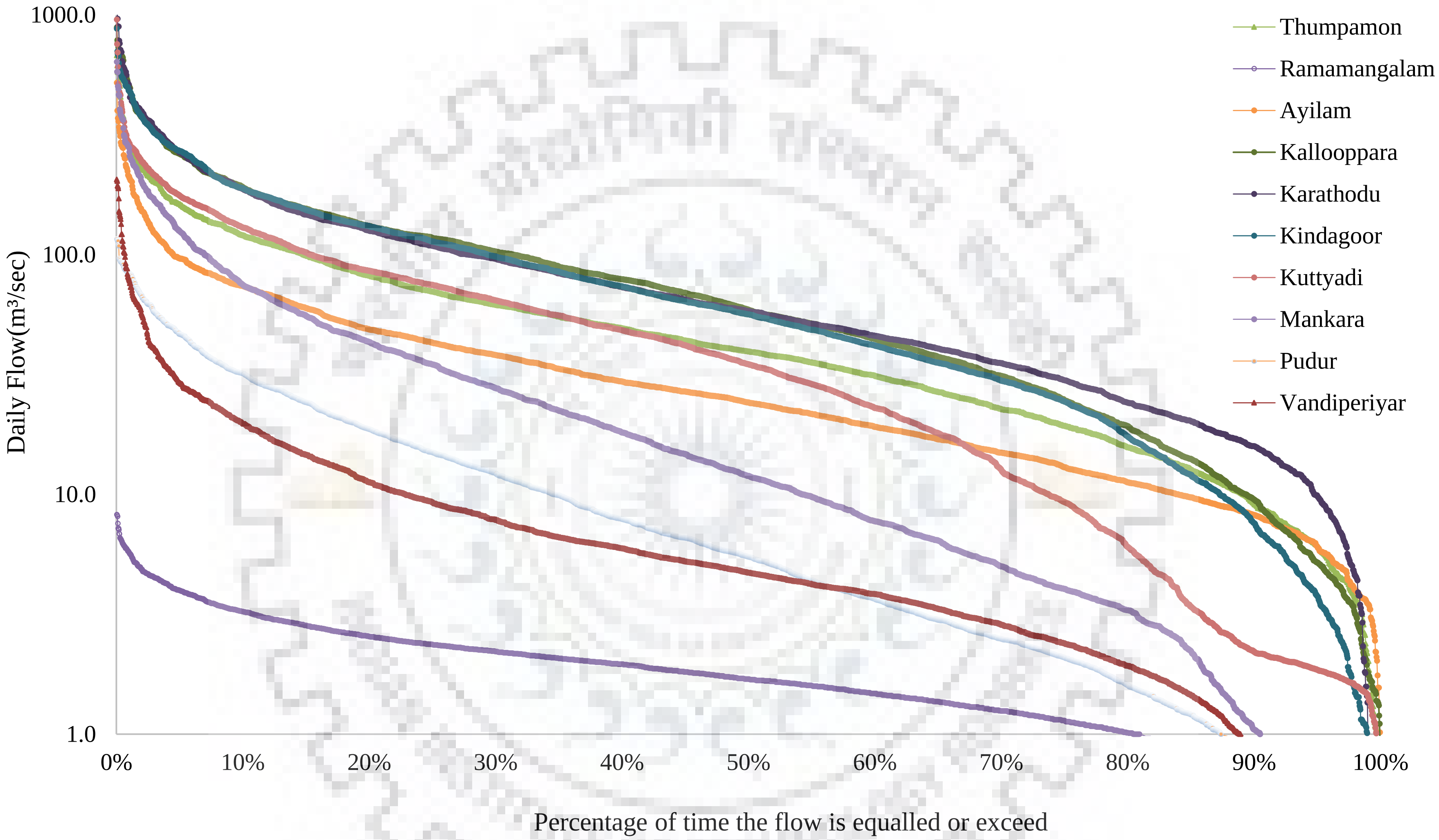

Figure 3.9 (b) Flow duration curves for nineteen gauged catchments

3.10 Stepwise Regression

The 5-, 50-, 90- and 95-percent-flow duration (q_{5}, q_{50}, q_{90}, q_{95},) notwithstanding the slope of the flow duration curve (FDC$_{slp}$) which have been evaluated prior for the nineteen gauging stations had been used as dependent variables for regression analysis. Specific high flow discharges qi (l/s/ km^{2}) had been figured by using standardizing Qi values through individual catchment areas to make the flow quantile values more comparable throughout scales (Table 3.10).

Table 3.10 Flow quantiles and index of gauged catchments

Gauging Station	**q_{5} (l/s / km^{2})**	**q_{50} (l/s / km^{2})**	**q_{90} (l/s / km^{2})**	**q_{95} (l/s / km^{2})**	**FDC$_{slp}$ (-)**
Vandiperiyar	39.70	6.42	1.17	0.47	4.2
Thumpamon	208.37	50.77	11.82	7.90	3.39
Ramamangalam	3.22	1.37	0.67	0.57	1.78
Pudur	40.52	4.57	0.70	0.46	4.87
Perumannu	673.25	91.99	2.48	1.08	6.99
Neeleswaram	200.17	60.48	14.00	7.36	3.16
Muthankera	333.65	46.63	2.86	1.64	5.38
Mankara	45.70	4.37	0.38	0.16	5.59
Malakkara	307.21	85.74	29.65	22.95	2.66
Kuttyadi	728.31	144.45	9.14	7.69	4.88
Kuniyil	422.24	77.45	27.52	18.85	3.01
Kumbidi	133.30	21.08	1.36	0.53	5.33
Kidangoor	457.80	95.55	12.90	6.41	4.26
Karathodu	348.31	75.98	20.76	12.96	3.53
Kalampur	478.28	132.18	31.15	19.30	3.21
Erinjipuzha	437.94	75.23	5.79	2.09	5.26
Ayilam	191.79	48.18	16.36	12.15	2.94
Kallooppara	371.96	83.53	13.50	7.37	3.95
Arangaly	231.94	50.06	13.92	5.10	3.14

In the wake of choosing the stream flow parameters (flow quantiles and index) and physiographic qualities of the selected gauged catchments, a multiple regression analysis, which is a factual methodology for investigating the connection between a structured or dependent and multiple independent (explanatory) elements or variables, used to be utilized. The most settled multiple regression conditions rely on linear relationships such as a logarithmic equation are also utilized. Equations (3.3) and (3.4) exhibit situations of linear non-transformed and linear log-transformed multiple regressions dependent on three independent factors. Both non-transformed and log- transformed, which avoids heteroscedasticity and non-typicality of the residuals of the regressions, have been utilized in this study.

$$Y' = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \tag{3.3}$$

$$\log(Y') = \log(\beta_0) + \beta_1 \log(X_1) + \beta_2 \log(X_2) + \beta_3 \log(X_3) \tag{3.4}$$

Where

Y' - estimated dependent variable by the regression equation,

β_0 - intercept which is a constant value, and

βi (i = 1, 2, 3) - regression coefficients which give the effects of the independent variables Xi on the dependent variable.

Regression models had been matched to all gauged catchments for predicting the flow quantiles (q_5, q_{50}, q_{90} and q_{95}) and index (FDC_{slp}). This was accomplished depend on the catchment characteristics, and in ascending order of the quantity of explanatory variables added using forward stepwise-regression procedure. Forward stepwise-multiple regression was completed utilizing the use of the R statistical computing software. It was once begun by using a simple linear model for predicting the parameter as a consistent value (i.e. beginning with no variables in the model) for each flow parameter. The strategy includes an extra explanatory variable (assuming any) to the model at every progression, choosing the variable that limits the Akaike information criterion (AIC). AIC is a measure of the relative quality of a statistical model (*Lindsey and Sheather, 2010*). As proven in Figure 3.10, the forward stepwise method is repeated till no further decreases in AIC can be acquired. The satisfactory set of explanatory variables (catchment characteristics) and the estimates of βi, (with i = 0, 1...., N) for the regression models have been analyzed using an ordinary least-squares (OLS) algorithm.

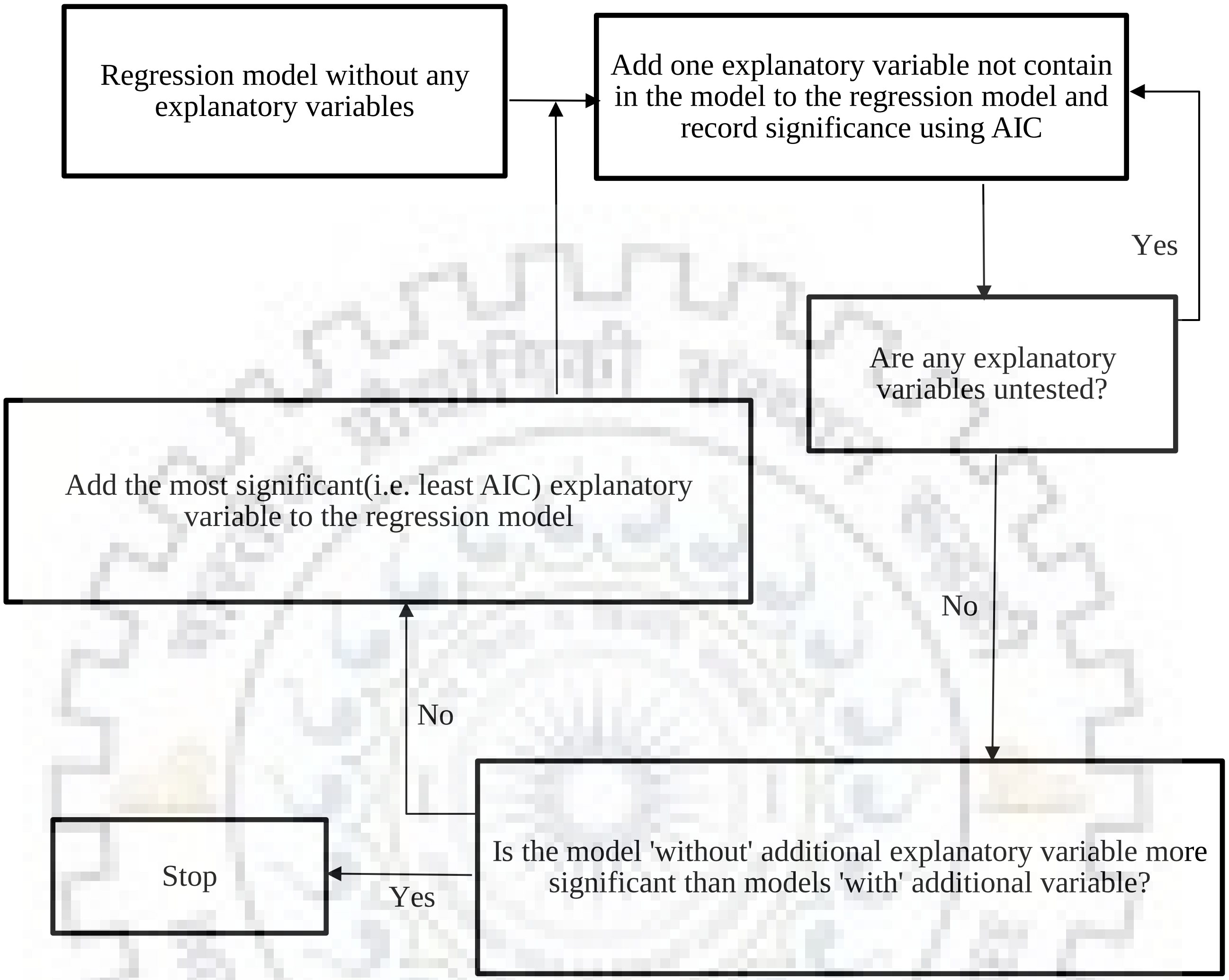

Figure 3.10 Flowchart of the forward stepwise regression procedure

The prediction accuracy of the non-transformed and log-transformed models used to be evaluated and analyzed using the R², the mean absolute error (MAE), root mean square error (RMSE) and Nash-Sutcliffe Efficiency (NSE). Equations for the comparison statistics are shown under.

$$R^2 = \frac{\sum_i (\hat{x}_i - \bar{x})^2}{\sum_i (x_i - \bar{x})^2} \tag{3.5}$$

$$MAE = \frac{\sum_i |\hat{x}_i - \bar{x}|}{N} \tag{3.6}$$

$$RMSE = \sqrt{\frac{\sum_i (\hat{x}_i - x_i)^2}{N}} \tag{3.7}$$

$$NSE = 1 - \frac{\sum_i (x_i - \hat{x}_i)^2}{\sum_i (x_i - \bar{x})^2} \tag{3.8}$$

Where, x_i = observed values

$\hat{x}_i$ = predicted values

$\bar{x}$ = observed mean value

N = number of catchments

The corrected Akaike information criterion (AICc) and Leave-one-out cross-validation (LOOCV) used to be examined for models' performance so as to assume about the non-transformed and log-transformed multi-regression models and furthermore to pick out the most suitable model. AIC is asymptotically similar to LOOCV when N is massive (*Chen et al., 2013; Simon et al., 2003*). Since N is significantly less than the total range of explanatory variables (p) regarded in this study, AICc which is prescribed when the quantity of observations(N) is below a couple of times the number of parameters (*Burnham and Anderson, 2002*). It is identified with the normal AIC with the aid of

$$AIC_C = AIC + \frac{2_p\, X\, (N-1)}{N - (p+1)} \tag{3.9}$$

and

$$AIC = 2p - 2\ln(L) \tag{3.10}$$

Where, L is the maximized value of the probability work for the evaluated model. AIC values for all models were obtained using R programming.

Leave-one-out cross-validation (LOOCV) is the degenerate case of K-Fold cross-validation, where K is chosen as the total number of catchments (N). In this methodology, every gauged catchment was once utilized as ungauged and the parameters for that catchment was evaluated from remaining gauged catchments. The approach was once repeated for each catchment and the LOOCV was computed for every flow parameter as the mean square error using R statistical computing software. While AICc penalizes for the extent of explanatory variables and small sample size, AICc and LOOCV do not always prompt a comparable model being chosen for a small sample size. Subsequently, LOOCV is given preferences in this study in model selection on account that all the uncertainty aspects which contain input information uncertainty, model uncertainty and parameter uncertainty (*Wagener and Montanari, 2011*) are consider. At the point when a case emerges where two or more models have practically or almost similar LOOCV values, the model with the most minimal AICc among them is chosen provided it has the least quantity of explanatory variables.

In regards to the physical connections between physiographic and climatic variables, a prior knowledge is required for assessing the magnitude of the explanatory variables identified for anticipating the different stream flow parameters. Unfortunately, these connections are not defined properly at catchment scale. Sefton and Howarth (1998) expressed that the identified connections are simply genuine even though forward stepwise regression evaluation can distinguish the physiographic and climatic factors that are good predictors of the stream flow parameters. A portion of these connections may essentially be an accident of the records even though it is measurably significant. While a few connections may also have solid physical significance, others would possibly be replacement predictors or may represent process interactions which cannot be clarified by current knowledge of the connections between hydrological processes and parameters controlling them at the catchment scale (*Mohamoud, 2008*).

Chapter 4
Results and Discussions

4.1 General

Regression models had been fit to all nineteen gauged catchments for predicting the flow quantiles (q_5, q_{50}, q_{90} and q_{95}) and index (FDC_{slp}). Forward stepwise-multiple regression procedure was carried out utilizing the use of the R statistical computing software. Non-transformed regression model and log-transformed regression model were utilized. The log- transformed model had been analyzed into two different cases as case 1 and case 2. Both the non-transformed and log-transformed model had been evaluated and analyzed using the R², MAE, RMSE and NSE. The AICc and LOOCV had been used to examined the models' performance. The details of the analysis are as follows.

4.2 Non-transformed regression model

All catchment parameters and climatic variables were tested using non-transformed stepwise-regression model. Following equations (4.1, 4.2, 4.3, 4.4 and 4.5) were obtained giving good correlation:

$$q_5 = 2907 + \{-0.0022*PREC - 184.7*D - 0.5956*H^- - 1.229*C_p - 14.87*ET_{pot} + 0.397*H_m\} \tag{4.1}$$

$$q_{50} = 383.57 + \{-0.0014*PREC - 0.073*H^- - 1.199*L_{GC} - 2.443*ET_{pot}\} \tag{4.2}$$

$$q_{90} = -49.34 + \{611.58*L_{EN} - 0.2914*L_{GC} + 0.405*ET_{pot} - 0.012*H^- + 0.66*C_s\} \tag{4.3}$$

$$q_{95} = -41.73 + \{512.15*L_{EN} - 0.187*L_{GC} + 0.339*ET_{pot} - 0.007*H^- + 0.403*C_s\} \tag{4.4}$$

$$FDC_{slp} = 26.71 + \{0.02*L_{GC} - 0.18*ET_{pot} - 98.03*L_{EN} + 0.0011*H^+ - 0.13*C_s - 2.43*L_W\} \tag{4.5}$$

The foremost non-transformed stepwise-regression model for each flow parameter was chosen based on LOOCV. In the event that if a case emerges whereby at least two models have basically the identical as LOOCV values, the model with the most decreased AICc among them is chosen in the event that it additionally has the lowest range of explanatory variables. For predicting high flows (q_5), it was perceived that precipitation (PREC), potential evapotranspiration (ET_{pot}), mean elevation (H_m), drainage density (D), minimum elevation (H^-) and catchment perimeter (C_p) are the explanatory variables. For median flow (q_{50}), it was perceived that precipitation (PREC), potential evapotranspiration (ET_{pot}), percent of grasses/crop cover (L_{GC}) and minimum elevation (H^-) are the dominant explanatory variables. In low flows (q_{90} and q_{95}) prediction, percent of evergreen needle leaf forest (L_{EN}), percent of grasses/crop cover

(L_{GC}), potential evapotranspiration (ET_{pot}), minimum elevation (H^-), and catchment slope (Cs) come into view in the stepwise model.

The significant explanatory variables for estimating the slope of flow duration curve (FDC_{slp}) using non-transformed model uses grasses/crop cover (L_{GC}), potential evapotranspiration (ET_{pot}), percent of evergreen needle leaf forest (L_{EN}), maximum elevation (H^+), catchment slope (Cs) and percent of waterbodies (L_W). For each model, residual standard error, NSE, MAE, RMSE, R^2, AIC, AICc and LOOCV were obtained and shown in Table 4.1.

The non-transformed ordinary least square regression models developed was build up on the assumptions that the residuals (predicted minus observed) are autonomous, homoscedastic and typically dispersed. Since non-transformed linear regression models frequently show heteroscedasticity (*Viglione et al., 2007; Vezza et al., 2010*), logarithmic changes have been utilized on all stream flow parameters and explanatory variables to stay away from heteroscedasticity and non-normality of the residuals of the regressions.

Table 4.1 Summary of Non-transformed Regression models

Parameters	**Explanatory Variables**	**Residual Standard Error**	**NSE**	**MAE**	**RMSE**	**AIC**	**AICc**	**R^2**	**LOOCV**
q_5	PREC, ET_{pot}, H_m, D, H^-, C_p	163.50	0.58	98.34	111.22	254.86	257.36	0.62	41842.20
q_{50}	PREC, ET_{pot}, L_{GC}, H^-	32.13	0.54	17.78	27.58	191.96	193.82	0.65	1025.24
q_{90}	L_{EN}, L_{GC}, Et_{pot}, H^-, C_S	7.50	0.12	5.38	6.52	137.29	139.44	0.61	87.71
q_{95}	L_{EN}, L_{GC}, Et_{pot}, H^-, C_S	5.14	0.62	3.10	4.26	122.94	125.09	0.62	49.13
FDC_{slp}	L_{GC}, ET_{pot}, L_{EN}, H^+, C_S, L_W	0.93	0.65	0.58	0.74	58.51	61.01	0.65	1.80

4.3 Log transformed regression model

Case 1: The best log-transformed stepwise-regression model for each flow parameter were obtained as in equation 4.6, 4.7, 4.8, 4.9 and 4.10 as follows:

$$q_5 = 43.95 + \{-0.19*PREC - 2.38*D - 0.28*L_U - 0.72*C_A - 6.22*ET_{pot} - 0.12*L_{GC}\} \tag{4.6}$$

$$q_{50} = 11.38 + \{-0.024*PREC - 0.156*H^- - 0.44*L_{GC} - 0.646*C_A - 2.36*D\} \tag{4.7}$$

$$q_{90} = 47.72 + \{-1.4*PREC - 0.063*L_{GC} + 1.045*L_W - 6.86*ET_{pot} - 0.524*H^- - 1.242*L_{EN}\} \tag{4.8}$$

$$q_{95} = 48.504 + \{-1.69*PREC - 0.144*L_{GC} + 1.006*L_W - 6.67*ET_{pot} - 0.56*H^- - 1.22*L_{EN}\} \tag{4.9}$$

$$FDC_{slp} = 17.30 + \{-0.17*Cp - 0.64*D - 3.09*ET_{pot} + 0.15*L_W - 0.237*L_B + 0.129*H_R\} \tag{4.10}$$

The best log transformed stepwise-regression model for each flow parameter was chosen on the basis of LOOCV.

For high flows (q_5) prediction, it was observed that precipitation (PREC), potential evapotranspiration (ET_{pot}), drainage density(D), catchment area (C_A) and percent of urban (L_U) are the explanatory variables. For median flow (q_{50}), precipitation (PREC), minimum elevation (H^-), percent of grasses/crop cover (L_{GC}), catchment area (C_A) and drainage density(D) were observed as the dominant explanatory variables. For low flows (q_{90}) prediction, precipitation (PREC), percent of water bodies (L_W), minimum elevation (H^-), potential evapotranspiration (ET_{pot}), percent of evergreen needle leaf forest (L_{EN}) and maximum elevation (H^+) appears in the stepwise model. And for low flows (q_{95}), precipitation (PREC), percent of water bodies (L_W), minimum elevation (H^-), potential evapotranspiration (ET_{pot}) and percent of evergreen needle leaf forest (L_{EN}) are the dominant explanatory variables.

The significant explanatory variables for estimating the slope of flow duration curve (FDC_{slp}) using non-transformed model are percent of broadleaf (L_B), drainage density (D), percent of waterbodies (L_W), catchment perimeter (Cp), potential evapotranspiration (ET_{pot}) and elevation range (H_R). For each model, residual standard error, NSE, MAE, RMSE, R^2, AIC, AICc and LOOCV were obtained and shown in Table 4.2. Precipitation (PREC) and percent of grasses/crop cover was observed as the dominant explanatory variables for all flow quantiles while elevation characteristics and land cover had the most significance for FDC_{slp} prediction.

Case 2: The best log-transformed stepwise-regression model for flow parameters of q_5 and q_{50} were obtained as in equation 4.11 and 4.12 with more explanatory variables as follows:

$$q_5 = 130.355 + \{-0.98*PREC - 3.64*D + 3.9*H_R - 2.33*C_A - 28.70*ET_{pot} - 0.46*L_{GC} + 0.78*L_W - 0.69*H^- + 3.14*Cp + 0.54*L_{DB} - 0.44*L_B\} \tag{4.11}$$

$$q_{50} = 102.36 + \{-0.61*PREC - 0.88*H_m - 0.62*L_{GC} - 2.38*C_A - 3.81*D - 22.64*ET_{pot} + 3.41*H_R + 3.03*C_p + 0.33*L_{DB} - 0.40*L_B + 0.59*L_W\} \tag{4.12}$$

For high flows (q_5) prediction, it was observed that precipitation (PREC), potential evapotranspiration (ET_{pot}), drainage density(D), catchment area (C_A), minimum elevation (H^-), percent of grasses/crop cover (L_{GC}), percent of waterbodies (L_W), catchment perimeter (Cp), percent of deciduous broadleaf forest (L_{DB}) and percent of broadleaf forest (L_B) are the explanatory variables.

For median flow (q_{50}), it was observed that precipitation (PREC), mean elevation (H_m), percent of grasses/crop cover (L_{GC}), catchment area (C_A) and drainage density(D), potential evapotranspiration (ET_{pot}), elevation range (H_R), catchment perimeter (Cp), percent of deciduous broadleaf forest (L_{DB}), percent of broadleaf forest (L_B) and percent of waterbodies (L_W) are the dominant explanatory variables.

Other flow parameter i.e, q_{90} an q_{95} and also FDC_{slp} are same as in Case 1. For each model, residual standard error, NSE, MAE, RMSE, R², AIC, AICc and LOOCV were obtained and shown in Table 4.3. It can be seen that different land cover type contribute to the explanatory variable which increase the efficiency value.

Table 4.2. Summary of Log-transformed Regression models (Case 1)

Parameters	Explanatory Variables	Residual Standard Error	NSE	MAE	RMSE	AIC	AICc	R^2	LOOCV
q_5	PREC, D, Et_{pot}, C_A, L_U, L_{GC}	1.32	0.53	107.72	138.61	71.93	74.43	0.60	2.01
q_{50}	PREC, D, C_A, L_{GC}, H^-	1.15	0.55	22.707	27.09	64.84	74.44	0.63	1.62
q_{90}	PREC, L_W, H^-, L_{GC}, ET_{pot}, L_{EN}	0.59	0.70	3.34	5.38	41.35	44.26	0.71	1.45
q_{95}	PREC, L_W, H^-, L_{GC}, ET_{pot}, L_{EN}	0.69	0.75	2.09	3.48	47.19	49.69	0.76	1.60
FDC_{slp}	L_B, D, L_W, Cp, ET_{pot}, H_R	0.22	0.92	0.30	0.36	3.98	6.48	0.92	0.09

Table 4.3 Summary of Log-transformed Regression models (Case 2)

Parameters	**Explanatory Variables**	**Residual Standard Error**	**NSE**	**MAE**	**RMSE**	**AIC**	**AICc**	**R^2**	**LOOCV**
q_5	PREC, D, Et_{pot}, C_A, L_B, L_{GC}, H_m, H_R, L_W, L_{DB}, C_p	0.69	0.77	72.32	97.73	46.75	52.46	0.80	10.30
q_{50}	PREC, L_W, ET_{pot}, L_{GC}, H_m, C_A, D, C_p, L_B, L_{DB}, H_R	0.58	0.74	14.016	20.76	40.43	74.44	0.75	7.48
q_{90}	PREC, L_W, H^-, L_{GC}, Et_{pot}, L_{EN}	0.59	0.70	3.34	5.38	41.35	43.85	0.71	1.45
q_{95}	PREC, L_W, H^-, L_{GC}, Et_{pot}, L_{EN}	0.69	0.75	2.09	3.48	47.19	49.69	0.76	1.60
FDC_{slp}	L_B, D, L_W, C_p, Et_{pot}, H_R	0.22	0.92	0.30	0.36	3.98	6.48	0.92	0.09

4.4 Discussion & Selection of regression model

The non-transformed and log-transformed models' performances (in terms of LOOCV) was used for making ultimate selection of the normal best-performing regression models. LOOCV values had been usually smaller for log-transformed models than for non-transformed models and therefore log transformed model was selected. In log transformed model, case 1 was selected as it has lesser explanatory variables with higher model performance (lesser LOOCV) while case 2 have more explanatory variables with lower performance (as compare to case 1 LOOCV) even though it gives higher NSE value. Models with more explanatory variables normally will have higher fit among predicted and observed values (in phrases of greater R^2 and NSE, and even decrease standard residual error, MAE and RMSE), meanwhile it does not generally recommend that the addition of extra variables improves the predictive performance of models (*Kokkonen et al., 2003*). Regardless of the way that R^2 and NSE are considerably used in numerous studies, their inclination to choose models with extra variables makes them less suitable for prediction than either AIC_C or LOOCV.

The stepwise regression analysis recognized precipitation (PREC), drainage density (D), potential evapotranspiration (ET_{pot}), catchment area (C_A) and percent of urban area (L_U) as the general satisfactory predictors for q_5. The controlling element of excessive flow response of the catchments is the flow concentration process and runoff which is explained with the aid of the determination of D as the explanatory variable. This looks sensible and can be defined through way of the reality that in order to make the values more comparable across scales, particular excessive flow discharges q_5 (l/s/km²) had been computed through standardizing q_5 values with the aid of respective catchment areas. As expected, the correlation between q_5 and D is effective which justify the high D (which additionally depends upon on soil permeability and underlying rock type) and excessive q_5 that is decided in uneven areas and catchments with high vary elevation. The percentage of urban area has a negative correlation ($r = -0.37$) which have an effect on the permeability thus contributing to excessive runoff. Precipitation and a soil permeability are also included in the power law regression model for predicting peak flows in a comparable study made by Laio et al. (2011). ET_{pot} ($r = -0.28$) which is also considered as a controlling water fluxes at the land surfaces of the catchments additionally identified as the significant variables.

The log-transformed model for q_{50} gave the satisfactory explanatory variable as precipitation (PREC), minimum elevation (H^-), drainage density (D), catchment area (C_A) and percent of grasses/crop (L_{GC}). Predictably, q_{50} is positively correlated to D. Small catchments have much less storage in with high drainage density and minimum elevation due to excessive surface runoff and rapid drop in water table (*Rastogi, 1988; Paniconi et al., 2003*) which have an impact in fast draining in the catchments.

The satisfactory model for predicting q_{90} and q_{95} had been the log-transformed model. The climate and physiography of the catchments effect low flow conditions. The identified as the significant variables were precipitation (PREC), percent of waterbodies (L_W), potential evapotranspiration (ET_{pot}) and minimum elevation (H^-), percent of grasses/crop (L_{GC}) and forest cover (L_{EN}) which are controlling water fluxes at the land surfaces of the catchments in dry seasons when there is little precipitation and high evaporation rates. A comparable report for low-flow evaluation (*Flynn, 2003; Wright and Ensminger, 2004*) additionally utilized catchment and climatic characteristics, for example, slope and mean annual precipitation. The effective relationship between precipitation and low flows (q_{90} and q_{95}) in the model is self-evident. There are different methods for storing water in the catchment, for example, in groundwater frameworks, in soil, in lakes, and so on that is discharged at various occasions to the streams and waterways. Of course, the negative type of evapotranspiration shows loss of water from catchments when it increases. The impact of a combination of minimum elevation (H^-), waterbodies (L_W), grasses/crop (L_{GC}) and forest cover (L_{EN}) had been successfully portray a catchment's attributes, which have an impact on the streamflow routine and in this manner assuming a significant role on q_{90} and q_{95} forecast.

The log-transformed model had been selected as the satisfactory model for predicting the slope of flow duration curve (FDC_{slp}). The most significant variables identified for the regionalization of FDC_{slp} are elevation range (H_R), percentage of broadleaf forest (L_B) and waterbodies (L_W), drainage density (D), catchment perimeter (Cp) and potential evapotranspiration (ET_{pot}). As indicated by Castellarin et al. (2013), contemporary research on predictions of flow duration curves rely drastically on measurable techniques, and furthermore topographic elevation (in mountainous areas) is amongst the most regularly utilized indicators of the slope and structure of FDC_{slp}. In this study, it was once considered that elevation range (H_R) is positively correlated to catchment area (C_A) i.e., $r = 0.57$, and that both H_R and C_A are positively correlated to FDC_{slp} which affects catchment reaction time being a bigger catchments stream flow for a greater amount of the time. Along these lines, the applicability of H_R can be ended up being sensible if assumption is made that the FDC slope likely decreases with the region of the catchment due to the fact of larger storage capacities. Not surprisingly, the regression model shows greater FDCslp for catchments with higher percentage of water bodies (L_W) and drainage density (D) since there will be arrival of water to streams and waterways in the midst of low-stream periods. Catchments having an excessive proportion of waterbodies (L_W) are impacted with the aid of overland stream flow and are normally rapidly reacting or 'flashy' catchments. Potential evapotranspiration (ETpot) has a positive exponent that can be depicted through the FDC_{slp} response to vegetation. The level of forest area or grasses/crop area increment in a catchment can lead to reduced high stream flows and much progressively decreased low stream flows (i.e. higher FDC_{slp}). Schofield (1996) and Vertessy (2000) additionally found practically indistinguishable outcomes that in some Australian catchments, deforestation prompted a fast increment of the groundwater table, and related groundwater stream which brought about huge increments in low stream flows.

The developed models utilized in assessing the coefficients of regression are confined to the study area and to the extents in the estimations of the gauged catchment characteristics. A full of uncertainties remains for utilizing the models to assess stream flow parameters of ungauged catchments as the precision of the evaluations may diminish on account of the excessive spatio-temporal heterogeneity of geography and land cover characteristics in the region. For example, the percentage of grasses/crop (L_{GC}) may be very large or small in an ungauged catchment as compared with the gauged catchments percent of L_{GC} that is used in the regression analysis. The regression model would not distinguish the impact of extrapolation if L_{GC} is not chosen as an explanatory variable in the stepwise methodology while exchanging the data to the ungauged catchment. In this way, a caution ought to be taken while assessing the ungauged catchments of interest to see whether the regression models are appropriate for their purpose. Furthermore, new regression models must be built up each time for their intended used so as to apply the strategy to different places around Kerala or whatever other spots which have comparative climate and landscape. Better quality information and more well-gauged stations may additionally supply specific estimates with much less uncertainty (*Snelder et al., 2013*).

4.5 Assessment of flow parameter in ungauged catchments

The predictions of flow parameter in ungauged catchments had been assessed (Figure 4.1- 4.5). Each figure makes use of the identical intervals for comparing the flow quantiles except figure on slope of flow duration curve. The general “best” regional regression model predicted for flow parameter is shown in the figure. The assessment of q_5 and q_{50} in ungauged catchments shows that a larger predicted value found along the coastal area mostly drain in to the Arabian sea. This is because, in most cases and being the most considerable explanatory variable, precipitation increases east to west in the central region to 700–2850 mm. It outstretches greater than 2300 mm in the south-western part, up to 3700–4000 mm in the vicinity of the north-western regions. The state has a higher amount of rainfall along the coastal region of the Arabian sea. Streamflow is greatly reduced during dry seasons, by means of evapotranspiration from the forest, grasses/crop land etc., that retain water from the soil and the groundwater system that diminishes baseflow and furthermore vanishing from waterbodies. The assessment of low flows i.e. q_{90} and q_{95} demonstrates a decreasing trend affecting agriculture and hydropower generation alongside the eastern parts which is mostly mountainous. The eastern region catchments are far from the seaside zone which decreases the impact of local subsurface stream flow system that are adding to baseflow. FDC_{slp} is higher in the south eastern catchments demonstrating a high variable streamflow owing to direct runoff. The lower values of FDC_{slp} are found in the western catchments or along the coastal area that indicates higher contribution and presence of groundwater in these catchments.

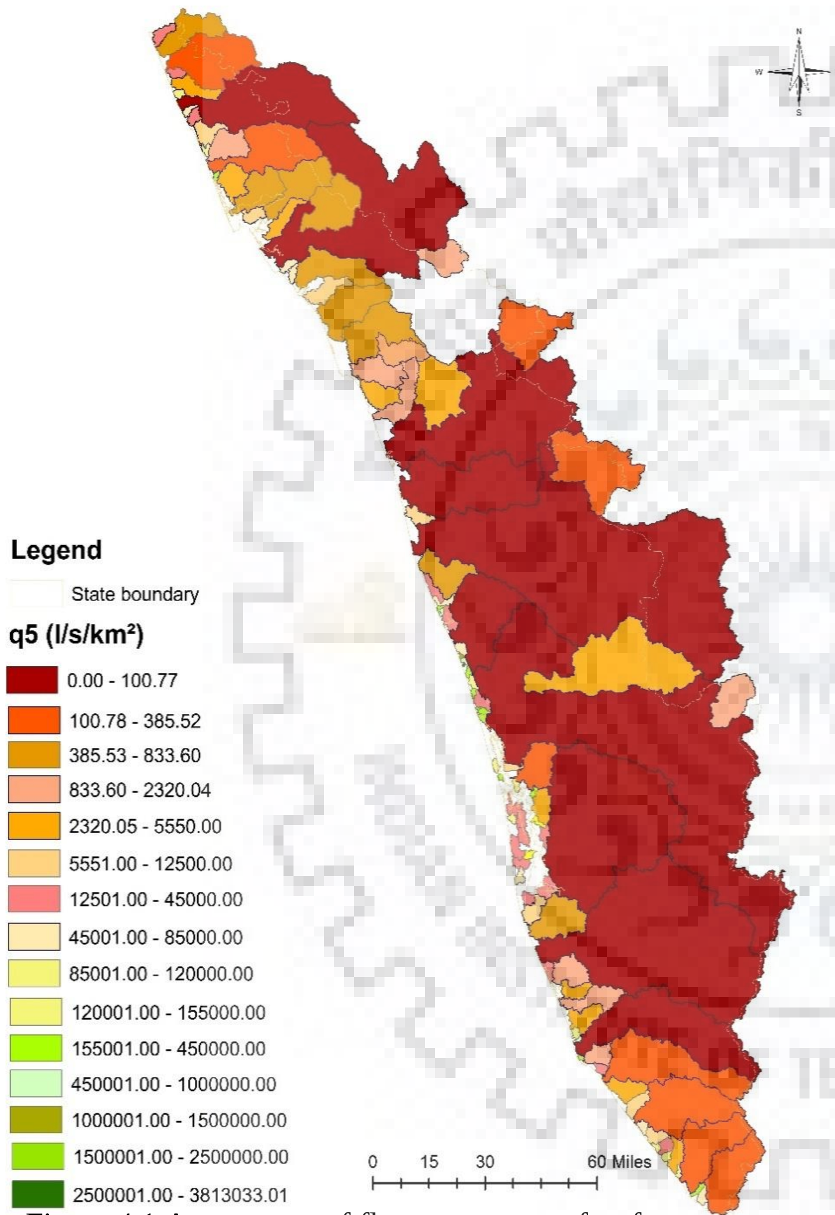

Figure 4.1 Assessment of flow parameter of q_5 for ungauged catchments

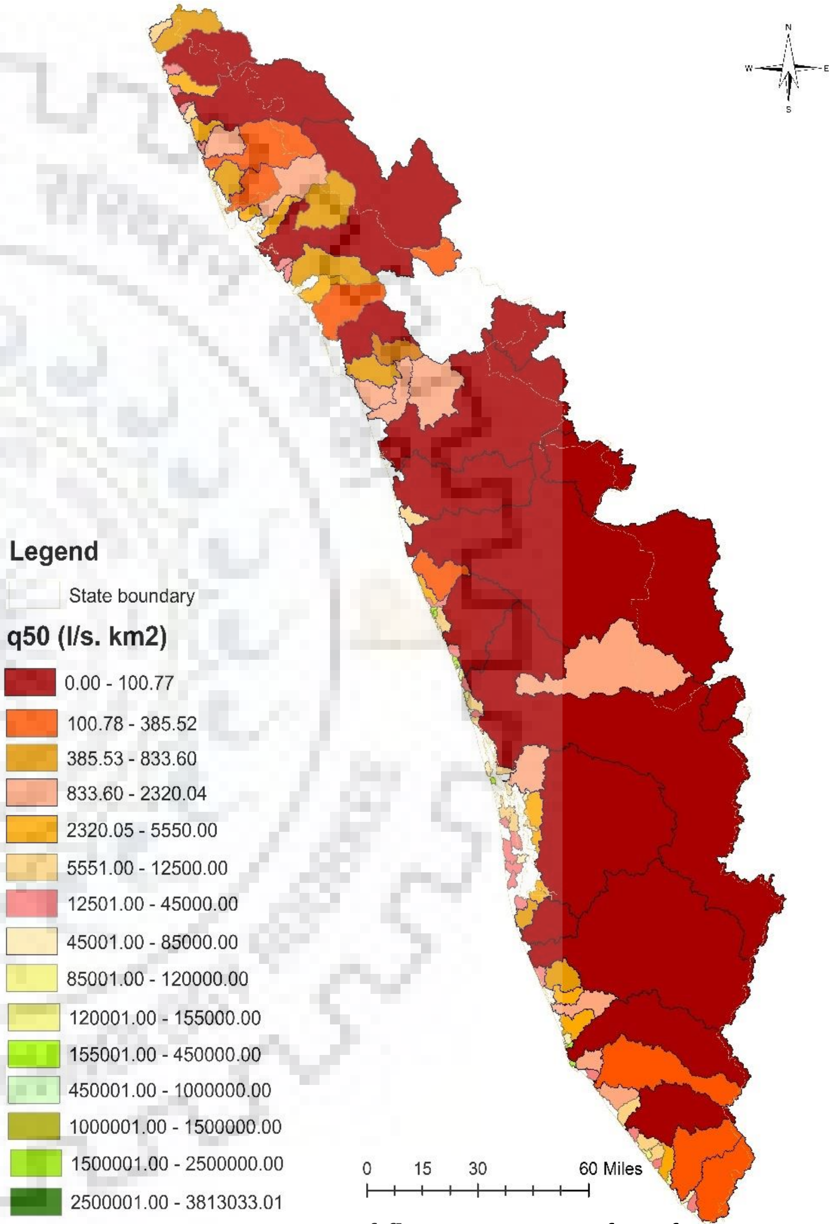

Figure 4.2 Assessment of flow parameter of q_{50} for ungauged catchments

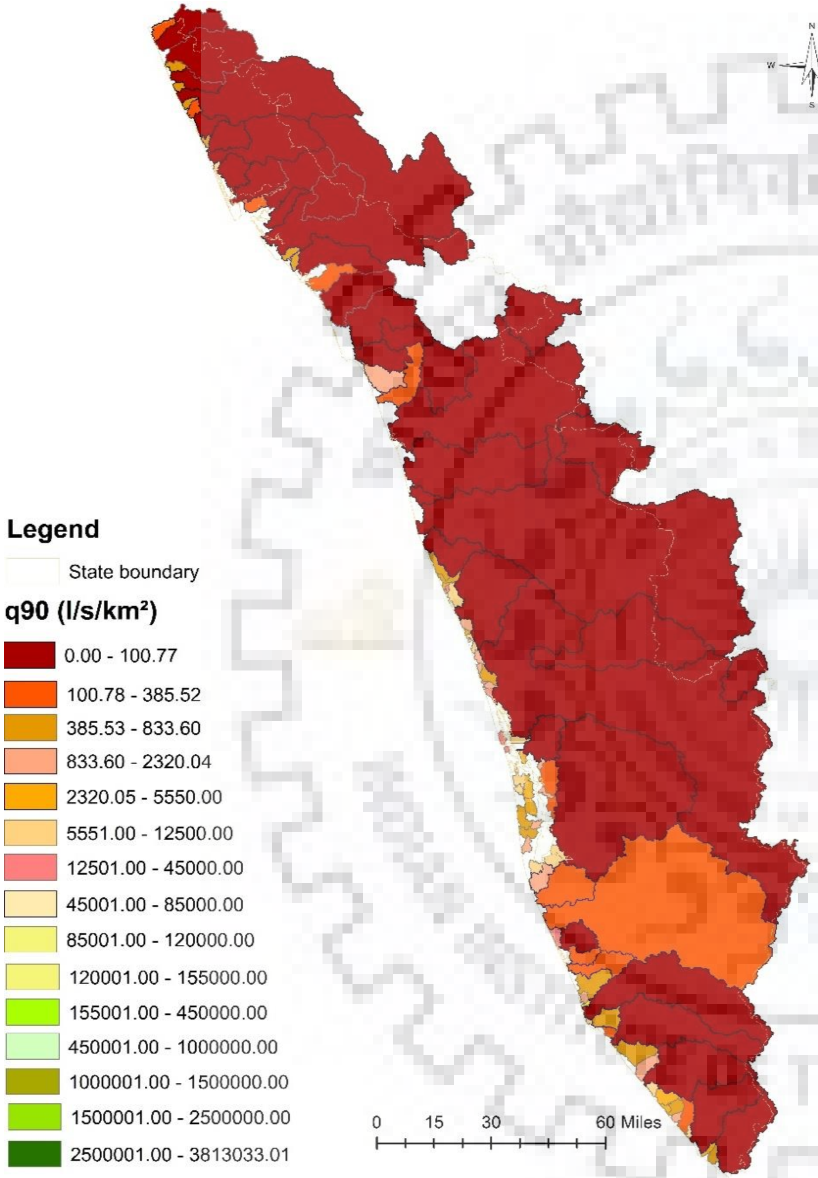

Figure 4.3 Assessment of flow parameter of q_{90} for ungauged catchments

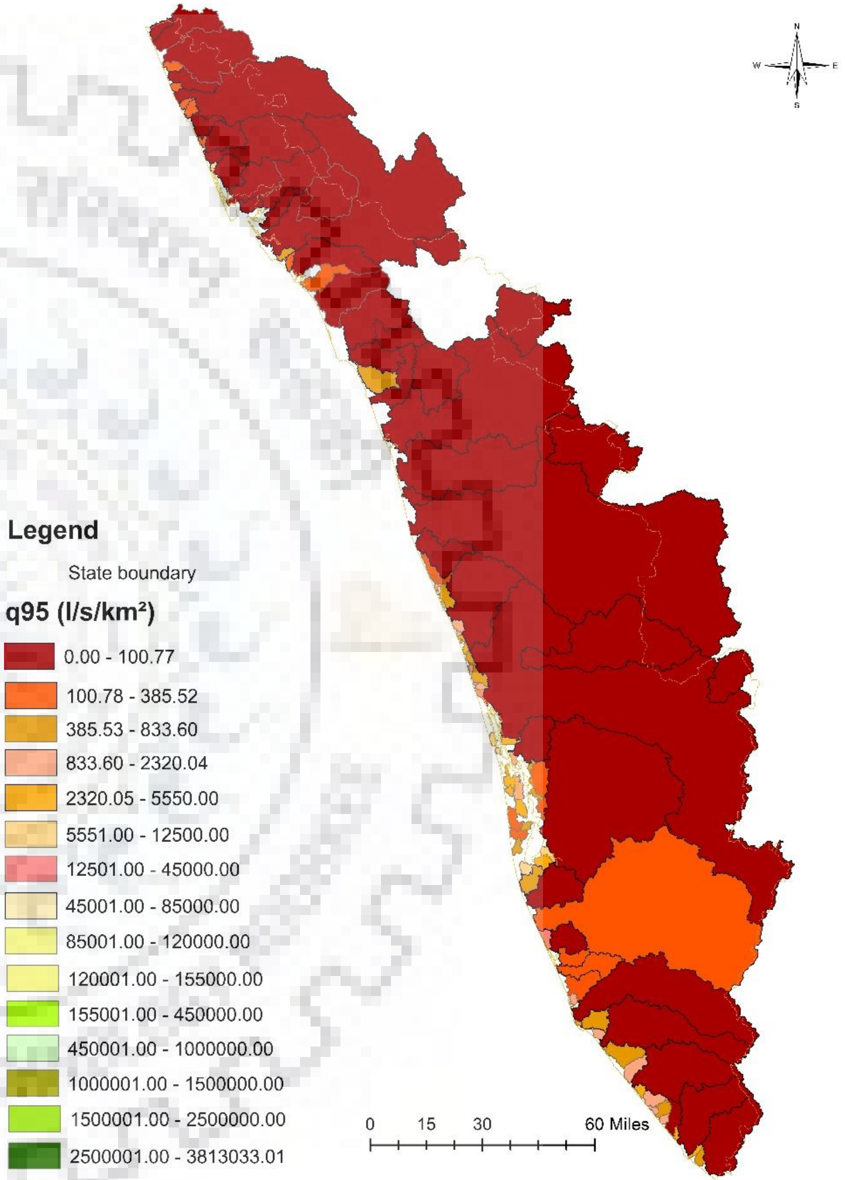

Figure 4.4 Assessment of flow parameter of q_{95} for ungauged catchments

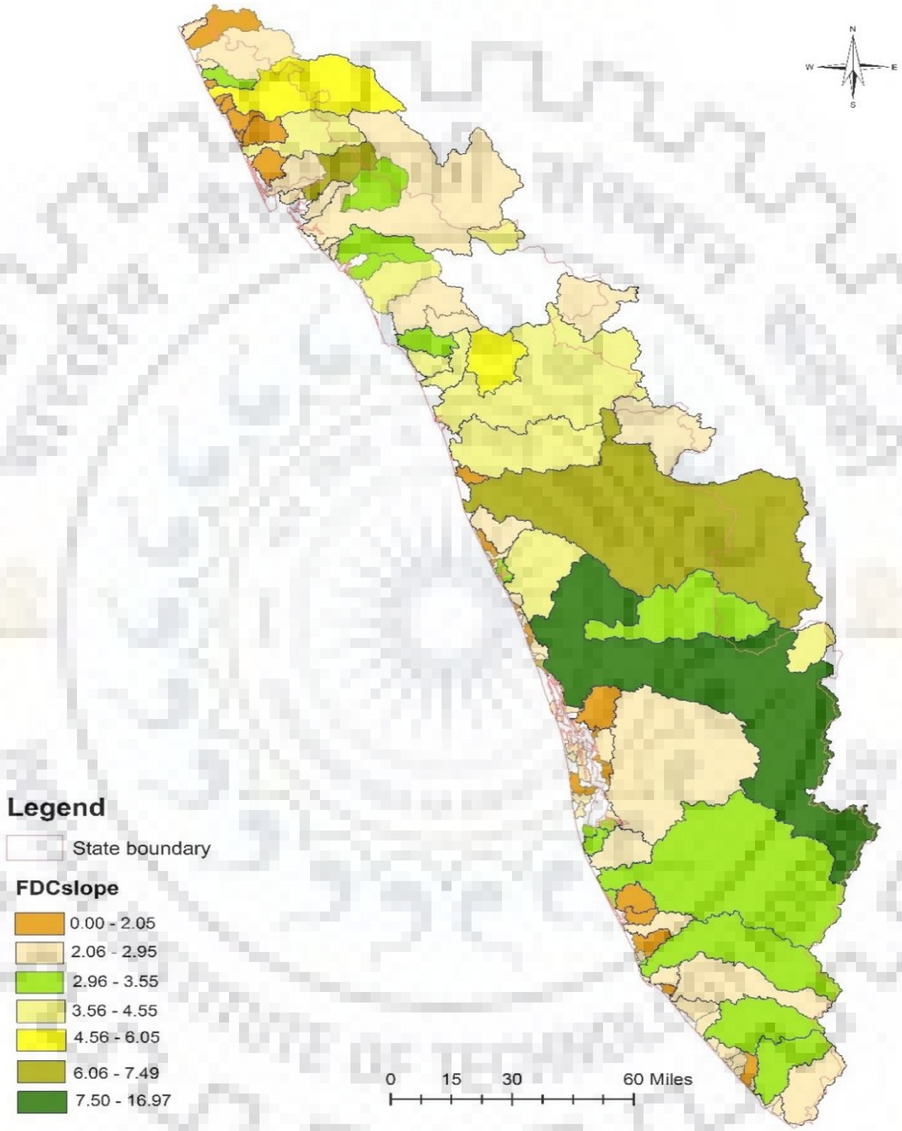

Figure 4.5 Assessment of FDC$_{slp}$ for ungauged catchments

Chapter 5
Conclusions, Limitations and Future scope of work

The magnitude of water resources scarcity or abundance and its imbalance in both space and time are largely unknown in the study area of gauged and ungauged catchment. A case study of the ungauged catchment of Kerala state was undertaken to assess flows. The catchment characteristics, flow quantiles and the flow duration curve of the gauged catchments were assessed. Nineteen gauged catchments and 110 ungauged catchments were selected. Climatic classification was carried out using Budyko curve. The analysis shows that all the gauged catchments are in the wet category with aridity index value ranges between 0.38 and 0.69 having similar evaporative indices (between 0.24 and 0.64). This implies closeness or similarity of climate in the catchments with regards to relative water and energy accessibility. In this way, all the nineteen gauged catchments have been chosen as the donor catchments and their geomorphological and hydrometeorological parameters were passed on from these catchments to the ungauged catchments.

The 5, 50, 90 and 95 percent flow duration (i.e., q_5, q_{50}, q_{90} and q_{95}), and also with the flow duration curve (FDC_{slp}) of the nineteen gauged catchments were estimated. A regression model was once developed for every parameter utilizing a forward stepwise-regression system and with the aid of considering non-transformed and log-transformed equations. As prediction of the parameters in ungauged catchments is the point of the study, leave-one-out cross validation (LOOCV) was utilized as the basic criteria for selecting the best performing models.

The outcomes demonstrated that the log-transformed models outperformed the non-transformed models. Climate, physiographic and land cover descriptors have been considered to study effect on the hydrology of the study region by means of utilizing the log-transformed models. Mean annual precipitation has all the earmarks of being the most significant climate descriptor for all stream flow quantiles. River/drainage density, elevation range, minimum and maximum catchment elevation, catchment area and perimeter were included in the dominant physiographical descriptors for the flow parameters. The identified dominant land cover descriptors had been the percentages of grasses/cropland, waterbodies, broadleaf forest and evergreen needleleaf forest.

It is also seen that models with increasingly more explanatory variables in many instances will in general have better fit amongst predicted and observed values (in terms of greater R^2 and NSE, and lower standard residual error, MAE and RMSE), but does not actually improves the performance of models.

The assessment of flow parameter of q_5 and q_{50} in ungauged catchments shows that a larger predicted value found along the coastal area mostly draining in to the Arabian sea. The assessment of low flows i.e. q_{90} and q_{95} demonstrates a decreasing trend alongside the eastern parts which is mostly mountainous. The slope of FDC is higher in the south eastern catchments demonstrating a high variable streamflow owing to direct runoff. The lower values of slope of FDC are found in the western catchments or along the coastal area that indicates higher contribution and presence of groundwater in these catchments. The regionalized Flow Duration Curve is more useful for estimating flows for applications such as hydraulic structure design and hydro-ecological assessment, which do not require accurate timing of prediction.

Limitations

- The developed regression models are only confined to the study area and the gauged catchment characteristics. A new regression models must be built up each time for their intended used so as to apply the strategy to different places having a comparative climate and landscape.
- Weather variables obtained from gridded data are used as regression parameters for estimation of flows in ungauged catchments. Weather variables obtained from station data might increase the accuracy in estimation of flows.
- Accuracy of estimation of flows increases with increase in number of gauged or observed stations.

Future scope of work

- Explore more catchment properties that are meaningful and can possibly be related to the selected indices.
- Merge ground-gauged rainfall data with the IMD gridded rainfall data (or other remotely-sensed rainfall products). This probably improves the accuracy of spatial rainfall estimation because the moderate quality of the remotely-sensed data covering an extensive area can be adjusted by using the higher accuracy point rainfall measurement at the locations of gauges.

  Rainfall downscaling is also an alternative to convert the remotely-sensed data into catchment scale estimates with uncertainty.
- Improving the predictability of the model for prediction of changes i.e. acquiring soil properties data from an experimental site and forcing them into the regression equations instead of using statistical selection methods such as stepwise, and attempt to distinguish the influence of land use change from climate change. However, this might be possible only when more data are available.

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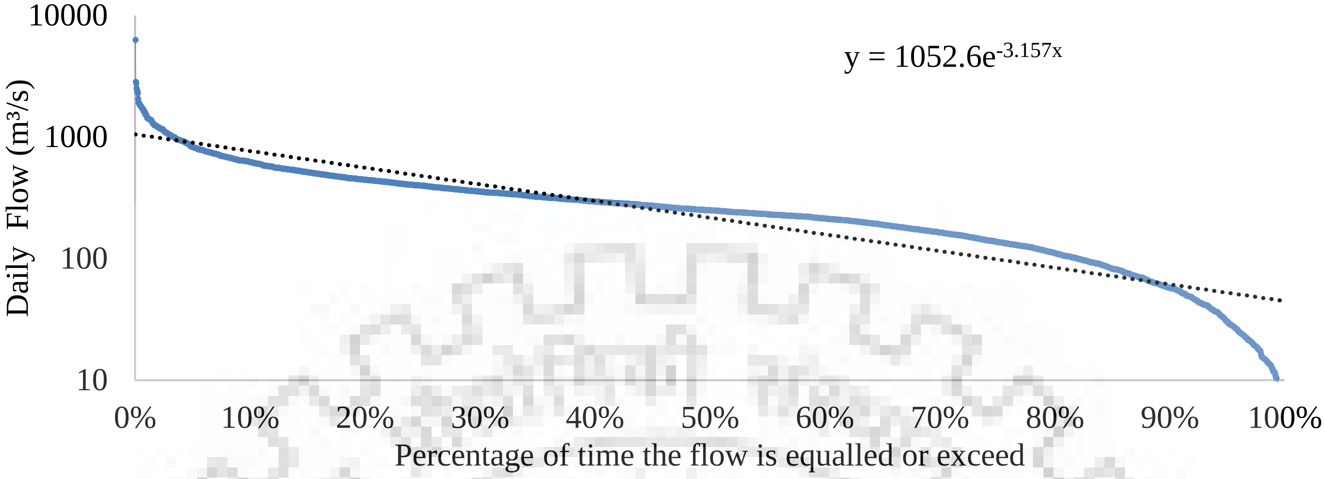
APPENDICES

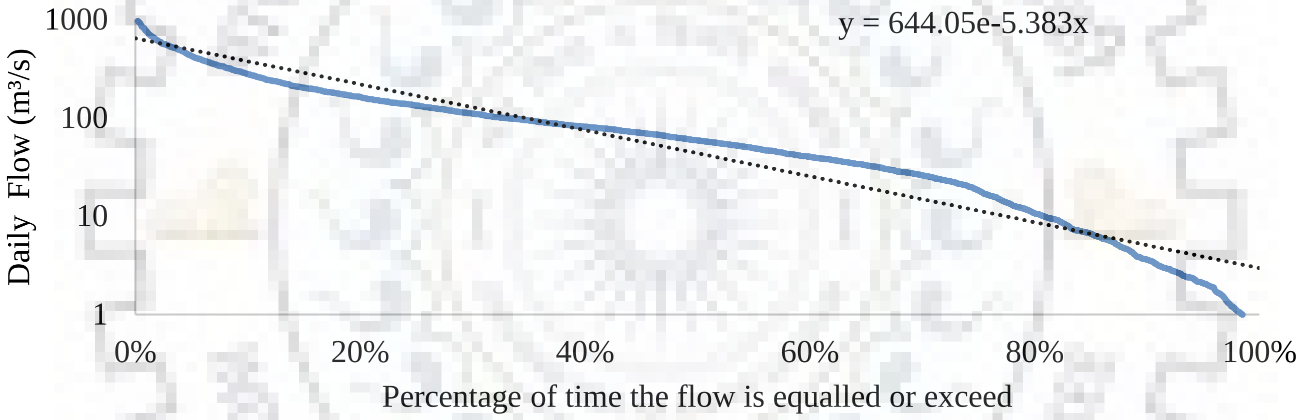
A.1. Potential evapotranspiration (ET_o), crop coefficient (Kc), actual evapotranspiration (ET_a), ETo/ PREC and ETa / PREC for 19 gauged catchments

Gauged Catchment	Precipitation (mm/day)	ETo	Kc	ET actual	E Ta / PREC	E To / PREC
Arangaly	7.14	4.21	0.52	2.19	0.31	0.59
Ayilam	5.58	3.9	0.54	2.08	0.37	0.69
Erinjipuzha	11.13	4.2	0.53	2.22	0.20	0.38
Kalampur	9.11	4.1	0.54	2.22	0.24	0.45
Kallooppara	7.48	4.1	0.55	2.26	0.30	0.55
Karathodu	6.02	4.0	0.55	2.22	0.37	0.67
Kindagoor	8.42	3.9	0.55	2.16	0.26	0.47
Kumbidi	5.19	3.6	0.78	2.81	0.54	0.69
Kuniyil	5.31	3.7	0.53	1.93	0.36	0.69
Kuttyadi	6.42	4.0	0.53	2.14	0.33	0.63
Malakkara	5.13	3.6	0.52	1.85	0.36	0.69
Mankara	4.80	3.3	0.55	1.82	0.38	0.69
Muthankera	5.37	3.6	0.96	3.46	0.64	0.67
Ramamangalam	7.60	4.0	0.54	2.14	0.28	0.52
Pudur	4.53	3.1	0.57	1.77	0.39	0.68
Perumannu	5.19	3.6	0.54	1.94	0.37	0.69
Neeleswaram	5.57	3.7	0.53	1.96	0.35	0.66
Thumpamon	4.71	3.2	0.52	1.66	0.35	0.68
Vandiperiyar	4.80	3.3	0.52	1.72	0.36	0.69

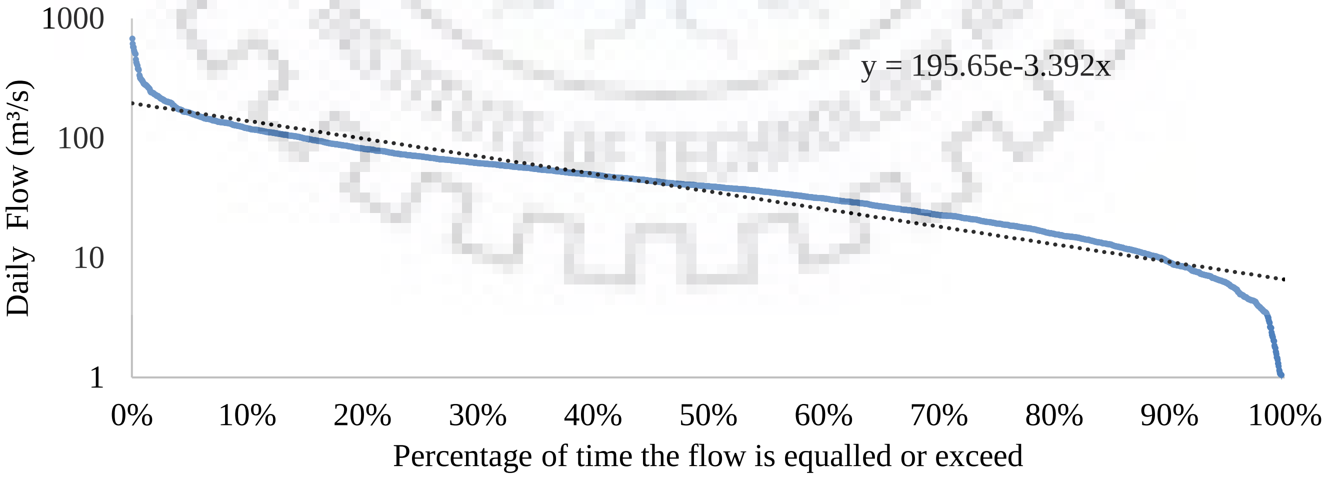
A.2. Flow Duration Curve for Gauged Catchments



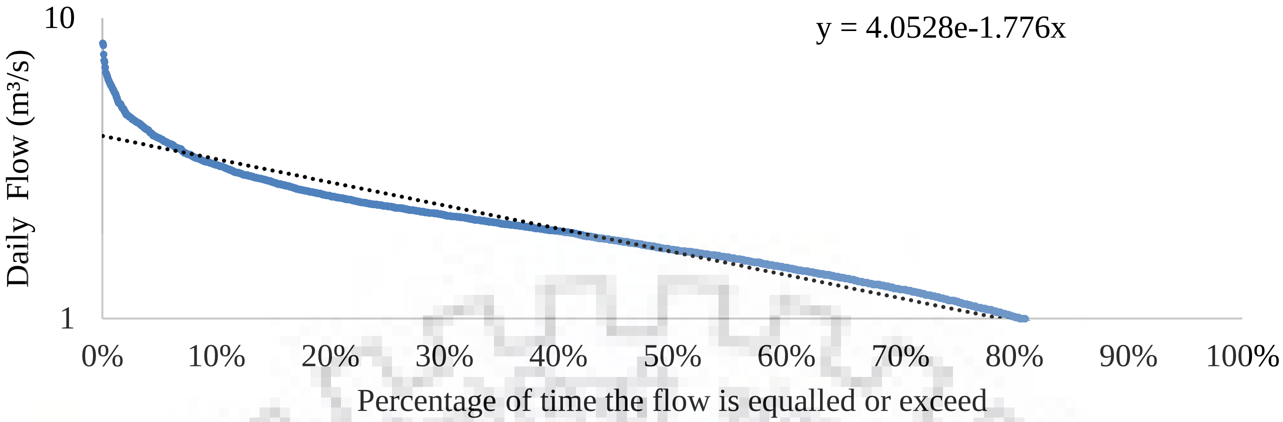
a) Neeleswaram



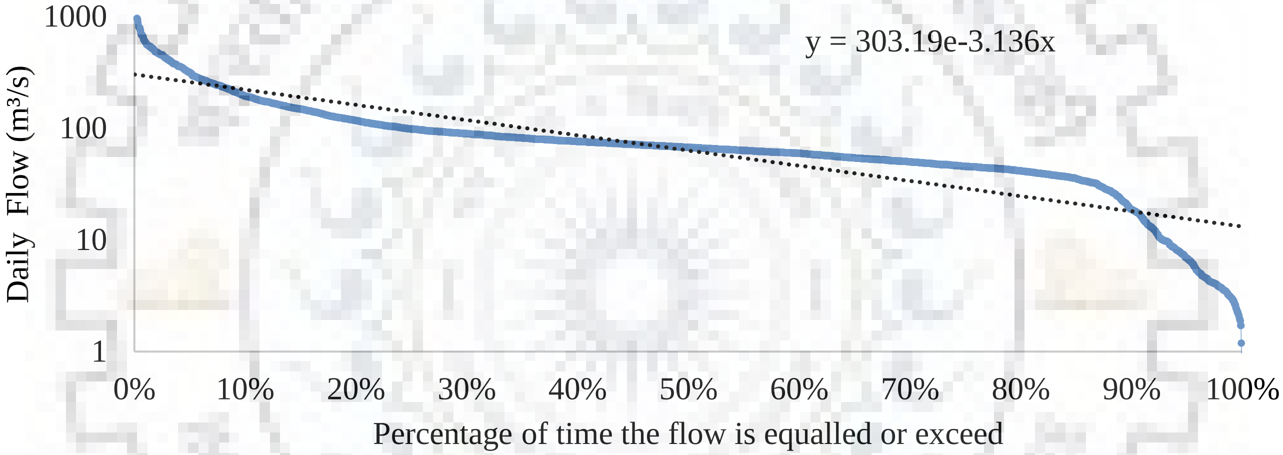
b) Muthankera



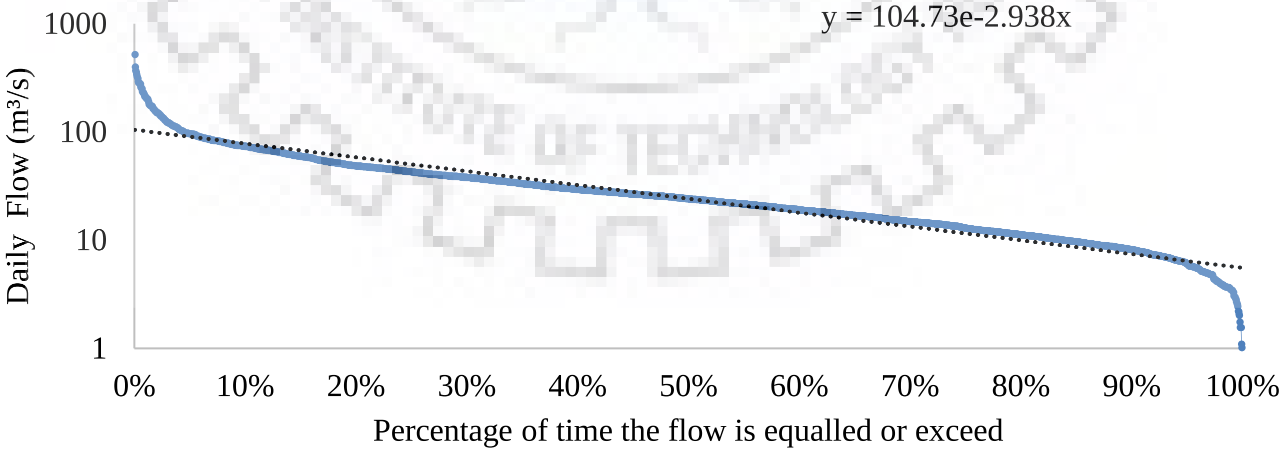
c) Thumpamon



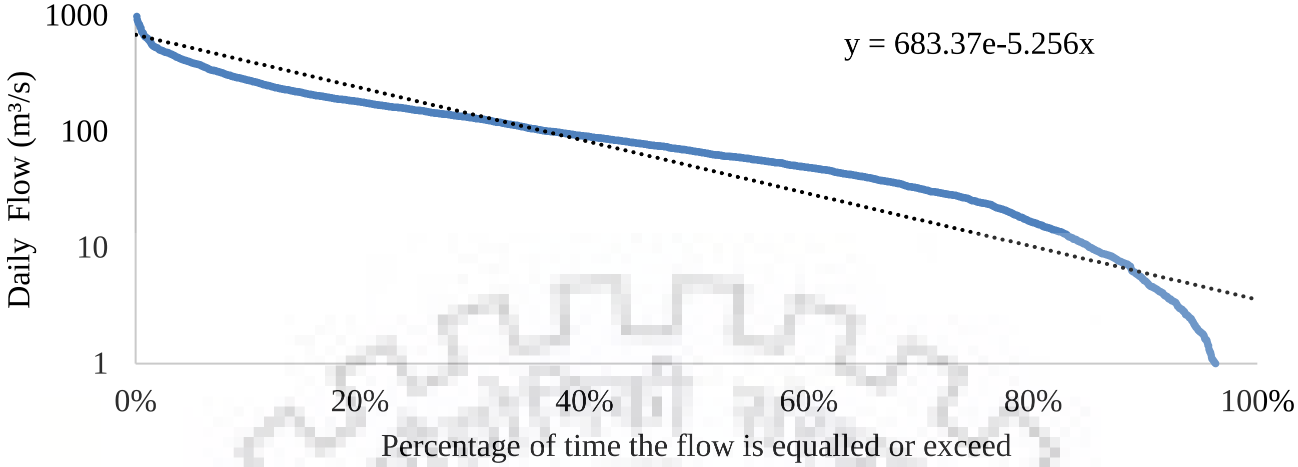
d) Ramamangalam



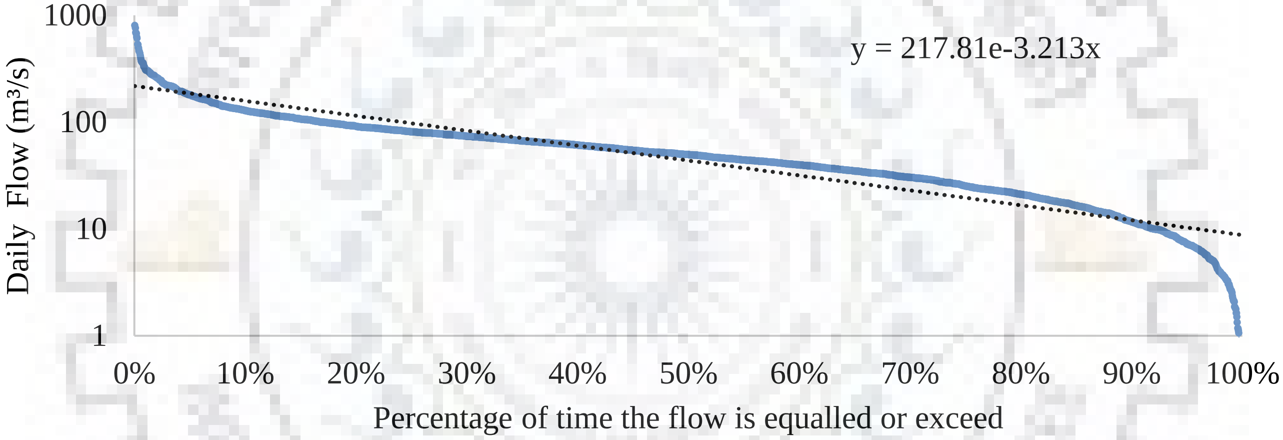
e) Arangaly



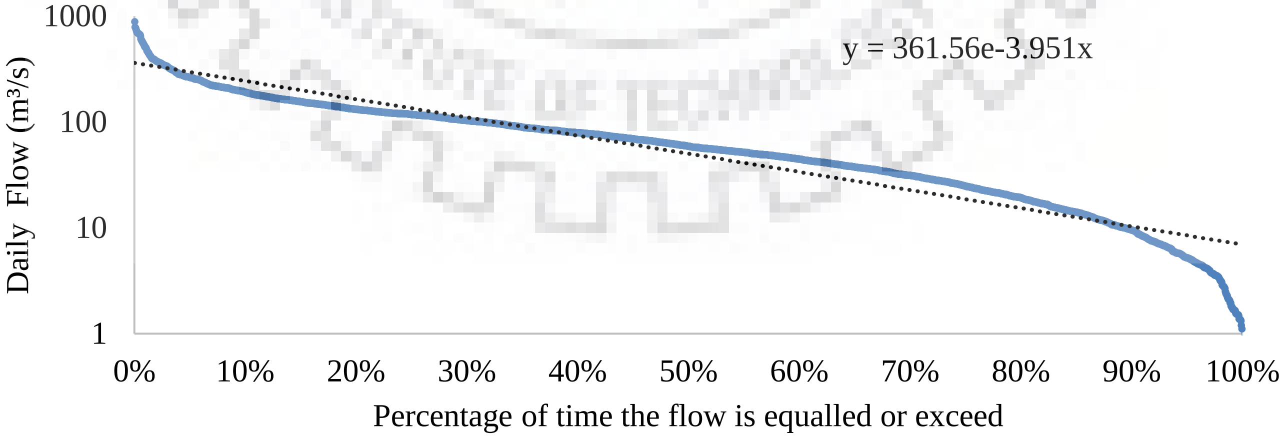
f) Ayilam



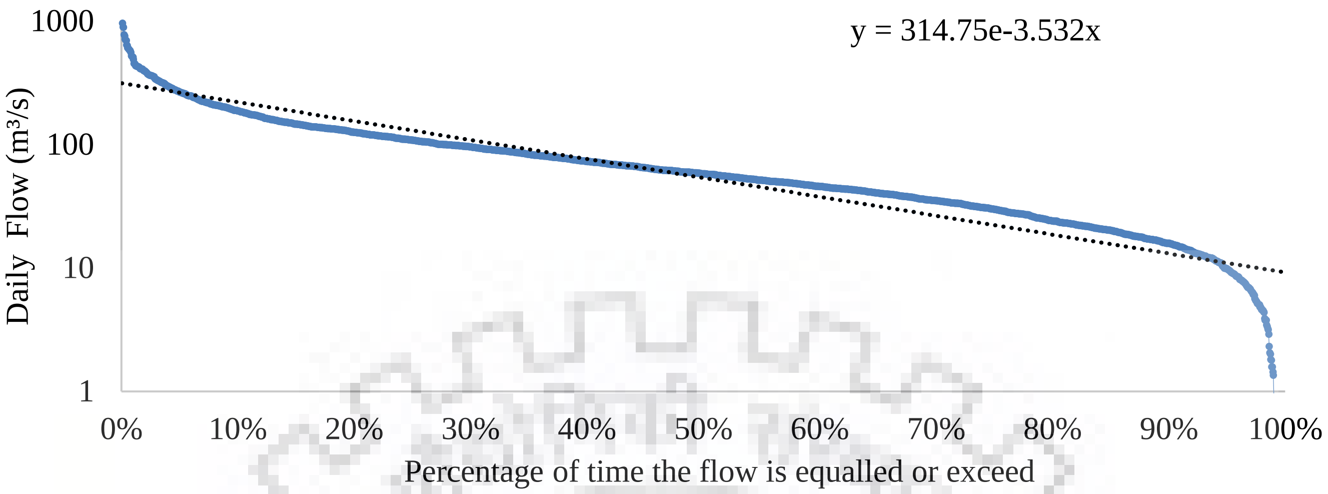
g) Erinjipuzha



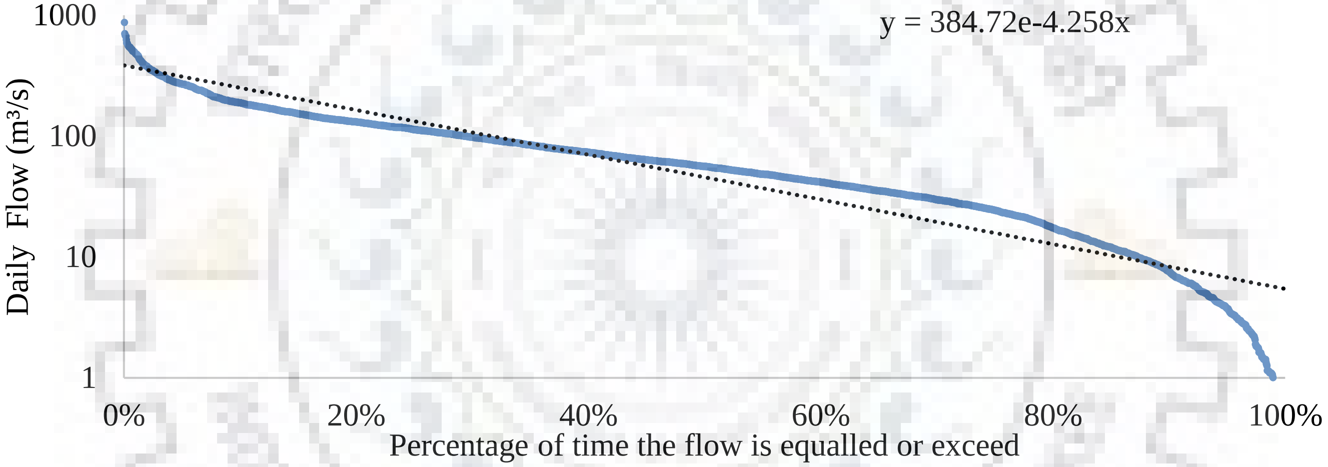
h) Kalampur



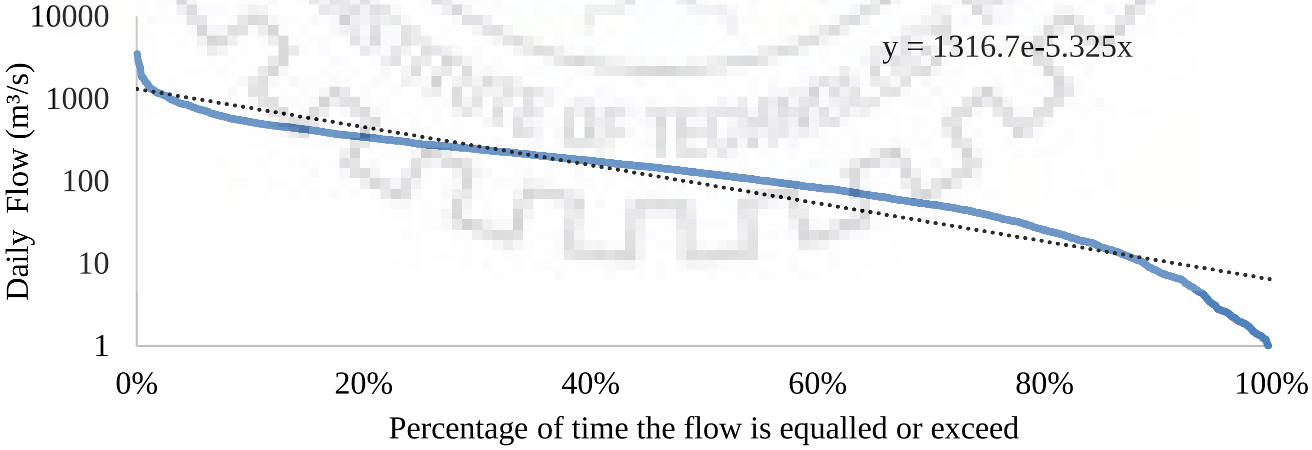
i) Kallooppara



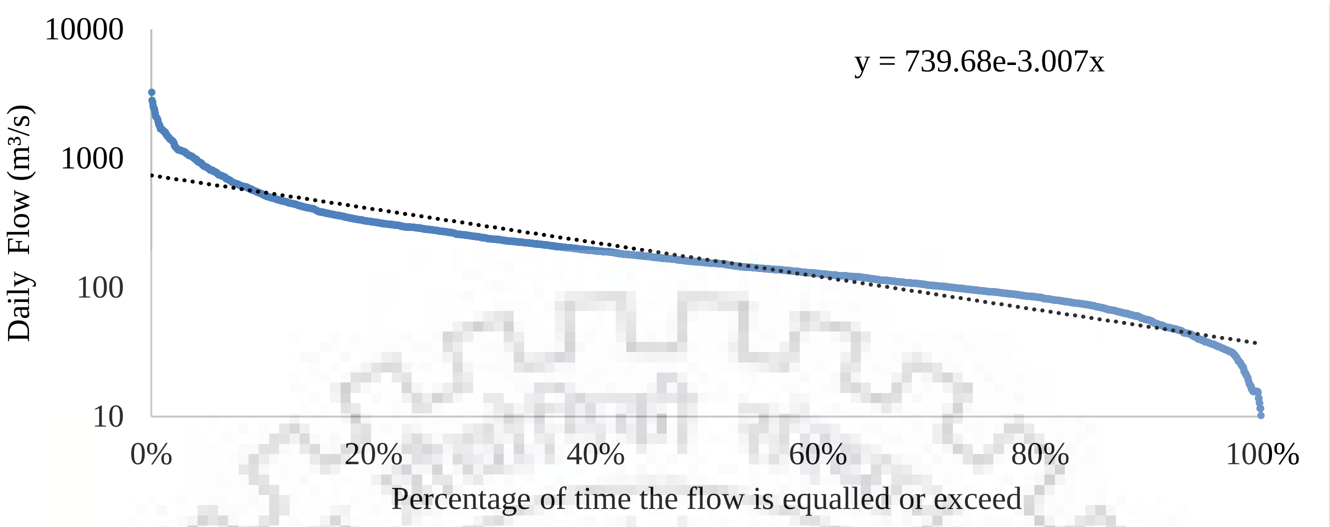
j) Karathodu



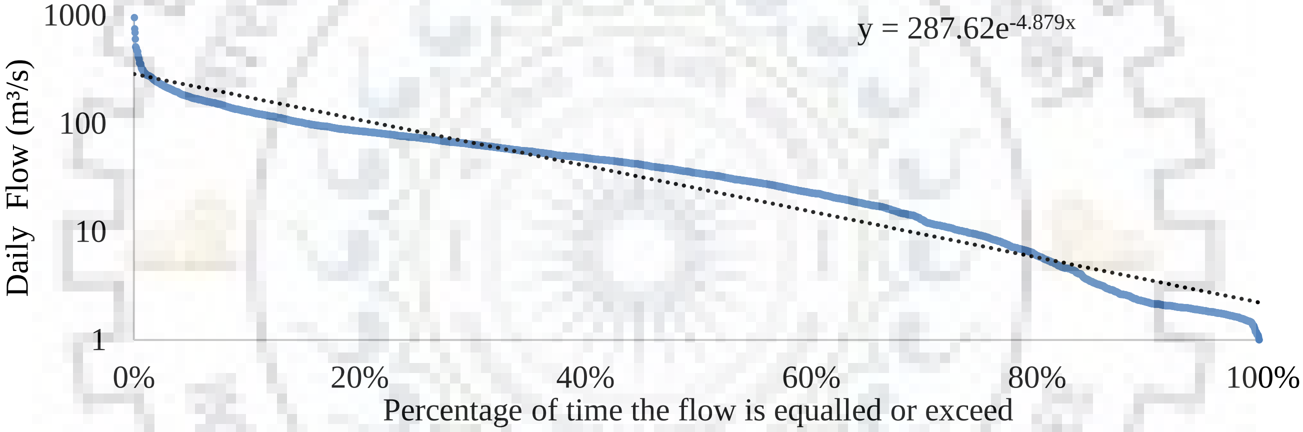
k) Kidangoor



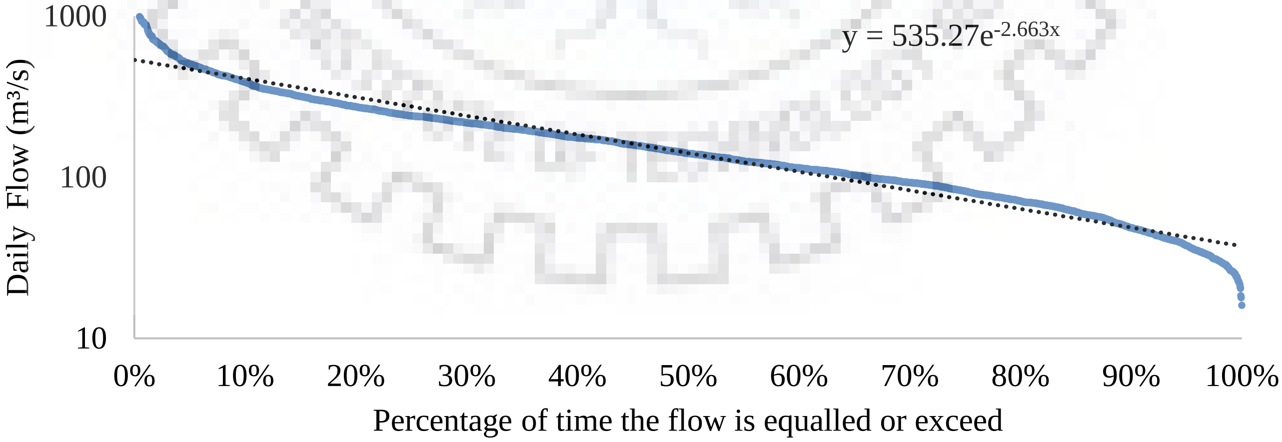
l) Kumbidi



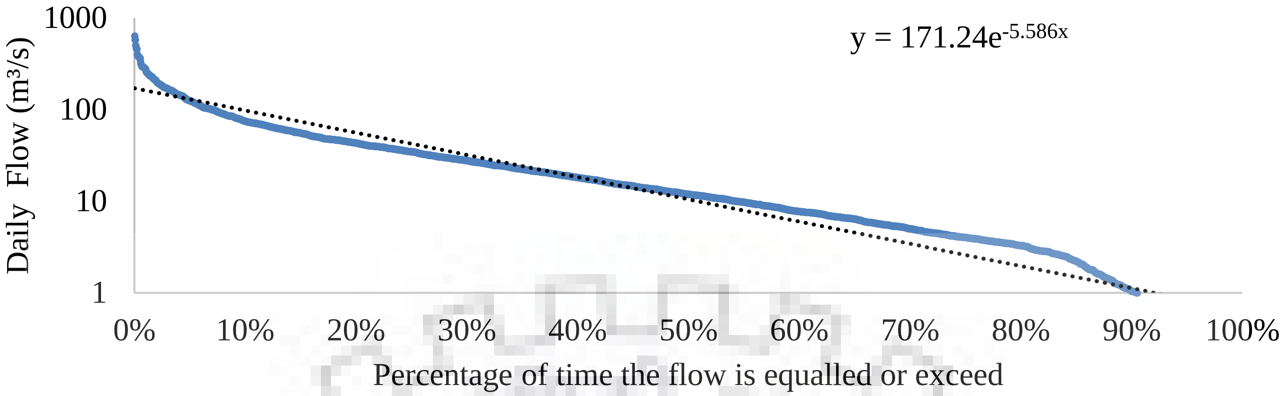
Kuniyil



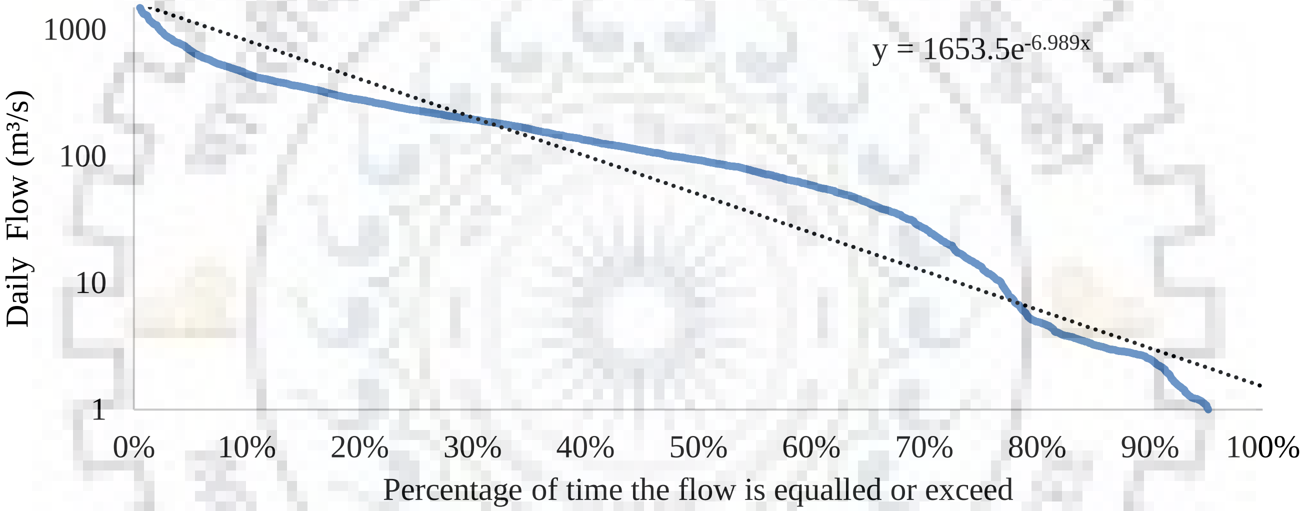
m) Kuttyadi



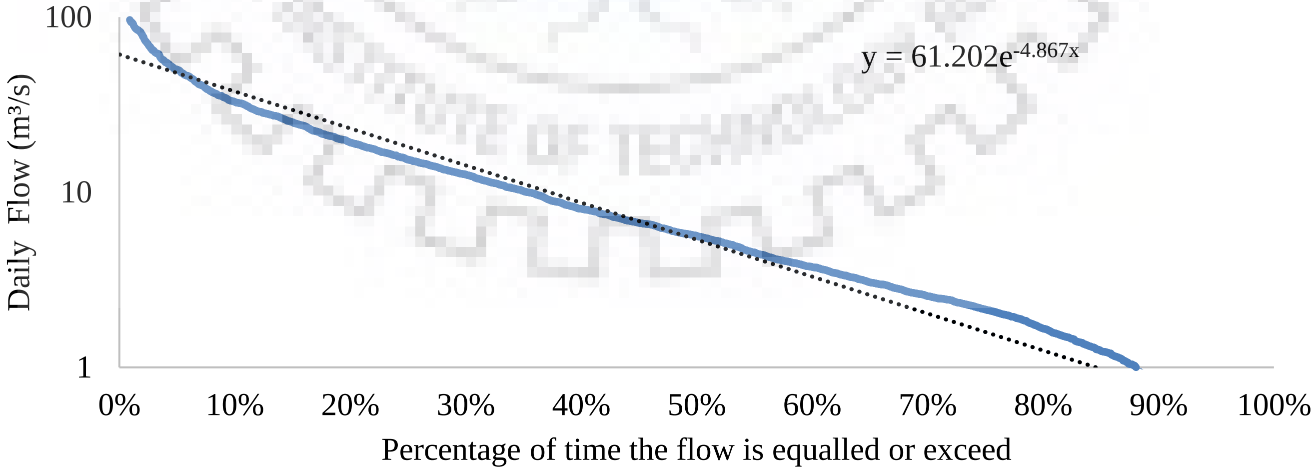
n) Malakkara



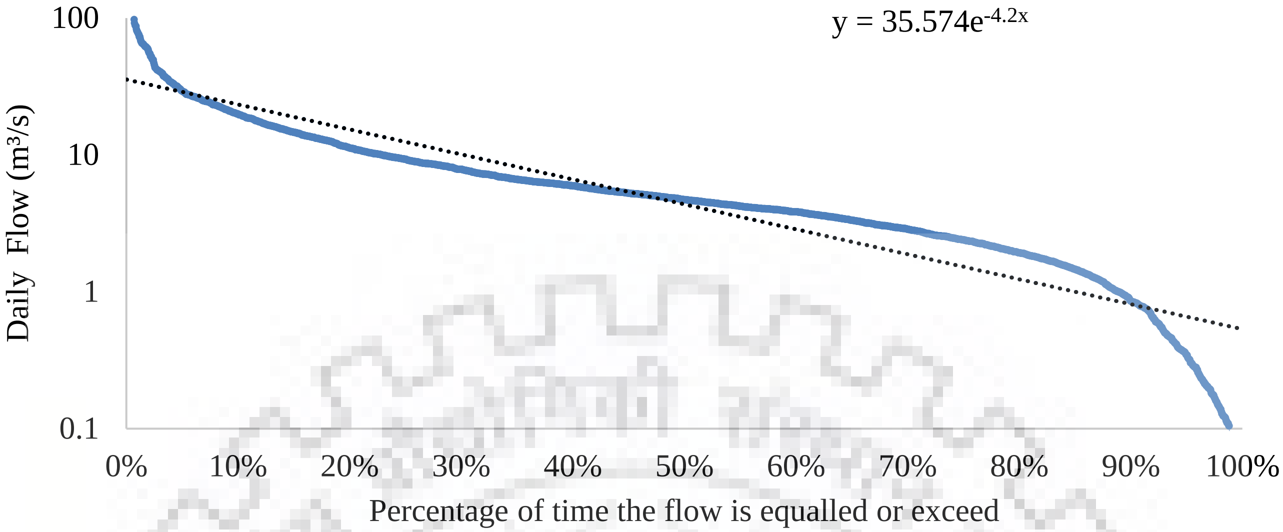
o) Mankara



p) Perumannu



q) Pudur



r) Vandiperiyar

A.3 Gauging Catchment Characteristics

Gauging Station	Catchment area	Perimeter	Drainage density	Elevation Mean	Elevation Range	Elev Max	Elev Min	Slope	Prec	Etpot	Water Bodies	Grasses Cereal crops
Vandiperiyar	736.00	208.00	3.03	1127.04	1212.00	1984.00	772.00	10.50	1750.90	127.87	0.00	1.25
Thumpamon	780.00	227.00	2.93	300.04	1914.00	1917.00	3.00	10.20	1719.36	137.21	0.00	0.00
Ramamangalam	1237.00	172.00	3.22	233.87	1251.00	1254.00	3.00	20.54	2774.27	122.56	0.07	0.00
Pudur	1292.00	300.00	3.34	537.38	2456.00	2493.00	37.00	19.90	1652.18	126.15	0.05	46.07
Perumannu	1020.00	199.00	3.27	719.56	1706.00	1712.00	6.00	10.60	1895.44	119.25	0.17	0.00
Neeleswaram	4152.00	609.00	2.20	896.64	2688.00	2692.00	4.00	21.87	2031.35	127.07	0.31	0.70
Muthankera	1269.00	230.00	3.30	819.80	1377.00	2039.00	662.00	21.24	1961.41	119.14	0.00	0.63
Mankara	2770.00	375.00	3.13	406.70	2483.00	2493.00	10.00	16.81	1752.18	130.19	0.06	55.48
Malakkara	1643.00	315.00	2.93	548.12	1911.00	1913.00	2.00	10.50	1871.29	117.75	0.01	0.14
Kuttyadi	242.00	83.00	3.01	492.09	2039.00	2043.00	4.00	10.60	2344.52	122.35	0.35	0.00
Kuniyil	2013.00	315.00	3.28	591.19	2603.00	2607.00	4.00	28.57	1936.95	128.64	0.00	0.28
Kumbidi	5949.00	578.00	1.43	289.06	2490.00	2493.00	3.00	16.82	1895.82	130.60	0.09	34.23
Kidangoor	591.00	145.00	3.09	170.61	1176.00	1181.00	5.00	22.82	3072.21	119.52	0.00	0.00
Karathodu	766.00	172.00	3.36	111.08	1298.00	1303.00	5.00	17.08	2197.55	120.22	0.00	0.00
Kalampur	377.00	129.00	3.15	234.34	1168.00	1173.00	5.00	22.63	3325.86	121.08	0.00	0.00
Erinjipuzha	894.00	201.00	3.00	289.47	1438.00	1446.00	8.00	25.47	4062.12	118.00	0.00	0.00
Ayilam	503.00	156.00	3.17	212.11	1669.00	1673.00	4.00	21.64	2035.50	131.71	0.00	0.00
Kallooppara	708.00	192.00	3.02	174.62	1389.00	1393.00	4.00	21.57	2731.10	126.17	0.00	0.00
Arangaly	1350.00	284.00	3.43	120.51	1134.00	1137.00	3.00	17.96	2605.24	124.30	0.32	0.64

A.3 Gauging Catchment Characteristics (continue...)

Gauging Station	Broadleaf crops	Savanna	Evergreen Broadleaf forest	Decidous Broadleaf forest	Evergreen Needleleaf forest	Urban
Vandiperiyar	0.00	30.31	68.44	0.00	0.00	0.00
Thumpamon	0.00	39.40	56.90	3.58	0.00	0.11
Ramamangalam	0.00	91.22	8.45	0.00	0.00	0.26
Pudur	0.08	42.20	9.02	1.94	0.00	0.63
Perumannu	0.02	63.35	36.42	0.00	0.00	0.04
Neeleswaram	0.00	61.68	37.23	0.06	0.00	0.02
Muthankera	0.71	80.15	17.70	0.59	0.00	0.22
Mankara	0.08	32.96	7.62	1.39	0.00	2.42
Malakkara	0.00	33.63	66.07	0.00	0.04	0.10
Kuttyadi	0.00	54.31	45.25	0.00	0.00	0.09
Kuniyil	0.00	64.67	34.39	0.59	0.00	0.07
Kumbidi	0.44	52.79	10.11	0.98	0.00	1.35
Kidangoor	0.00	97.97	1.88	0.00	0.00	0.14
Karathodu	0.00	97.51	2.18	0.00	0.00	0.31
Kalampur	0.00	77.18	22.82	0.00	0.00	0.00
Erinjipuzha	0.00	50.72	49.28	0.00	0.00	0.00
Ayilam	0.00	79.85	20.15	0.00	0.00	0.00
Kallooppara	0.00	93.24	6.64	0.00	0.00	0.12
Arangaly	0.00	35.83	52.82	10.23	0.00	0.16

A.4 Ungauged Catchment Characteristics

Station Name	Catchment Area (km²)	Perimeter (kms)	Drainage Density (km/km²)	Elevation (masl)				Slope (%)			Prec	ETo
				Max	Min	Mean	Range	Max	Min	Mean	mm	mm
UG1	597.00	159.43	3.40	335.00	5.00	104.68	330.00	22.46	0.31	16.77	3824.55	133.08
UG2	584.00	176.73	3.18	1697.00	4.00	302.10	1693.00	23.77	0.13	10.40	4206.30	132.08
UG3	142.00	81.64	3.38	131.00	4.00	32.75	127.00	23.09	0.31	10.24	5025.71	131.04
UG4	256.00	116.57	3.41	332.00	4.00	70.73	328.00	22.86	0.38	14.34	5025.71	128.11
UG5	342.00	130.18	2.99	1701.00	2.00	346.95	1699.00	24.13	0.13	10.20	5025.71	125.35
UG6	400.00	114.92	3.10	1713.00	3.00	334.10	1710.00	23.12	0.22	10.10	3669.89	126.14
UG7	362.00	132.29	3.16	1165.00	1.00	106.09	1164.00	28.98	0.24	16.61	2944.29	128.00
UG8	115.00	78.30	3.15	660.00	3.00	51.25	657.00	28.74	0.17	11.21	2439.51	127.82
UG9	400.00	128.76	3.22	1363.00	3.00	148.03	1360.00	32.30	0.09	18.02	2439.51	125.84
UG10	211.00	125.38	3.26	1117.00	3.00	91.43	1114.00	30.49	0.20	18.56	2629.53	123.39
UG11	482.00	134.88	1.42	2318.00	2.00	330.24	2316.00	29.41	0.02	10.50	2555.71	130.29
UG12	782.00	629.28	4.47	528.00	0.00	32.55	528.00	32.92	0.08	9.07	2425.51	124.59
UG13	127.00	268.88	3.32	2340.00	3.00	706.41	2337.00	29.35	0.03	10.40	2531.72	127.08
UG14	242.00	111.12	3.50	106.00	4.00	21.78	102.00	23.07	0.21	8.12	2969.13	135.29
UG15	820.00	244.19	3.22	1762.00	0.00	182.00	1762.00	30.55	0.08	18.29	1705.49	133.97
UG16	482.00	136.25	3.32	1811.00	3.00	165.91	1808.00	40.06	0.01	18.97	1505.73	135.63
UG17	514.00	161.00	3.11	1673.00	0.00	141.29	1673.00	35.32	0.04	17.58	1365.51	128.84
UG18	168.00	109.29	3.70	120.00	0.00	26.32	120.00	25.22	0.19	9.56	2523.22	128.20
UG19	314.00	119.63	3.81	58.00	3.00	12.90	55.00	29.57	0.06	4.77	2677.65	126.95
UG20	248.00	109.56	4.22	159.00	3.00	19.44	156.00	25.65	0.13	7.80	2504.26	128.25
UG21	202.00	94.36	3.32	692.00	3.00	52.02	689.00	28.73	0.26	15.20	2777.17	124.07
UG22	174.00	88.09	3.08	1534.00	5.00	327.49	1529.00	26.53	0.21	10.10	2649.84	133.23

A.4 Ungauged Catchment Characteristics (continue...)

Station Name	Water Bodies	Grasses/Cereal crops	Broad leaf crops	Savanna	Evergreen Broadleaf forest	Decidous Broadleaf forest	Evergreen Needleleaf forest	Urban
UG1	0.00	0.00	0.00	96.94	3.06	0.00	0.00	0.00
UG2	0.04	0.15	0.04	62.61	37.17	0.00	0.00	0.00
UG3	0.15	1.97	2.12	95.30	0.30	0.00	0.00	0.15
UG4	0.08	1.01	0.25	98.49	0.17	0.00	0.00	0.00
UG5	0.00	0.06	0.06	67.78	32.10	0.00	0.00	0.00
UG6	0.00	0.21	0.00	74.85	24.93	0.00	0.00	0.00
UG7	0.00	0.48	0.00	81.15	18.37	0.00	0.00	0.00
UG8	0.00	0.19	0.00	93.66	5.97	0.00	0.00	0.19
UG9	0.00	0.86	0.00	80.53	18.62	0.00	0.00	0.00
UG10	0.00	0.10	0.00	94.50	5.40	0.00	0.00	0.00
UG11	0.00	0.00	0.00	81.28	18.64	0.00	0.00	0.09
UG12	0.16	10.63	0.08	82.85	3.30	0.00	0.00	2.97
UG13	0.34	0.64	0.00	33.07	55.05	10.90	0.00	0.00
UG14	0.09	0.09	0.35	92.72	0.00	0.00	0.00	6.74
UG15	0.47	0.16	0.00	73.92	25.24	0.00	0.00	0.21
UG16	0.22	0.27	0.00	78.69	20.60	0.00	0.00	0.22
UG17	0.33	0.21	0.00	77.88	18.86	0.00	0.00	2.72
UG18	0.00	0.25	0.00	99.11	0.00	0.00	0.00	0.63
UG19	2.59	23.91	0.00	72.21	0.00	0.00	0.00	1.29
UG20	0.43	3.39	0.17	95.05	0.52	0.00	0.00	0.43
UG21	0.63	1.27	0.00	90.80	7.29	0.00	0.00	0.00
UG22	0.49	0.00	0.00	58.82	40.69	0.00	0.00	0.00

A.4 Ungauged Catchment Characteristics (continue...)

Station Name	Catchment Area (km²)	Perimeter (kms)	Drainage Density (km/km²)	Elevation (masl)				Slope (%)			Prec	ETo
				Max	Min	Mean	Range	Max	Min	Mean	mm	mm
UG23	109.00	80.77	3.27	240.00	4.00	70.13	236.00	22.89	0.20	14.31	3573.49	130.28
UG24	172.00	79.33	3.23	582.00	5.00	89.09	577.00	22.74	0.24	16.76	5025.71	133.27
UG25	81.00	66.91	3.27	215.00	4.00	52.40	211.00	22.18	0.31	11.58	3573.49	127.81
UG26	1322.00	255.13	3.29	1446.00	0.00	274.46	1446.00	26.68	0.17	10.60	3766.88	130.96
UG27	106.00	81.14	3.26	362.00	3.00	63.02	359.00	22.49	0.44	12.26	3449.06	126.02
UG28	3055.00	423.23	2.68	1713.00	0.00	582.65	1713.00	29.66	0.10	21.24	2297.86	131.20
UG29	24.00	33.41	3.14	83.00	0.00	24.77	83.00	19.86	0.31	9.11	3449.06	129.21
UG30	22.00	28.72	3.61	90.00	3.00	28.57	87.00	20.12	0.28	9.71	3449.06	126.39
UG31	634.00	149.10	3.23	2043.00	2.00	266.07	2041.00	29.03	0.18	24.28	2579.73	129.64
UG32	139.00	79.37	3.36	285.00	0.00	36.25	285.00	27.26	0.24	14.17	2777.17	115.95
UG33	2987.00	416.66	2.74	2607.00	0.00	459.45	2607.00	32.74	0.04	26.10	2143.21	120.13
UG34	1202.00	258.16	3.46	1303.00	2.00	90.72	1301.00	35.89	0.04	15.52	2470.11	123.74
UG35	58.00	52.80	3.33	114.00	3.00	25.70	111.00	23.24	0.27	9.17	2687.44	128.53
UG36	5989.00	630.72	1.20	2493.00	0.00	280.22	2493.00	44.75	0.01	16.51	1633.76	127.17
UG37	7224.00	823.24	1.12	2692.00	2.00	661.32	2690.00	28.92	0.02	25.24	2096.62	121.47
UG38	2819.00	343.27	3.16	1254.00	3.00	146.99	1251.00	33.19	0.07	17.25	2787.07	126.65
UG39	73.00	59.73	3.78	79.00	4.00	11.22	75.00	38.19	0.01	3.71	2677.65	125.32
UG40	3729.00	442.07	2.29	1917.00	1.00	342.10	1916.00	27.20	0.05	10.50	2217.24	129.95
UG41	152.00	667.03	3.80	59.00	2.00	14.22	57.00	24.85	0.05	7.08	2514.54	129.75
UG42	72.00	52.18	3.56	52.00	0.00	14.45	52.00	23.71	0.04	7.49	2514.54	134.44
UG43	1302.00	301.83	3.48	1765.00	0.00	180.74	1765.00	28.01	0.16	20.94	1710.05	136.29
UG44	83.00	60.26	3.76	75.00	2.00	22.79	73.00	22.80	0.17	9.12	2357.70	136.29

A.4 Ungauged Catchment Characteristics (continue...)

Station Name	Water Bodies	Grasses/Cereal crops	Broad leaf crops	Savanna	Evergreen Broadleaf forest	Decidous Broadleaf forest	Evergreen Needleleaf forest	Urban
UG23	0.00	0.20	0.20	99.02	0.59	0.00	0.00	0.00
UG24	0.13	0.13	0.00	99.75	0.00	0.00	0.00	0.00
UG25	0.26	0.26	0.00	99.48	0.00	0.00	0.00	0.00
UG26	0.11	0.00	0.03	57.46	42.39	0.00	0.00	0.00
UG27	0.20	0.20	0.00	99.59	0.00	0.00	0.00	0.00
UG28	0.31	0.30	1.67	71.31	23.68	2.66	0.00	0.07
UG29	0.00	0.00	0.00	99.14	0.00	0.00	0.00	0.86
UG30	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
UG31	0.24	2.13	0.00	68.87	28.69	0.00	0.00	0.07
UG32	2.94	0.31	0.00	84.70	12.06	0.00	0.00	0.00
UG33	0.11	0.28	0.00	72.80	26.28	0.40	0.00	0.14
UG34	0.00	0.46	0.00	97.34	1.64	0.00	0.00	0.55
UG35	0.36	0.36	0.00	97.13	0.00	0.00	0.00	2.15
UG36	0.16	34.23	0.44	54.32	8.53	0.96	0.00	1.35
UG37	0.48	0.70	0.04	62.15	33.95	1.97	0.00	0.72
UG38	0.38	2.03	0.00	92.44	4.75	0.00	0.00	0.40
UG39	8.28	15.98	0.00	75.74	0.00	0.00	0.00	0.00
UG40	0.24	0.48	0.00	55.30	43.04	0.75	0.02	0.18
UG41	0.42	0.00	0.00	99.16	0.14	0.00	0.00	0.28
UG42	0.00	0.59	0.00	96.14	0.00	0.00	0.00	3.26
UG43	2.77	0.15	0.00	66.55	30.31	0.00	0.00	0.21
UG44	2.77	0.15	0.00	66.55	30.31	0.00	0.00	0.21

A.4 Ungauged Catchment Characteristics (continue...)

Station Name	Catchment Area (km²)	Perimeter (kms)	Drainage Density (km/km²)	Elevation (masl)				Slope (%)			Prec	ETo
				Max	Min	Mean	Range	Max	Min	Mean	mm	mm
UG45	708.00	190.55	3.24	1673.00	3.00	145.92	1670.00	30.97	0.07	18.19	1422.84	134.22
UG46	110.00	67.79	3.63	118.00	0.00	40.51	118.00	21.23	0.23	10.17	1817.93	136.17
UG47	45.00	42.35	3.45	114.00	0.00	30.07	114.00	23.29	0.27	9.74	1611.23	135.71
UG48	66.00	712.94	3.27	169.00	3.00	38.28	166.00	23.90	0.33	10.89	1575.35	136.14
UG49	32.00	32.85	3.30	114.00	4.00	35.30	110.00	22.02	0.25	11.68	1641.57	129.33
UG50	9.00	18.22	3.44	33.00	3.00	10.68	30.00	24.37	0.48	4.96	1641.57	128.44
UG51	13.00	18.08	3.37	71.00	3.00	23.15	68.00	24.66	0.03	9.55	1641.57	129.08
UG52	10.00	19.98	3.21	52.00	3.00	13.34	49.00	27.26	0.12	5.75	1575.35	129.48
UG53	14.00	24.03	2.99	97.00	0.00	55.49	97.00	20.75	0.45	10.78	1575.35	128.59
UG54	23.00	28.18	3.31	98.00	7.00	48.77	91.00	20.08	0.39	11.08	1575.35	134.83
UG55	18.00	24.42	3.39	77.00	0.00	21.57	77.00	22.27	0.34	8.07	1817.93	134.04
UG56	60.00	46.54	3.57	125.00	3.00	33.36	122.00	20.81	0.28	10.78	1817.93	126.70
UG57	24.00	27.88	3.84	38.00	5.00	12.24	33.00	34.41	0.13	4.25	2677.65	122.17
UG58	28.00	37.98	3.81	41.00	4.00	11.20	37.00	29.70	0.08	3.51	2947.69	128.30
UG59	94.00	57.13	3.42	80.00	3.00	19.73	77.00	27.17	0.02	7.54	2996.02	128.88
UG60	110.00	75.31	3.53	71.00	0.00	17.29	71.00	29.89	0.02	8.13	2357.70	135.57
UG61	21.00	27.09	3.84	55.00	0.00	18.41	55.00	21.24	0.30	8.16	1817.93	130.63
UG62	14.00	23.22	3.31	60.00	2.00	11.92	58.00	22.45	0.06	6.78	2357.70	131.16
UG63	6.00	15.92	3.36	75.00	0.00	12.03	75.00	28.17	0.16	6.48	2357.70	133.11
UG64	5.00	12.92	3.30	41.00	0.00	11.08	41.00	24.19	0.29	7.17	2357.70	127.77
UG65	28.00	34.94	3.99	38.00	0.00	8.32	38.00	24.58	0.30	5.00	2514.54	125.11
UG66	21.00	29.75	4.16	37.00	5.00	11.22	32.00	27.07	0.06	3.71	2677.65	125.49

A.4 Ungauged Catchment Characteristics (continue...)

Station Name	Water Bodies	Grasses/Cereal crops	Broad leaf crops	Savanna	Evergreen Broadleaf forest	Decidous Broadleaf forest	Evergreen Needleleaf forest	Urban
UG45	0.00	0.00	0.00	85.14	14.65	0.00	0.00	0.21
UG46	2.51	0.00	0.00	96.53	0.97	0.00	0.00	0.00
UG47	2.90	1.45	0.00	94.20	0.97	0.00	0.00	0.48
UG48	0.32	0.00	0.95	58.41	0.00	0.00	0.00	40.32
UG49	0.00	1.32	0.00	91.39	0.00	0.00	0.00	7.28
UG50	0.00	0.00	0.00	59.09	0.00	0.00	0.00	40.91
UG51	0.00	3.13	0.00	89.06	0.00	0.00	0.00	7.81
UG52	2.27	0.00	2.27	40.91	0.00	0.00	0.00	54.55
UG53	0.00	0.00	0.00	82.81	17.19	0.00	0.00	0.00
UG54	0.00	0.91	0.00	40.00	59.09	0.00	0.00	0.00
UG55	3.49	3.49	0.00	83.72	9.30	0.00	0.00	0.00
UG56	2.51	0.36	0.00	94.62	2.51	0.00	0.00	0.00
UG57	15.18	0.00	0.00	76.79	0.00	1.79	0.00	6.25
UG58	0.00	15.38	0.00	83.85	0.77	0.00	0.00	0.00
UG59	2.31	0.23	0.00	92.13	5.32	0.00	0.00	0.00
UG60	2.12	0.39	0.00	97.11	0.39	0.00	0.00	0.00
UG61	0.00	0.00	0.00	93.55	0.00	0.00	0.00	6.45
UG62	0.00	0.00	0.00	93.85	6.15	0.00	0.00	0.00
UG63	29.63	0.00	0.00	29.63	40.74	0.00	0.00	0.00
UG64	0.00	0.00	0.00	73.91	0.00	0.00	0.00	26.09
UG65	15.91	0.76	0.00	63.64	19.70	0.00	0.00	0.00
UG66	21.21	7.07	0.00	70.71	1.01	0.00	0.00	0.00

A.4 Ungauged Catchment Characteristics (continue...)

Station Name	Catchment Area (km^2)	Perimeter (kms)	Drainage Density (km/km^2)	Elevation (masl)				Slope (%)			Prec	ETo
				Max	Min	Mean	Range	Max	Min	Mean	mm	mm
UG67	29.00	40.15	3.41	48.00	4.00	13.49	44.00	25.78	0.08	6.20	2812.67	126.79
UG68	20.00	29.19	3.58	33.00	4.00	12.93	29.00	22.82	0.15	5.81	2677.65	124.89
UG69	28.00	40.20	3.64	50.00	2.00	12.16	48.00	26.27	0.04	5.39	2947.69	128.96
UG70	36.00	42.53	3.57	39.00	4.00	10.54	35.00	25.88	0.03	4.49	2889.63	127.93
UG71	15.00	26.69	3.56	27.00	2.00	11.16	25.00	26.31	0.32	4.97	2889.63	128.72
UG72	22.00	25.89	3.50	33.00	2.00	11.67	31.00	21.18	0.26	6.08	2564.64	126.83
UG73	37.00	47.75	3.92	36.00	3.00	13.29	33.00	20.04	0.51	5.85	2504.26	124.86
UG74	22.00	40.89	3.29	61.00	4.00	16.35	57.00	22.95	0.18	7.32	2504.26	129.22
UG75	42.00	47.66	3.29	82.00	0.00	12.60	82.00	27.76	0.04	6.90	2564.64	129.26
UG76	5.00	15.42	3.39	44.00	4.00	12.10	40.00	22.13	0.16	5.58	2504.26	129.24
UG77	5.00	14.50	3.31	33.00	3.00	10.51	30.00	24.50	0.22	5.50	2504.26	128.25
UG78	11.00	21.24	3.50	101.00	4.00	11.24	97.00	40.80	0.15	5.33	2889.63	128.04
UG79	7.00	15.05	3.57	21.00	4.00	9.92	17.00	26.53	0.35	4.12	2889.63	127.98
UG80	9.00	18.84	3.23	25.00	3.00	11.98	22.00	24.36	0.27	5.45	2889.63	128.34
UG81	4.00	11.24	3.33	26.00	3.00	11.08	23.00	22.07	0.29	5.95	2564.64	130.71
UG82	6.00	15.20	3.26	25.00	3.00	11.54	22.00	22.92	0.27	5.61	2564.64	128.25
UG83	2.00	7.13	3.32	26.00	4.00	12.30	22.00	20.51	0.49	6.18	2564.64	128.08
UG84	3.00	9.94	3.13	22.00	4.00	9.92	18.00	24.72	0.27	4.21	2889.63	128.57
UG85	22.00	31.53	5.00	34.00	4.00	9.10	30.00	37.03	0.10	3.47	2893.90	128.28
UG86	10.00	18.51	3.61	101.00	0.00	9.77	101.00	39.11	0.10	4.58	2889.63	128.89
UG87	12.00	19.36	3.57	98.00	0.00	8.61	98.00	45.80	0.05	3.11	2893.90	132.62
UG88	27.00	42.53	3.72	40.00	4.00	8.67	36.00	29.71	0.09	3.31	2893.90	131.05

A.4 Ungauged Catchment Characteristics (continue...)

Station Name	Water Bodies	Grasses/Cereal crops	Broad leaf crops	Savanna	Evergreen Broadleaf forest	Decidous Broadleaf forest	Evergreen Needleleaf forest	Urban
UG67	0.00	0.00	0.00	99.25	0.00	0.00	0.00	0.75
UG68	1.06	0.00	0.00	98.94	0.00	0.00	0.00	0.00
UG69	0.00	0.00	0.00	93.82	6.18	0.00	0.00	0.00
UG70	1.81	0.00	0.00	94.58	0.60	0.00	0.00	3.01
UG71	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
UG72	2.04	0.00	0.00	97.96	0.00	0.00	0.00	0.00
UG73	0.00	1.70	0.00	37.13	0.00	0.00	0.00	0.00
UG74	0.00	1.92	0.00	97.12	0.00	0.00	0.00	0.96
UG75	7.73	1.55	0.00	88.14	0.00	0.00	0.00	2.58
UG76	0.00	0.00	0.00	86.36	0.00	0.00	0.00	13.64
UG77	4.00	0.00	0.00	96.00	0.00	0.00	0.00	0.00
UG78	2.00	2.00	0.00	96.00	0.00	0.00	0.00	0.00
UG79	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
UG80	4.55	0.00	0.00	95.45	0.00	0.00	0.00	0.00
UG81	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
UG82	3.45	0.00	0.00	96.55	0.00	0.00	0.00	0.00
UG83	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
UG84	7.14	0.00	0.00	92.86	0.00	0.00	0.00	0.00
UG85	14.14	1.01	1.01	10.10	0.00	0.00	0.00	73.74
UG86	16.33	2.04	0.00	81.63	0.00	0.00	0.00	0.00
UG87	11.29	0.00	0.00	85.48	3.23	0.00	0.00	0.00
UG88	28.80	2.40	0.00	57.60	11.20	0.00	0.00	0.00

A.4 Ungauged Catchment Characteristics (continue...)

Station Name	Catchment Area (km²)	Perimeter (kms)	Drainage Density (km/km²)	Elevation (masl)				Slope (%)			Prec	ETo
				Max	Min	Mean	Range	Max	Min	Mean	mm	mm
UG89	32.00	43.08	4.18	41.00	4.00	11.14	37.00	29.37	0.05	4.11	2947.69	125.98
UG90	31.00	32.27	3.56	35.00	6.00	11.92	29.00	35.22	0.01	3.20	2677.65	129.63
UG91	11.00	19.60	3.78	26.00	5.00	10.55	21.00	38.48	0.16	3.20	2893.90	128.08
UG92	9.00	19.96	3.55	47.00	6.00	15.64	41.00	23.25	0.34	5.81	3044.35	129.91
UG93	5.00	12.53	3.52	23.00	3.00	8.18	20.00	35.13	0.13	2.92	2893.90	123.91
UG94	30.00	32.82	3.52	32.00	4.00	11.94	28.00	27.72	0.25	4.10	2947.69	124.24
UG95	13.00	24.21	3.35	39.00	4.00	14.02	35.00	22.65	0.14	6.42	2947.69	128.96
UG96	12.00	25.58	3.19	38.00	5.00	11.15	33.00	29.98	0.15	4.11	2947.69	132.72
UG97	11.00	19.73	3.52	40.00	4.00	10.31	36.00	29.66	0.13	3.74	3072.21	138.02
UG98	267.00	116.78	3.31	1.00	0.00	0.09	1.00	72.76	0.39	10.00	4075.61	138.02
UG99	46.00	43.48	3.00	127.00	5.00	44.76	122.00	20.89	0.41	12.98	3824.55	134.37
UG100	28.00	33.01	3.18	120.00	0.00	50.75	120.00	19.79	0.52	13.05	3573.49	132.69
UG101	15.00	20.34	3.11	80.00	6.00	30.74	74.00	21.46	0.21	10.71	3573.49	132.87
UG102	16.00	26.19	3.30	115.00	5.00	44.08	110.00	19.79	0.35	11.98	3573.49	132.85
UG103	30.00	34.54	3.53	110.00	4.00	46.05	106.00	20.30	0.49	10.49	3573.49	132.74
UG104	13.00	25.37	3.25	88.00	4.00	16.63	84.00	27.11	0.04	6.60	5025.71	132.78
UG105	9.00	16.24	3.25	53.00	0.00	13.10	53.00	25.00	0.13	7.22	5025.71	131.75
UG106	48.00	41.97	3.51	94.00	4.00	28.25	90.00	22.78	0.26	9.85	3449.06	122.83
UG107	535.00	154.41	3.40	1497.00	800.00	919.70	697.00	25.30	0.12	18.76	1702.82	124.07
UG108	188.00	81.26	3.30	1601.00	686.00	901.09	915.00	23.43	0.34	10.00	1452.60	128.40
UG109	774.00	178.32	3.03	2470.00	431.00	1080.14	2039.00	25.22	0.11	10.50	1083.82	130.20
UG110	250.00	89.03	3.40	2528.00	462.00	1441.73	2066.00	25.15	0.06	10.40	1372.29	129.40

A.4 Ungauged Catchment Characteristics (continue...)

Station Name	Water Bodies	Grasses/Cereal crops	Broad leaf crops	Savanna	Evergreen Broadleaf forest	Decidous Broadleaf forest	Evergreen Needleleaf forest	Urban
UG89	9.46	0.00	0.00	78.38	12.16	0.00	0.00	0.00
UG90	33.57	4.20	0.00	61.54	0.70	0.00	0.00	0.00
UG91	3.85	0.00	0.00	90.38	1.92	0.00	0.00	3.85
UG92	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
UG93	4.35	0.00	0.00	17.39	0.00	0.00	0.00	78.26
UG94	8.45	0.70	0.00	80.28	10.56	0.00	0.00	0.00
UG95	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
UG96	1.85	0.00	0.00	98.15	0.00	0.00	0.00	0.00
UG97	16.98	15.09	0.00	60.38	7.55	0.00	0.00	0.00
UG98	0.00	0.00	0.00	98.95	1.05	0.00	0.00	0.00
UG99	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
UG100	0.00	0.77	0.00	99.23	0.00	0.00	0.00	0.00
UG101	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
UG102	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
UG103	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
UG104	1.79	1.79	0.00	96.43	0.00	0.00	0.00	0.00
UG105	12.50	0.00	0.00	75.00	12.50	0.00	0.00	0.00
UG106	0.44	2.21	0.44	96.90	0.00	0.00	0.00	0.00
UG107	0.00	0.20	3.09	55.05	27.83	13.83	0.00	0.00
UG108	0.00	0.00	0.34	41.83	30.40	27.43	0.00	0.00
UG109	0.00	3.52	8.79	57.65	29.71	0.33	0.00	0.00
UG110	0.00	6.01	0.00	74.40	19.59	0.00	0.00	0.00