**TALLINN UNIVERSITY OF TECHNOLOGY**

SCHOOL OF ENGINEERING

Department of Civil Engineering and Architecture

# Assessing Baseflow Index Contribution to Estonian Rivers

# Eesti jõgede baasäravoolu osakaalu hindamine

MASTER THESIS

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Tallinn 2022

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# THESIS TASK

**Student**: BEN NA-SNOH GRANT 194394EABM

Study programme, Master Degree

Main specialty: Environmental Engineering and Management

Supervisor(s): ARVO IITAL, Doctor, Professor,

**Thesis topic**: **Assessing Baseflow Index Contribution to Estonian Rivers** (in English)

**Eesti jõgede baasäravoolu osakaalu hindamine** (in Estonian)

**Thesis main objectives**:

1. Assessing Baseflow Index (BFI) contribution to 11 selected Estonia rivers
2. Identifying seasonal runoff increasing and decreasing trends of the selected rivers
3. Creating a reference study for further research on BFI for these rivers

**Thesis tasks and time schedule:**

| No | Task description | Deadline |
|---|---|---|
| 1. | Literature review | 10. 2021 |
| 2. | Data collection of daily flow for 14 rivers discharging to the Baltic Sea and data calculation | 11.2021 |
| 3. | Analysis on groundwater runoff into rivers | 12.2021 |

**Language:** English **Deadline for submission of thesis:** “5” January.2022a

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## LIST OF ABBREVATION AND ACRONYMS

| | |
|---|---|
| BFI | Baseflow index |
| BFLOW | Baseflow separation |
| CSI | Composite Sustainability Index |
| EEA | European Environment Agency |
| ET | Evapotranspiration |
| DOC | Dissolved Organic Carbon |
| FUKIH | Filtered smoothed minima baseflow separation method of the United Kingdom Institute of Hydrology (UKIH) |
| GP | Genetic Programing |
| HSC | Habitat Sustainability Curse |
| HYSEP | Streamflow Hydrograph Separation |
| IPCC | Intergovernmental Panel on Climate Change |
| LOADEST | Load Estimator |
| Ntot | Nitrogen total |
| Ptot | Phosphorous |
| PCA | Principal Component Analysis |
| RDF | Recursive Digital Filter |
| UKIH | United Kingdom Institute of Hydrology |
| USGS | United State Geological Survey WHAT |
| | Web-Based Hydrograph Analysis Tool |
| WRM | Water Resource Management |
| WTF | Water Table Fluctuation |
| WUA | Weighted Usable Area |

# CHAPTER ONE

## 1. INTRODUCTION

Base-flow is defined as stream-flow discharging from a low subsurface and shallow subsurface storage track between precipitation and/or snowmelt activities (Tallaksen, 1995; Price, 2011), and which is determined as a hydrological phenomenon that represents a total catchment response to meteorological and other environmental signals (Bloomfield et al., 2011). It can be considered an amalgamated result of a wide range of natural and human-influenced surface and sub-surface catchment processes.

Base-flow is considered a stream-low component that correlates with groundwater flow and discharges from a variety of tributary sources. Base-flow considers groundwater flow, part of interflow (water in the unsaturated zone) traveling in subsoil and tributaries or delayed sources. It is very useful in river flow seasonal regulations, supporting aquatic species, and keeping a steady flow of water supplies. It is also used to explain nutrient and chemicals transport through rivers and hydropower generation as well. These separation methods are built to partition the fast from slow base-flow components. This is done by pointing the start rising limbs and the end surface runoff of the total stream hydrograph (Bloomfield, Allen, and Griffiths et. al., 2009).

The method for determining or measuring the ratio of long-term mean base-flow to total stream flow which indicates the slow continuous contribution of groundwater to river is called base-flow index (BFI). With the use of BFI a river's base flow over a specific period can be determined; which can be expressed in percentage. A result of BFI relies largely on climatic and physiographic features of catchments. This can be obtained went hydrograph separation is completed.

## 1.1. Background

In general, river flow is assessed into two groups: surface flow and subsurface flow. The subsurface flow is defined as the base-flow contributions to river flow. The base-flow refers to the flow rate from underground to a stream. The base-flow is closely related to geological catchment properties. Base-flow often influences the surface channel and hyporheic zones which will maintain a river's productivity and biodiversity, habitat availability, and aquatic species migration, and influence water quality. The degree of dependency on the base-flow is important for maintaining the biodiversity, habitat connectivity, composition, and function of an aquatic ecosystem (Water, 2018). Understanding the characteristics of the base-flow is vital when handling various environmental issues (e.g., aquatic ecosystem, water quality, and river restoration). However, unfortunately, base-flow cannot easily be measured using direct methods and commonly it's estimated by employing a sort of methods. The conventional approach to base-flow assessment is typically based on hydrograph analysis on a long-term basis, for example, the displacement recession curve techniques, the curve-fitting method, the Water Table Fluctuation (WTF) method, the hydrograph-separation method, BFlow, and the Web GIS-based Hydrograph Analysis Tool. Several fundamental approaches underlying the varied analysis methods are developed, but these aren't always correct. This is because the hydrological cycle is a complicated physical process and involves highly three-dimensional flows. An alternative method is to use techniques for computational modeling of fluid dynamics. This method can indeed be used to reveal the detailed mechanisms that are relevant to the entire terrestrial portion of the hydrologic cycle (Hydrol, 2008).

Base-flow is usually determined by employing hydrometric or the tracer-based hydrograph separation method to breakdown the various stream-flow contributions (Smakhtin, 2001). Hydrometric-based hydrograph separation contains vast period of usage but has however been questioned over its vague results relative to contemporary methods established on chemical based or isotopic tracers (Klaus and McDonnell, 2013).

These contemporary methods are concluded to be physically more significant with ability to predate the water with respect to age (transit and residence time modeling), water merging (e.g. pre-event and event water), and the starting point of various water contribution (e.g. groundwater, snowmelt). However, most often isotope or chemical data sets are accessible for a limited period of time. Therefore, hydrograph analysis is the most effective means in determining the quantity of slowly varying flow or delayed streamflow.

Estimation of the slow reaction to likely sources are essential to presuming stream flow, including its seasonal variation and water sustainability. The role of seasonal contributions to stream-flow is significant to understanding environmental flow assessment is key because the due to the variation of the high and low flows which are critical to the integrity of river ecosystem (Acreman, 2016). Various slow contributions may support stream-flow during time duration with low precipitation which are rather essential to understanding aquatic ecosystems at risk due to global warming impact (Olden et al., 2011). For wet season periods, stream-flow contributions will eventually experience a relatively slower flow (e.g. the result of regular rainfalls). For dry season periods, catchment specific drainage of water storages, such as groundwater aquifers, snowmelt, wetlands, etc., to sway the steadiness and the inter-annual variability of low flows.

## 1.2. Problem statement

Groundwater and surface water can be considered a single water resource and thus it is important to understand groundwater influence to stream-flow, or base-flow, within a region. BFI is key to water management in understanding the seasonal discharge and nutrients of the rivers, because a better understanding of baseflow is essential to the health of Estonian rivers. An extensive baseflow index study of all the rivers covered in this study has not be done of recent.

## 1.3. Aim and objective

One of the major aims of the study besides of the calculation of BFI is to compare the BF with total flow and compare the results with some previously produced results in Estonia. This master's thesis goal is to assess the contribution of base-flow on 11 Estonian rivers looking at the monthly and annual base-flow contributions from tributaries and other sources. The comparison of the trends in the flow over these years of study is intended to provide an understanding to the changes in water supply to these rivers vis-à-vis climate change impact on the Estonia hydrological cycle. This is essential to water resource management, water quality, aquatic organisms, and nutrient runoff.

# CHAPTER TWO

## 2. LITERATURE REVIEW

The statistical distribution of weather patterns is subject to change with factors like air temperature and precipitation influencing the hydrologic cycle, and thereby, water resources. Climate change is caused by a combination of natural processes and human activity, although the extent of anthropogenic influence is still uncertain. According to the Inter-governmental Panel on Climate Change (IPCC) fourth assessment report, the global linear trend (1906 – 2005) for the annual near-surface mean temperature has been increasing by 0.74 oC per decade (IPCC, 2007). Furthermore, according to Tietavaiinen et al. 2010, the rate of warning has tripled during the last 50 years (up to 0.30 oC per decade) in the northern part of the Baltic Sea (Finland). Jaegus (2006) analyzed the time series trends of air temperature and precipitation in Estonia during the period 1951 – 2000. There was a statistically significant increase in the air temperature trend during the cold period. Increases were also present in the precipitation trend from October to March, and in June. Furthermore, he determined that the snow cover duration in Estonia has decreased to 17-20 and 21-36 days on the inland and coast, respectively. An increase in winter flow has been detected in the Baltic Sea sub-basins, attributed to the earlier snowmelt caused by higher temperatures (BACC Author Team, 2008). From the above, it can be concluded that the climate in the eastern Baltic Sea region is changing. As climate changes are expected to continue in the current century, the future impact of climate change on hydrology (I, II) is of great interest to both scientists and policymakers.

## 2.1. Base-flow Index Assessment

In further studies, it is explained the traditional method to separate the base-flow is to research the discharge records (Arnold and Allen 1999, Arnold et al. 1995; Aksoy et al. 2009; Wang and Cai 2010). Determining the relative contributions of base-flow and surface runoff is usually of prime importance for the choice of watershed management strategies and techniques related to development projects, and the water quality variables needing most attention during a watershed are closely linked to the sources of flow. The geology of a region impacts its baseflow. Groundwater is mostly housed in rocks which is a baseflow contributor; and the difference in the rock type influences the groundwater, recharge, and baseflow. The petrological attributes of the catchment impact long-term eroding and the physiographic of the catchment which influences the soil and the magnitude of precipitation across the catchment area. These listed factors have huge impacts on the BFI which is the observational measure of the baseflow (Lacey and Grayson 1998). The development of methods to estimate or separate base flow from streamflow is progressing contemporarily with time. Regression models are popular in research due to their ability to be easily used to estimate base-flow with reasonable accuracy (Ahiablame et al. 2013; Zhu and Day 2009). However, more digital methods for implementing separation of base-flow from stream hydrographs have developed. Base-flow index are often understood because the ratio of long-term mean base-flow to the entire stream-flow (Beck et al. 2013; Eckhardt 2008). These baseflow indices have been utilized alone, or concerning selected watershed variables, for the estimation of the base-flow component of watershed yield in gauged and ungauged watersheds (Beck et al. 2013; Lacey et.al. 1998; Mazvimavi et al. 2004; Neff et al. 2005; Eckhardt 2008). In a recent study, Zhang et al. (2013) employed a two-parameter recursive digital filter method to determine the base-flow index in Michigan (USA). Meshgi et al. (2014) using an empirical equation to approximate base-flow time series using Genetic Programming (GP) and a groundwater numerical model for an urban watershed in Singapore conducted a study.

The results based on three parameters: minimum daily base-flow of the entire period, watershed area, and variation in groundwater table showed that this approach is better for base-flow estimation for an un-gauged watershed without stream-flow discharge.

Li et al. (2014) simulated two different filters and located that the Lyne and Hollick (LH) filter performs relatively better than the Boughton and Eckhardt filters, for a variety of physical conditions at the watershed scale. However, the numerous separation methods produce widely varying estimates of base-flow indices (Eckhardt 2008, Gan et al, 2015) with the utilization of automated digital filter method of base-flow separation using historical long-term daily stream-flow data and fed by rainfall, snowmelt, and glacier melt, and reported that the base-flow index, with 65% variability, was expressively correlated with catchment climatic factors and aquifer properties. Factors that increase and facilitate infiltration and recharge of subsurface storage will produce the rise in base-flow, while factors related to higher evapotranspiration (ET) will reduce base-flow. Therefore, there is a need to explore the possible relationship of these base-flow indices with the physiographic and physical characteristics of the watershed for the separation of stream hydrograph into a slow response component and a rapid response component. Therefore, in comparing the study objective with other objectives below:

i. To gauge and compare the most conventionally used six base-flow separation methods for application in Southern Ontario conditions, and

ii. To describe base-flow dominated and quick response flow dominated by watersheds which is associated base-flow indices with the physiographic and physical characteristics of a watershed.

Freshwater is important to an enduring ecosystem. During dry weather sustained stream-flow is vital for groundwater-surface-water-interactions (Sophocleous, 2002), stream-flow drought severity (Zaidman et al., 2002), the variability of water temperature (Constantz, 1998), or the dilution of contaminants (Schuetz et al., 2016). In hydrology, sustained stream-flow and hence freshwater availability is often estimated by the amount or timing of base-flow or as a single value base-flow index (BFI). The BFI is that the proportion of base-flow to total stream-flow, thus higher BFI values are often understood as an indicator of huge water quality being provided from stored sources (Tallaksen and van Lanen, 2004).

Total stream-flow is composed of quick- and base-flow. Quick flow is the portion of total streamflow originating rather directly from precipitation input (also termed direct runoff or storm-flow). In contrast, different names for base-flow (i.e. sustained flow, delayed flow, groundwater flow, and dry- or fair-weather flow) highlight its relevance during prolonged dry weather. Base-flow has most commonly been considered as the flow of groundwater from delayed sources (Hall, 1968).

In further studies, it is explained because of the contribution from continuous and slowly different sources, including groundwater flow (Sophocleous, 2002). Dingman (2015) understands base-flow as water maintaining stream-flow between water-input events. Between these events, different sources like groundwater, meltwater from snow, glacier or ice, lakes, riverbanks, floodplains, wetlands, spring, or return be due irrigation can contribute to the base-flow component of stream-flow (Smakhtin, 2001). Using the definition of baseflow, baseflow can be explained as the quantity of base flow and its seasonal variability is regulated by multiple delayed sources. Groundwater contributes to the base-flow component of the river's stream-flow, but base-flow is not a measure of groundwater storage only. There are several methods for determining base-flow separation, namely Lyne and Hollick digital filter, Eckhardt digital filter method, etc. (Lyne and Hollick, 1979). Soil profile can also be used as a parameter for understanding base-flow (Bastola, Seong, Lee, Youn, Oh, Jung, Choi and Jang et. al., 2018). The Institute of Hydrology of the United Kingdom has developed a soil grouping category that approximates the flow duration and frequency (Gustard et. al., 1992, Boorman et al., 1995). The effective calculation is pivotal to systematic river ecology supervision (Bastola, Seong, Lee, Youn, Oh, Jung, Choi, and Jang et. al., 2018).

The specification of direct runoff and base- flow is essential in river management. Base-flow separation study done in Nepal employed three methods, namely; WHAT, BFLOW and HYSEP (Bastola, Seong, Lee, Youn, Oh, Jung, Choi and Jang et. al., 2018).

WHAT is a base-flow separation method used in online analysis (Bastola, Seong, Lee, Youn, Oh, Jung, Choi and Jang et. al., 2018). It means module is the Eckhardt filter. Eckhardt filter parameter has "aquifer characteristics". In this module BFI, max should be provided. This is the ratio maximum value on a long term to the total stream-flow. The accuracy of the BFI max selection is key in obtaining the best result of separation in this module (Bastola, Seong, Lee, Youn, Oh, Jung, Choi and Jang et. al., 2018).

BFLOW separation method is associated with Lyne and Hollick recursive digital technique. This method of analysis signals separation from high frequency ranges to low (Bastola, Seong, Lee, Youn, Oh, Jung, Choi and Jang et. al., 2018).

BFLOW equation: $Fk = a . fk-1 + 1+a/2 (Yk-Yk-1)$

$$bk = Yk-fk \text{ if } 0 \leq bk \leq yk$$

In this equation, *fk* is the filtered quick response, k is the sampling instant, yk is the original streamflow, *a* is the filter parameter and *bk* is the base-flow (Bastola, Seong, Lee, Youn, Oh, Jung, Choi and Jang et. al., 2018). HYSEP method is software introduced by the U.S. Geological Survey. This separation technique employs three methods, namely; fixed-interval (H1), Sliding-interval (H2), and local minimum (H3) (Sloto et. al., 1996). The software method systematically connects lines of low points indicating the base-flow hydrograph (Bastola, Seong, Lee, Youn, Oh, Jung, Choi and Jang et. al., 2018). As Price (2011) has noted in his study, there are four broad approaches to quantifying base-flow, they are as follows: low flow event time 70 series; flow-duration statistics; base-flow recession analysis; and, metrics of the proportion of base-flow to total flow, also known as base-flow indices. The research was provided understanding specifically on the two methods of Baseflow Index (Coxon et al., 2020a; 2020b).

## 2.2. Contribution of Base-flow to River Flow

River flow can be categorized into surface flow and subsurface flow. The subsurface flow is essential, because of the baseflow contributions to river flow (Choi, Kang and Lee et. al., 2018). The baseflow generally, refers to the delayed flow of groundwater into stream. When considering baseflow the geological catchment properties are recognized. Baseflow is of importance to the surface channel and hyporheic zones that contributes to retaining a river's "productivity and biodiversity, habitat availability and aquatic species migration, and influence water quality" (Choi, Kang and Lee et. al., 2018). A higher understanding of baseflow is paramount to monitoring biodiversity, habitat connectivity, composition, and performance of an aquatic ecosystem (Choi, Kang and Lee et. al., 2018).

The importance of base-flow intrusion into aquatic ecosystem processes and biodiversity in rivers has been addressed in this previous study (e.g. Choi, Kang, and Lee et. al., 2018). Habitat availability and aquatic species migration, and influence water quality. The reliance on the knowledge of base-flow is important for maintaining the biodiversity, habitat connectivity, composition, and function of an aquatic ecosystem which provides important oversight when handling various environmental issues (e.g., aquatic ecosystem, water quality, and river restoration). However, unfortunately, base-flow cannot easily be measured using direct methods and commonly it's estimated by employing a sort of methods. Several fundamental approaches underlying the varied analysis methods are developed, but these are not always correct. This is because the hydrological cycle may be a complicated physical process and involves highly three-dimensional flows. an alternate method is to use techniques for computational modeling of fluid dynamics. This method can indeed be wont to reveal the detailed mechanisms that are relevant to the whole terrestrial portion of the hydrologic cycle (Kronholm and Capel 2015).

In stream structures, like dams, it can affect the flow regimes, and end in reducing or increasing flows; changing the frequency, duration, magnitude, and timing; and altering the extent of surface and subsurface water. Dams also block the flyway for fish, reduce the density and composition of aquatic species like phytoplankton and benthic macroinvertebrate, decrease aquatic species growth and survival,  and alter the morphological and hydrological conditions of the stream. additionally, flow patterns are regularly changed by pumping or extraction of surface and subsurface water. The change of flow regimes affects both the aquatic ecosystems and therefore the biodiversity within the downstream reach from the dam. To mitigate the dam effects, various ecological models are proposed and used. Nguyen et al. 2018, acknowledged that ecological models are a crucial tool for investigating the impacts of dams on the aquatic habitat. They developed an integrated conceptual model which will be wont to select an appropriate ecological modeling method to assess the complex interactions in aquatic ecosystems. Aquatic ecosystems are complex and ecological indicators are often wont to represent and understand them, which may be useful in restoring or designing rivers. Previous studies showed that released water from a dam adversely affects the downstream fish habitat (Carpenter et al., 1998; Smith et al.,  1999).

A variety of physical habitat simulations are administered, showing that hydropeaking and Thermo peaking flows decrease habitat suitability for target species within the downstream reach of the dam. However, most previous physical habitat simulations did not consider the base-flow and modifying dam operations effects when analyzing the drawback of regulation by the dam on the aquatic habitat.

As a general strategy, a scenario of the modification of dam operations through natural flow patterns is presented. The determination of the impact of the proposed scenario in physical habitat simulations was performed quantitatively. The Composite Suitability Index (CSI), which is an aggregation of habitat suitability indices including individual physical habitat variables and therefore the Weighted Usable Area (WUA). Under modified dam operations were computed, and that they are discussed.

Intensification of human activities has led to widespread nutrient enrichment of surface waters causing a variety of environmental, social, and economic problems encompassed under the term of eutrophication (Carpenter et al., 1998; Smith et al., 1999). the foremost common effects of eutrophication are enhanced vegetation growth and therefore the imbalance of the aquatic ecosystems (Smith et al., 1999). However, the degradation of water resources by eutrophication has also more far-reaching effects like fishing and boating recreation use losses, reduced biodiversity and conservation and amenity values, human health threat through the assembly of toxic cyanobacterial blooms (Carpenter et al., 1998; Smith et al., 1999; Moss et al., 2005; Dodds et al., 2009). Rivers directly impact due to population centers and sensitivity to land-use changes (Withers & Jarvie, 2008). Nutrient concentrations in rivers are of great importance to the ecology of the river itself, but riverine transport of nutrients is additionally relevant to any longer receiving medium (Salvia-Castellví et al., 2005). Eutrophication is that the most serious environmental problem in many shallow lakes in lowland areas (Moss et al., 2005). Example is the Estonian Lake Peipsi. Eutrophication has led to undesirable growth of algae, massive blooms of cyanobacteria amid oxygen depletion during the night and fish kills, low tide transparency, and siltation of rock bottom of water bodies (Kangur & Möls, 2008). To reduce the nutrient input into lakes there should be focus especially on decreasing the inputs by rivers, and requires knowledge of the sources and their contribution to the transport by the rivers which brings in the knowledge of baseflow (Behrendt & Opitz, 2000). Regional differences in weather and therefore the hydrological regime in catchments alongside local variations in nutrient emissions from various point and diffuse sources have an excellent impact on the accuracy of estimating the riverine loads (Kronvang et al., 2007).

The qualitative and quantitative observation of nutrients (i.e. concentrations and loads) are needed in order characterize and predict for systematic feedback on river conditions. In other studies, they focused on nitrogen and phosphorus because the improved availability of those nutrients may be a worldwide cause for the eutrophication of rivers, lakes, estuaries, and coastal oceans (Carpenter et al., 1998).

### 2.3. General Description of Estonian River Basin Districts

The Estonian rivers basin districts are divided into the West-Estonia river basin, East-Estonia river basin and Koiva river basin districts (Ministry of Environment, 2015).

I. The East-Estonia river basin district including the Peipsi, Viru, and Võrtsjarve sub-river basin; (Sandra Oisalu, Baltic Environmental Forum – Estonia, 2007)

II. The West-Estonia river basin district including Läänesaarte, Harju, Matsalu and Pärnu sub-river basins; (Sandra Oisalu, Baltic Environmental Forum – Estonia, 2007)

III. The Koiva river basin found in the south forms a joint cross border river basin with Latvia. (Sandra Oisalu, Baltic Environmental Forum – Estonia, 2007)

The description of these river basins is to display the hydrological view of Estonia in which the rivers in this thesis form part of. The location of each of rivers selected for this thesis is indicated in the text describing each river.

## 2.4. Baseflow Separation Method

The methods to separate base-flow from the flow are investigated by many researchers, like Arnold et al. (1995), Aksoy et al. (2009), Wang and Cai (2010), et al., Arnold et al. (1995) developed an automatic base-flow separation method employing a digital filter and tested it against three other automated techniques and manual separation methods. Since then the automated base-flow separation method has been widely wont to separate baseflow from the streamflow.

Aksoy et al. (2009) coupled the smoothed minima base-flow separation method of the UK Institute of Hydrology (UKIH) with the recursive digital filter (RDF) to develop the filtered smoothed minima base-flow separation (FUKIH) method, during which a smooth hydrograph representing the base-flow generating mechanisms is obtained. Wang and Cai (2010) provided an analytical base-flow recession equation to debate the impact of human interferences, which include groundwater pumping, water diversion, and return flow, on the determination of the recession slope curve. within the study, the automated base-flow separation method proposed by Arnold et al. (1995) (hereafter noted as Arnold separation method) is employed to separate the base-flow of the daily stream-flow at Beidao hydrological station within the Upper Wei basin from 2001 to 2004. The base-flow index is defined because the ratio of the base-flow to the entire runoff. With the daily base-flow from the Arnold separation method, the typical intra-annual monthly base-flow index and annual base-flow index are calculated.

# CHAPTER THREE

## 3. METHODOLOGY

### 3.1 Method of the Baseflow Index Study

This thesis analyzes groundwater runoffs to major Estonian rivers flowing into the Baltic Sea (Gulf of Finland) and calculated the baseflow index of each of these rivers which also indicates seasonal baseflow contribution. Daily runoff discharge was calculated to determine the baseflow and the baseflow index of these rivers in order to identify the slow continuous contribution of groundwater to river flow.

The knowledge of the BFI of these rivers is important to understanding the nutrients entering streamflow from wastewater, agricultural processes and urban runoff (industrial waste). These groundwater runoff into rivers eventually end up into the Gulf of Finland contributing to eutrophication.

### 3.2 Selected Rivers and Map

This thesis research covers eleven major Estonian rivers which run into the Baltic Sea at the Gulf of Finland; namely, Jagala, Keila, Loobu, Kunda, Pirita, Purtse, Puhajogi, Pudisoo, Selja, Valgejogi, and Vihterpalu. These rivers were selected for this study because they are some of the largest and most important river in Estonia running into the Baltic Sea at the Gulf of Finland. Their catchments or basin are some of the largest in Estonia holding large agricultural space, forest, wetlands, etc. The 11 rivers chosen for this study provide detailed information on the various river districts in Estonia. Majority of these rivers play a significant role in the livelihood of Estonia from industrial use to public use.

There are other rivers like Parnu and Narva rivers which discharges in the Baltic Sea at the Gulf of Finland, but they are not included in this study due to the fact that research on their runoff have been partial covered in other studies.

The research cover data and river characteristic over 30 years. This is a lengthy period which provides sufficient comparison on the wavelength movement or highs & lows of groundwater flow or runoffs and nutrient losses out of these catchments. The impact of global warming and climate change can be seen in this period. There has been lots of development agricultural practices changes in water usage/abstraction, industrialization, geology and land-use in Estonia and these rivers over the last three decades.

This thirty-year period is very significant because advancement of technology to monitoring groundwater flow has heavily impacted scientific research during period. The effect of climate change is visible during this period, promoting a global debate or discussion of this subject.

These changes in climatic conditions are mostly in annual temperature and annual precipitation which influences baseflow, considering extremely hot & wet years.

During this period there has been reported increase in winter runoff discharge in the sub-basin of the Baltic Sea. High temperature is responsible for each snow melt (BACC Author Team, 2008). The impact of climate change during these years can be seen from the above-mentioned indicators. With urban migration increasing from the end of the 1990s to the 2000s with change in land-use has impacted hydrology and water resources as well (Wang et. al., 2006).

The respective positions of these rivers and their hydrological stations in Estonia can be seen in figure 1. Hydrometric station map of Estonia. These rivers are represented by a blue line and number.

Fig. 1: River and their hydrological stations on the Estonian map.
1.Kasari (not in this study) 2. Vihterpalu 3. Keila 4. Vaana (not in this study) 5. Pirita 6. Jagala 7. Pudisoo 8. Valgejogi 9. Loobu 10. Selja 11. Kunda 12. Purtse 13. Puhajogi 14. Narva (not in this study)
Source: Diego Ordonez, Master Thesis, TMDL of nutrient of 14 Estonian river

### 3.3 Data Sources and Availability

The long-term daily flow hydrological monitored data of Estonia rivers is available and can be acquired from the “Historical Observation Data” bank of the Estonian Weather Service.

The data used for this study are secondary date of daily river discharges, annual total nutrient load of nitrogen & phosphorous, information on agriculture and land cover data of various catchments or basins.

These BFI data are calculated with the use of software “A. Gustard, A. Bullock, J.M. Dixon, 1992.. **Low Flow Estimation in the United Kingdom. Report No. 108**, Institute of Hydrology, United Kingdom” and the “Marco” developed by A. Vassiljev at the Tallinn University of Technology were used in the calculation of BFI with the use of these equations:

BFI = VB/VA

BFI is defined as the ratio VB/VA where VB represents the volume beneath the baseflow separation line and VA represents the mean flow beneath the hydrograph.

Firstly, the daily discharge data was collected from the "Estonia Weather Service" inland database of water levels. The Estonia Weather Service holds rivers' daily discharge as far back as the early 1920s to 2020. Data found on the website are scientifically generated through monitoring devices and systems. These data are grouped according to each month and year of the thirty-year study. In some cases, data were not found from 1990 to 2020. Example of case are rivers Loobu river (Arbavere station) 2007-2020, Pirita river (Kloostrimetsa station) 2000-2020, Puhajogi river (Tolia-Oru station) 2008-2020. Reasons for these omissions are not revealed on the Estonia Weather Station. The BFI and baseflow results aid the analysis of small to medium water supply or flow, water quality, nutrient loads, and the environment of the river basin or catchment. These data are used to help understand the seasonal flow out of the catchment groundwater into the rivers; which is important for water resource management.

### 3.4 Gathering Data

With the use of these data gathered of each of these rivers on the long-term daily groundwater runoff during the thirty years period of study (1990-2020) the daily baseflow and yearly BFI was calculated.

### 3.5 Rivers and Characteristics

Table 1. Main characteristics of rivers with nutrient load data from 2014-2019
Source: Lips, Iital, Väli, Laanemets, Stoicescu, Pachel, Loigu, Roosalu, 2021. Siseveekogude ja mere veenormide vahelised seosed ja võrreldavus. Lõpparuanne (in Estonian).Tallinn University of Technology, 190 p

| Rivers | Size km | Catchment area km2 | Agricultural area % | Forest area % | Wetland % | Water % | Nutrient load discharge to river t/y (Nitrogen, Phosphorous total) 2014-2019<br>Ntot Ptot |
|---|---|---|---|---|---|---|---|
| Jagala-Jagala | 98.8 | 1,481.3 | 31 | 62.5 | 4.4 | 0.3 | 0.9, 8.1 |
| Keila-suue | 107 | 669.3 | 47 | 45 | 5.3 | 0 | 1.6, 7.1 |
| Kunda-Kunda | 65.8 | 528 | 37 | 59.1 | 2.4 | 0.1 | 0.1, 0.4 |
| Loobu-Vihasoo | 62 | 308 | 45 | 51.6 | 2.9 | 0 | 0.5, 2.0 |
| Pirita-Lukati | 105 | 794 | 37 | 56 | 3.0 | 0.7 | 0.7, 2.8 |
| Puhajogi | 36.5 | 219.7 | 32 | 58.1 | 0.0 | 0.2 | 0.9, 4.3 |
| Pudisoo-Pudisoo | 32 | 132 | 20 | 75 | 3.4 | 0 | 0.2, 0.3 |
| Purtse-suue | 51.2 | 811 | 24 | 66 | 5.3 | 0.1 | 2.3, 6.8 |
| Selja-Selja | 47.7 | 410 | 67 | 28.7 | 0.2 | 0 | 2.4, 7.4 |
| Valgejogi-Loksa | 85 | 451.5 | 29 | 62 | 5.2 | 0.4 | 0.5, 2.9 |
| Vihterpalu-Vihterpalu | 54 | 474 | 17 | 72 | 10.6 | 0 | 0.002, 0.03 |

- Jagala river is found in north-west part of Estonia with an average flow of 7.3 m3/s (https://keskkonnaportaal.ee/register/body-of-water/8380306) . Jagala river forms part of the West-Estonian river basin district. This flows through Jarva and Harju counties and drain into the Ihasalu Bay and discharge into the Baltic Sea at the Gulf of Finland. The six major tributaries of this river are: Ambla, Janijogi, Mustjogi, Aavoja, Soodla and Joelahtme rivers.

  Jagala river forms part of the Natura 2000 network and is part of the Tallinn drinking supply system. This river supports several dams with Linnamae hydroelectric power plant being the highest at 11m in height on a 1.3km distance from the mouth of the river (Estonian Environmental Agency, EELIS Infoleht, 2021)

- Keila river is located in the north-west part of Estonia having an average flow of 6.45 m3/s (https://keskkonnaportaal.ee/register/body-of-water/8380306 ). Keila river belongs to the Natura 2000 network with the lowest point of 1.8 km. This river has a waterfall with a 6m height which is 1.7 km away from the Baltic Sea. Keila river as supports a hydroelectric power plant (Estonian Environmental Agency, EELIS Infoleht, 2021).

- Kunda river is found in the East-Estonia river basin district in the Laane-Viru county with an average flow of 4.42 m3/s (https://keskkonnaportaal.ee/register/body-of-water/8380306 ). This river forms part of the Natura 2000 network in its majority. The two major tributaries of this river are: Adara and Vaekula rivers (Estonian Environmental Agency, EELIS Infoleht, 2021). Kunda river supports five dams.
- Loobu river is found in the East-Estonia river basin district Eru Bay with an average flow of 2.36 m3/s (https://keskkonnaportaal.ee/register/body-of-water/8380306 ). This river forms part of the Natura 2000 network in its majority. The three major tributaries of this river are: Udriku, Vohnja and Lasna rivers (Estonian Environmental Agency, EELIS Infoleht, 2021). Loobu river has three man made constructions on it.
- Pirita river is found in north-west part of Estonia with an average flow of 7.77 m3/s (https://keskkonnaportaal.ee/register/body-of-water/8380306 ). The four major tributaries of this river are: Kuivajõgi, Tuhala, Angerja, and Leiva rivers. Pirita river belongs to the Natura 2000 network with the lowest point of 22 km. This river is an important part of the drinking water supply system of Tallinn (Estonian Environmental Agency, EELIS Infoleht, 2021).
- Pudisoo river is found in north-west part of Estonia with an average flow of 1.04 m3/s (https://keskkonnaportaal.ee/register/body-of-water/8380306 ) (Estonian Environmental Agency, EELIS Infoleht, 2021).
- Purtse river is found in the East-Estonia river basin district in the Ida-Viru and Laane county with an average flow of 6.56 m3/s (https://keskkonnaportaal.ee/register/body-of-

water/8380306 ). The four major tributaries of this river are: Hirmuse, Erra, Kohtla and Ojamaa. Purtse river supports a dam which is 4.9 km away from the mouth of Purtse river. Purtse river is one river which is not part of the Natura 2000 network (Estonian Environmental Agency, EELIS Infoleht, 2021).

- Puhajogi river is found in the East-Estonia river basin district Viru sub-basin with an average flow of 1.85 m3/s (https://keskkonnaportaal.ee/register/body-of-water/8380306). The two major tributaries of this river are: Rausvere and Vasavere rivers (Estonian Environmental Agency, EELIS Infoleht, 2021).
- Selja river is found in the East-Estonia river basin district in the Laane county with an average flow of 3.19 m3/s (https://keskkonnaportaal.ee/register/body-of-water/8380306). The major tributary of this river is called Someru river. This river supports a dam 39.2 km away from the Baltic Sea (Estonian Environmental Agency, EELIS Infoleht, 2021). The lower parts of this belongs to the Natura 2000 network.
- Valgejogi river is found in the East-Estonia river basin district with an average flow of 3.49 m3/s (https://keskkonnaportaal.ee/register/body-of-water/8380306). This river does not have any important tributary. Valgejogi river form part of the Natura 2000 network in its majority (Estonian Environmental Agency, EELIS Infoleht, 2021).
- Vihterpalu river is found in the West-Estonia river basin district with an average flow of 4.48 m3/s (https://keskkonnaportaal.ee/register/body-of-water/8380306).

# CHAPTER FOUR

## 4. RESULTS AND DISCUSSION

The result of BFI per river of each of this study is presented in table 3 and the result is also presented in graphs where the linear trends is visible, which shows a slight closeness to with each other with decreasing pattern in the annual BFI from the mid-1990s to an increasing or higher pattern in the 2000s. The BFI of the 1990s is mostly less the 2000s at most stations. The average of annual baseflow index this study is 0.681.

From the observation of the runoff data used in calculating the annual BFI the projection can be made that the seasonal baseflow of Estonia experienced changes relatively and seasonal BFI varied hugely relatively due to change from snowfall to rainfall, and warming effects and snow melting timing. Example to this claim can be seen in table 4 in which each runoff river is presented by per month in the year nominal value of 2000s.

An extensive daily runoff was recorded to estimate or determine the runoff flow rate or discharge. The result of BFI per river of each of this study is presented in table 2 and the result is also presented in graphs where the linear trends is visible, which shows a slight closeness to with each other with decreasing pattern in the annual BFI from the mid-1990s to an increasing or higher pattern in the 2000s. The BFI of the 1990s is mostly less the 2000s at most stations. The average of annual baseflow index this study is 0.681.

From the observation of the runoff data used in calculating the annual BFI the projection can be made that the seasonal baseflow of Estonia experienced changes relatively and seasonal BFI varied hugely relatively due to change from snowfall to rainfall, and warming effects and snow melting timing. Example to this claim can be seen in table 4 in which each runoff river is presented by per month in the year nominal value of 2000s.

The BFI analysis of these 11 stations from 1990 to 2020 which are the years of this research the data of daily streamflow when calculated projected station Arbavere (Loobu river) with the highest BFI of 0.920 in 2020 through the years, while the lowest BFI result was at the Tolia-Oru station (Puhajogi rive) with 0.378 in 2011 of these studied years.

In the graphs of some rivers it can be seen that there are rivers with decreased baseflow in the 1990s but increased the 2000s. In graphs of figure (3, 3.1, and 3.10) which are rivers Jagala, Pirita, and Vihterpalu the numerical data of the BFI per year of these rivers can be seen in table 3. But Vihterpalu river showed an interesting trend with most of its high and low BFI happening in the 2000s. It must be noted that Vihterpalu catchment has the largest wetland of these researched catchment and the global warming climate change development mostly in the 2000s has greatly impacted groundwater runoffs and baseflow. However, it is also clear that between 2008 to 2011 the BFI of some rivers took serious dip. According to my research one reason for this dip in BFI during this period can be due to the huge abstraction of groundwater for different public and industrial usages (https://www.oecd.org/env/resources/48925356.pdf). An example of this is Pirita river (graph…) which is in the Tallinn region an urbanized region which host the capital city where the extraction of ground and surface water is largely done (Ministry of Environment, 2005). It must be noted that although the Estonian water sector had under gone reforms in its water abstraction laws the global warming and climate change noticeable impacts shaping weather seasons cannot be overlooked. The change is air temperature, precipitation, snow melting time and rainfalls (Tan, Lin, and Tan et al., 2020).

From the BFI calculated during these years we can be seen that during the spring season which is usually dominated by rainfall and snow or glacier melts there is increase in groundwater runoffs which transports nutrients and chemicals to these rivers, thus influencing a reduced BFI of these rivers. While the summer season reduces groundwater runoffs due to depreciation of glaciers or snow and lack of much rainfall. With this a raise in BFI can be seen in the baseflow calculation and nutrients load of the rivers.

Table 2: Calculated BFI of each river over 30 years annually

| Year | Jagala | Keila | Loobu | Kunda | Pirita | Purtse | Puhajogi | Pudisoo | Selja | Valgejogi | Vihterpalu |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 0.77 | 0.68 |  | 0.84 | 0.66 | 0.61 |  | 0.65 |  | 0.77 | 0.56 |
| 1991 | 0.78 | 0.65 |  | 0.79 | 0.50 | 0.55 |  | 0.57 |  | 0.67 | 0.56 |
| 1992 | 0.81 | 0.78 |  | 0.85 | 0.70 | 0.73 |  | 0.75 |  | 0.80 | 0.67 |
| 1993 | 0.55 | 0.70 |  | 0.82 | 0.54 | 0.57 |  | 0.57 |  | 0.68 | 0.55 |
| 1994 | 0.61 | 0.58 |  | 0.85 | 0.48 | 0.57 |  | 0.58 |  | 0.64 | 0.38 |
| 1995 | 0.68 | 0.73 |  | 0.81 | 0.63 | 0.67 |  | 0.60 |  | 0.66 | 0.58 |
| 1996 | 0.69 | 0.67 |  | 0.88 | 0.61 | 0.51 |  | 0.66 |  | 0.73 | 0.38 |
| 1997 | 0.79 | 0.63 |  | 0.86 | 0.67 | 0.70 |  | 0.69 |  | 0.72 | 0.54 |
| 1998 | 0.74 | 0.65 |  | 0.78 | 0.64 | 0.61 |  | 0.60 |  | 0.78 | 0.59 |
| 1999 | 0.52 | 0.72 |  | 0.56 | 0.77 | 0.41 |  | 0.67 |  | 0.64 | 0.74 |
| 2000 | 0.76 | 0.66 |  | 0.77 |  | 0.63 |  | 0.69 |  | 0.77 | 0.68 |
| 2001 | 0.64 | 0.54 |  | 0.72 |  | 0.47 |  | 0.52 |  | 0.77 | 0.49 |
| 2002 | 0.76 | 0.66 |  | 0.84 |  | 0.67 |  | 0.72 |  | 0.76 | 0.72 |
| 2003 | 0.64 | 0.61 |  | 0.72 |  | 0.58 |  | 0.59 |  | 0.63 | 0.60 |
| 2004 | 0.69 | 0.60 |  | 0.66 |  | 0.61 |  | 0.58 |  | 0.62 | 0.63 |
| 2005 | 0.65 | 0.56 |  | 0.76 |  | 0.43 |  | 0.54 |  | 0.67 | 0.54 |
| 2006 | 0.78 | 0.82 |  | 0.79 |  | 0.51 |  | 0.49 |  | 0.69 | 0.39 |
| 2007 | 0.60 | 0.60 | 0.87 | 0.74 | 0.65 | 0.42 |  | 0.59 |  | 0.69 | 0.53 |
| 2008 | 0.74 | 0.73 | 0.73 | 0.77 | 0.68 | 0.55 | 0.48 | 0.66 |  | 0.71 | 0.67 |
| 2009 | 0.66 | 0.64 | 0.77 | 0.75 | 0.48 | 0.64 | 0.66 | 0.67 |  | 0.81 | 0.43 |
| 2010 | 0.61 | 0.59 | 0.68 | 0.69 | 0.53 | 0.49 | 0.48 | 0.69 |  | 0.79 | 0.49 |
| 2011 | 0.60 | 0.55 | 0.71 | 0.67 | 0.55 | 0.50 | 0.38 | 0.63 | 0.71 | 0.62 | 0.49 |
| 2012 | 0.73 | 0.69 | 0.83 | 0.80 | 0.75 | 0.65 | 0.68 | 0.63 | 0.82 | 0.74 | 0.65 |
| 2013 | 0.60 | 0.55 | 0.75 | 0.76 | 0.62 | 0.47 | 0.58 | 0.59 | 0.73 | 0.69 | 0.44 |
| 2014 | 0.78 | 0.72 | 0.89 | 0.84 | 0.70 | 0.67 | 0.69 | 0.69 | 0.84 | 0.78 | 0.60 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2015 | 0.67 | 0.68 | 0.89 | 0.87 | 0.67 | 0.64 | 0.64 | 0.76 | 0.86 | 0.75 | 0.57 |
| 2016 | 0.67 | 0.72 | 0.84 | 0.76 | 0.72 | 0.57 | 0.58 | 0.60 | 0.79 | 0.81 | 0.43 |
| 2017 | 0.79 | 0.69 | 0.91 | 0.84 | 0.67 | 0.69 | 0.68 | 0.67 | 0.89 | 0.79 | 0.64 |
| 2018 | 0.79 | 0.79 | 0.92 | 0.85 | 0.77 | 0.81 | 0.81 | 0.70 | 0.88 | 0.86 | 0.51 |
| 2019 | 0.79 | 0.75 | 0.89 | 0.88 | 0.70 | 0.78 | 0.75 | 0.71 | 0.79 | 0.79 | 0.66 |
| 2020 | 0.76 | 0.69 | 0.92 | 0.85 | 0.64 | 0.75 | 0.74 | 0.71 | 0.89 | 0.82 | 0.59 |

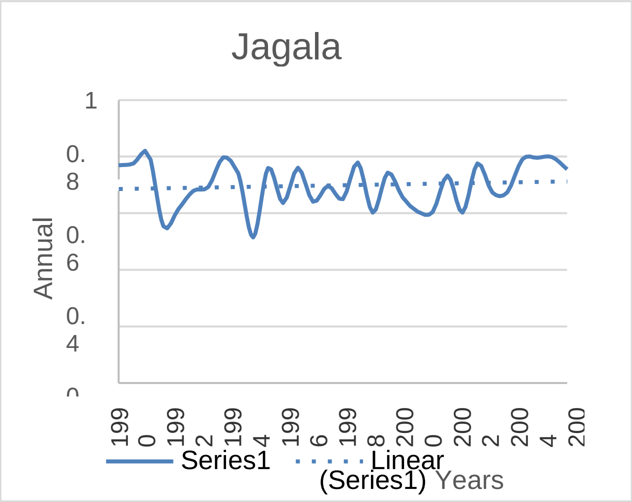


Fig. 2 BFI graph of Jagala river

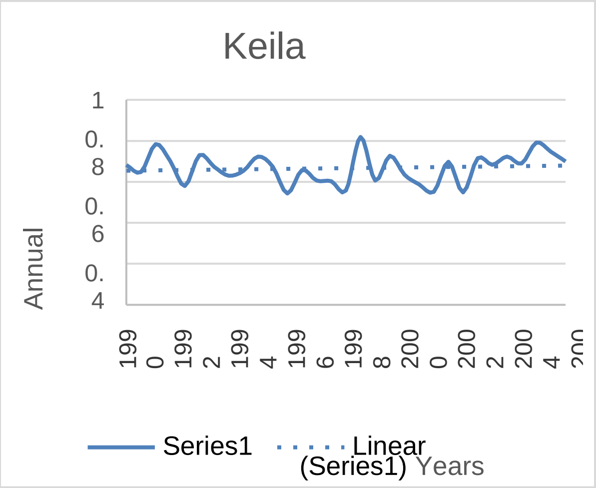


Fig. 3 BFI graph of Keila river

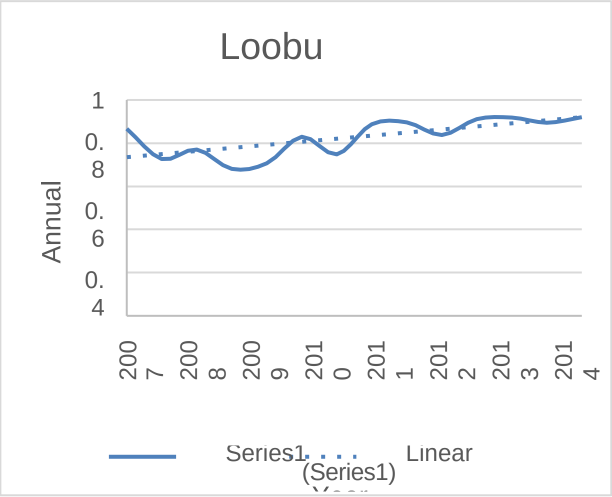


Fig. 4 BFI graph of Loobu river

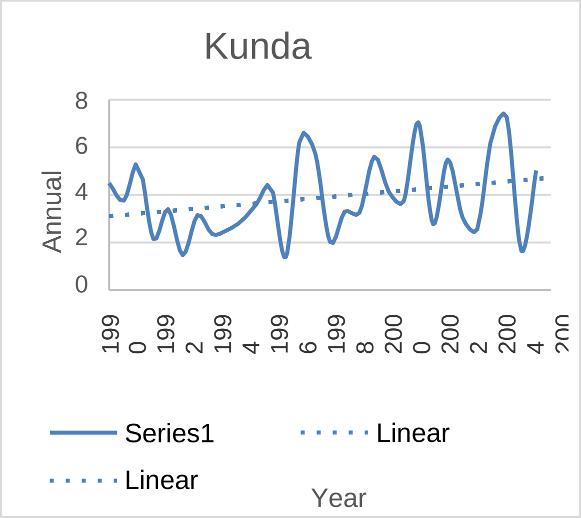
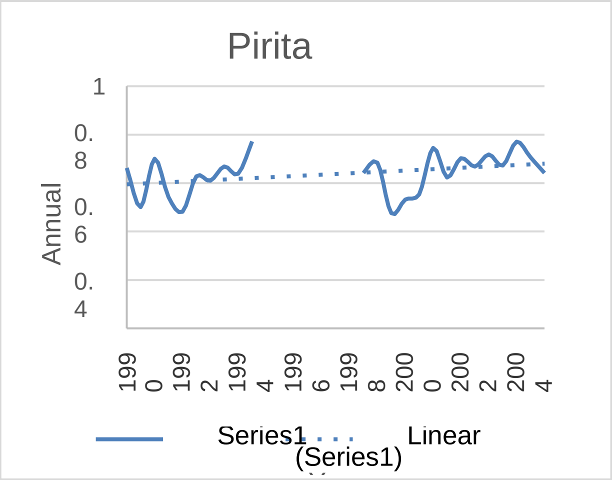


Fig. 5 BFI graph for Kunda river



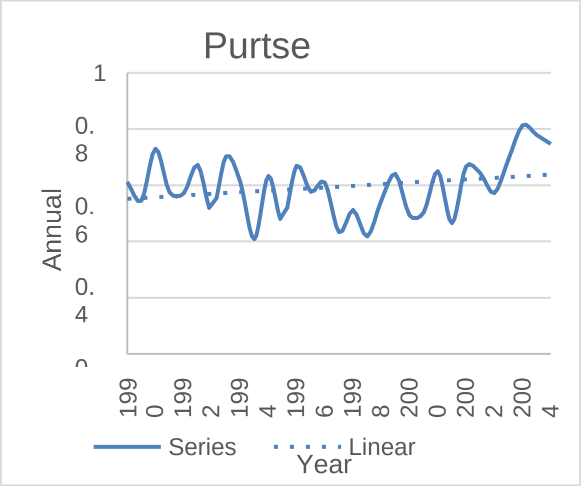
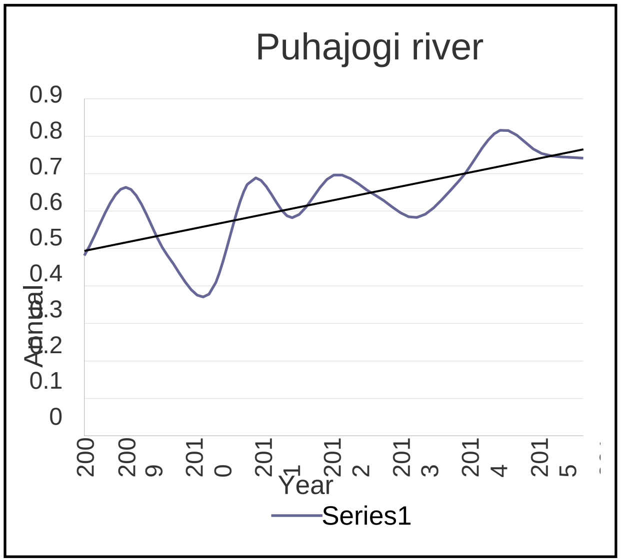


Fig. 6 BFI graph of Pirita river

Fig. 7 BFI graph for Purtse river



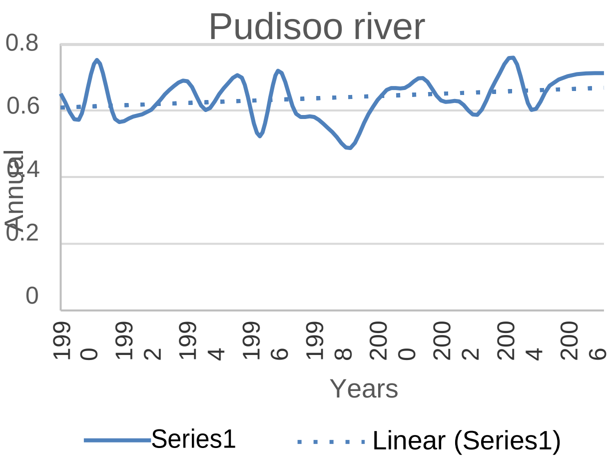


Fig. 8 BFI graph of Puhajogi river

Fig. 9 BFI graph for Pudisoo river

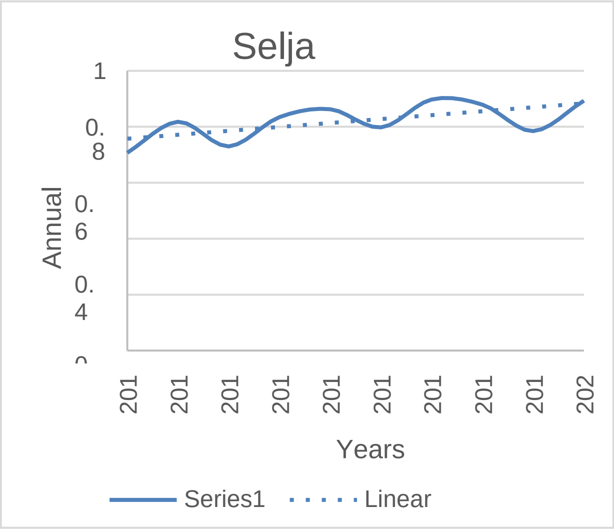


Fig. 10 BFI graph of Selja river

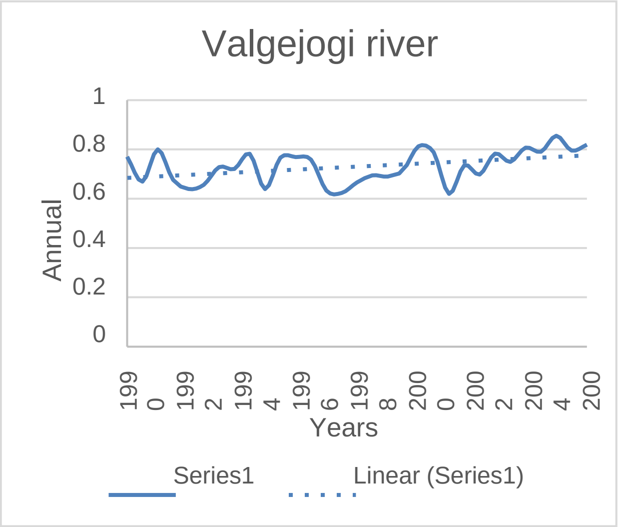


Fig. 11 BFI graph for Valgejogi river

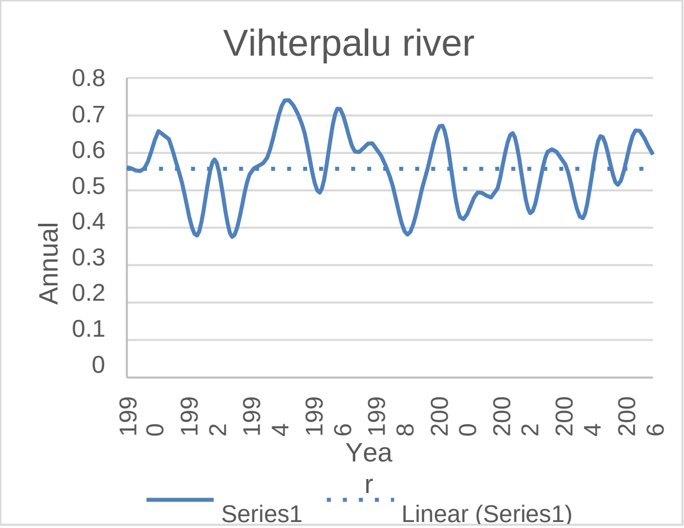


Fig. 12. BFI graph of Vihterpalu river

Legend: Blue dotted lines represents the linear trend ……………….

The thick blue line represents the wavelength movement of the BFI over the studies years

Y-axis is the annual BFI ratio

X-axis is the years covered in the study

The baseflow index is mostly determined on an annual basis. Indication of a permeable catchment is a high BFI which means the catchment area is storing more water during the spring wet seasons and releasing it in the dry season. The from the rivers characteristics table it can be seen that Vihterpalu catchment has the highest wetland of 10%. Considering the wavelength movement of the curves in Vihterpalu river graph assumed that a lot of changes occurred in the monthly runoff of period studied, thus influencing the annual BFI of this river. The temperature and precipitation shift from snow to rain should be consider as a significant factor contributing to the change in runoff (Tan, Lin. And Tan et. al., 2020). The spring season runoff increases due to snow melt, while the summer runoff takes a downward trend on the background of a dry weather without rainfall or snow melt. But the raise in the runoff can be seen again in autumn presents a slightly cold and wet weather in Estonia, while the winter presents a period of low runoff due to snowpack and glacier which are not melting properly as a result of the temperature.

The contribution of the calculated or determined baseflow index shows the ratio of the long-term streamflow to the total flow. This provides understanding on the increase in water levels at various seasons and various years of the study.

This 2010 findings by the EEA (European Environment Agency) recorded the annual average runoff from territory of Estonia to be 11.7km3 which equals 260mm of precipitation that could makeup around 40% of the annual average precipitation.
Annual renewal of groundwater aquifers is approximately 70mm or 3.2km3 coming by means of precipitation (eea.europa.eu/soer/2010).

The average monthly runoff shows the level of increase and decrease in the rivers' runoff per season. This indicates that the BFI index representing an increase in runoff will be lower, because the BFI is the groundwater flow stored at this will release a discharge in dry weather. This can be explained as flow regime having large number of floods are highly inconsistent and will have low BFI. Therefore, the lowest BFI value will come in the spring and winter seasons, while the highest will most likely be in the summer and autumn seasons. It is challenging to give a definite declaration in this case as to what factors clearly defines a certain BFI value in these catchments, however a variety of factors over this period can be pointed to influencing the BFI (e.g. vegetation, precipitation, evapotranspiration, etc). The factor increasing runoff during this time is a highlight of climatic change during this time which is a usual phenomenon in the study of groundwater discharge study. However, this case can be associated with warmer winter of recent decades which has led to increase in runoff and most times flooding (Kont et. al., 2007).

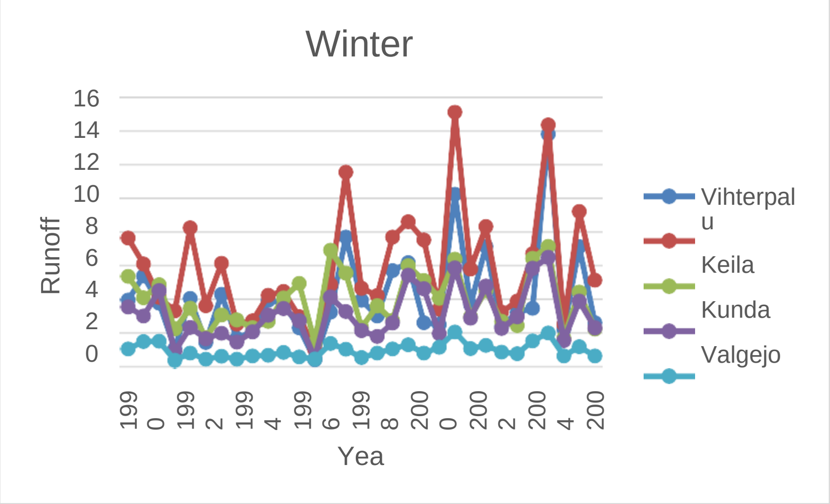


Fig. 13: Seasonal flow graph of the rivers during Winter

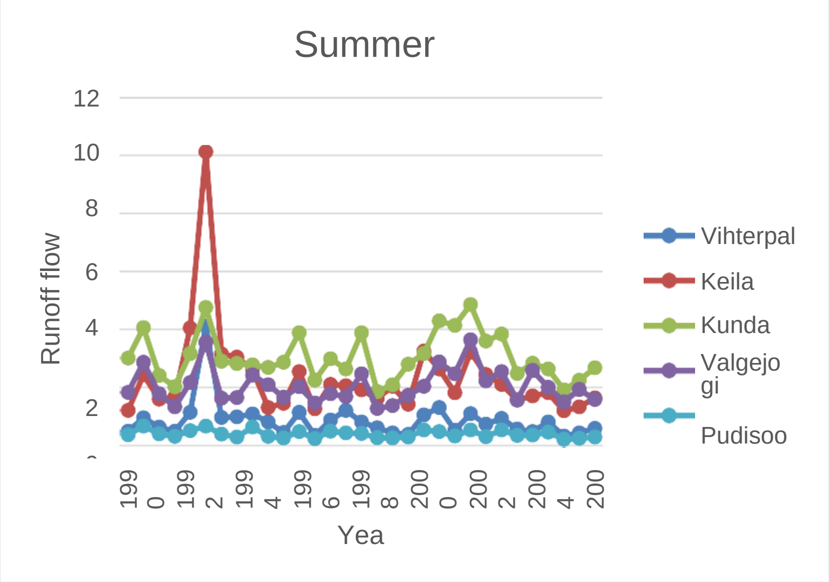


Fig. 14: Seasonal flow graph of the rivers during Summer

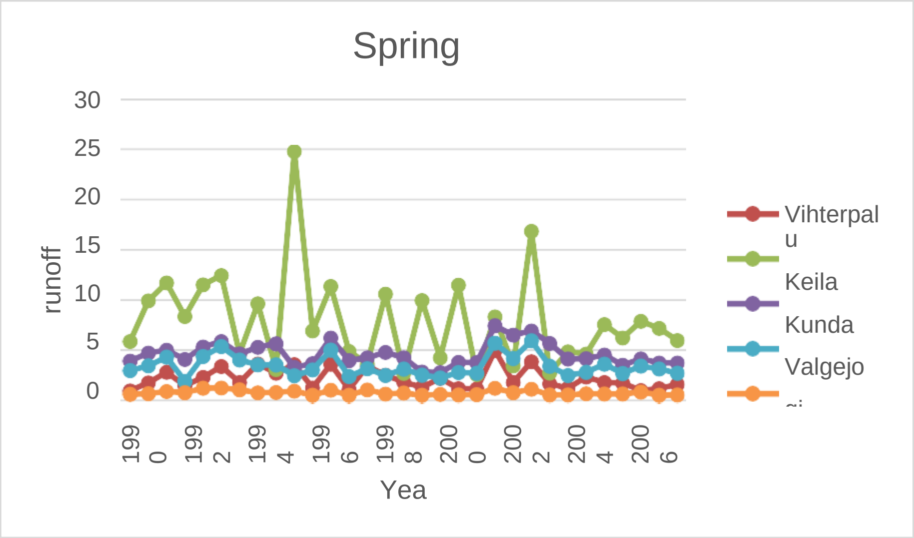


Fig. 15: Seasonal flow graph of the rivers during Spring

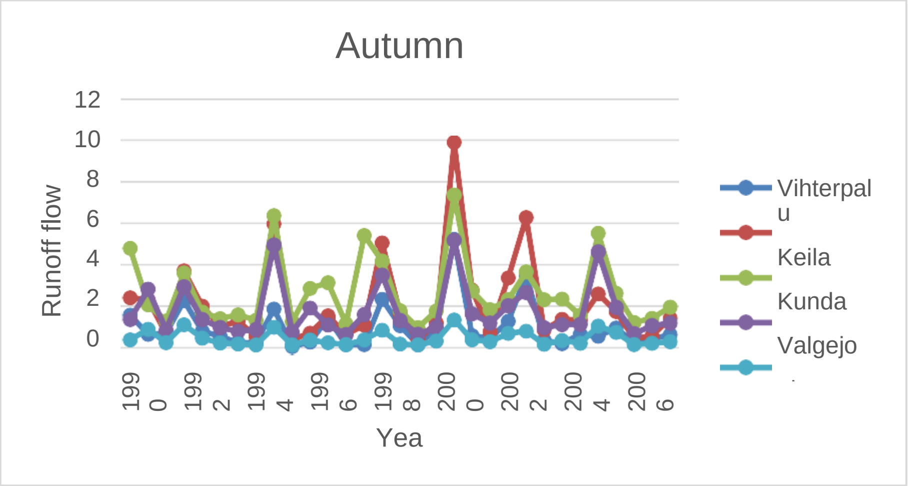


Fig. 16: Seasonal flow graph of the rivers during Autumn

The seasons are defined as used in the study of climates which consist of winter (December, January, and February), spring (March, April, and May), summer (June, July, and August) and autumn (September, October, and November). The seasonal flow of these rivers presented in the graph show the amount of contribution to these rivers. As can be seen the spring season graph the runoff flow in the spring season is higher than the summer, which is an obvious case because during the dry season the is a reduced runoff because of snow melt which has already occurred in the spring season when the weather temperature was slightly raise from cold to warm without snowfall but just rainfall. Keila river has shown the highest runoff amongst the rivers as can be observed in the graph. This can be attributed the geology (tectonic) and hydrological happenings in this river basin.

The highest runoff flow of the summer season covered over the 30 years period took place between 1993 to 1996 and 1997, the highest runoff in the spring season happened between 1998 to 2000 which is a shift in the runoff rise as compare to the summer. As also seen the winter season graph the Keila river recorded the most runoff from the early 2000s to the end of the study period. In this seasonal runoff presented in the graph river Keila runoff increasing trend is consistent throughout the various climatic seasons. However, not all the rivers maintained their runoff frequency across the seasons as river Keila. The inconsistency can be observed in the runoff levels as displayed in the graphs.

The high runoff during the winter season throughout the 2000s period of the study years can be associated with warming winter as a result of climate change or global warming. In agreement with 2017 study done by Jaagus, Tamm, Sepp, Jarvet and Moisja where these authors studied runoff data from 1951 to 2015 and concluded that the lower snow cover duration is responsible for higher runoffs in winter. Most especially in the 2000s the warming effects or impact has been on the rise globally with higher air temperatures being recorded.

According to the data and plotting on the graph the summer and autumn seasons recorded the approximate same frequency at river Keila and the following rivers measuring slightly the same range of data.

The nutrient discharge to rivers recognizes the nutrient export to waterbodies through transporting process. As can be seen the river characteristics table 1 total annual nutrient discharge (nitrogen and phosphorous) from 2014-2019 is displayed per river, and involvement baseflow groundwater as a conduit for delivery is highly likely although this study did not investigate that.

The BFA (baseflow average) of these rivers calculated the highest average in Loobu river with 0.828 BFA, while the lowest BFA mean was recorded in Vihterpalu river with 0.557 BFA.

Table 3: Long-term mean annual BFI calculated for all rivers from 1990 to 2020.

| River: | Jagala | Keila | Loobu | Kunda | Pirita | Purtse | Puhajogi | Pudisoo | Selja | Valgejogi | Vihterpalu |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BFA | 0.70 | 0.67 | 0.83 | 0.79 | 0.63 | 0.59 | 0.62 | 0.63 | 0.82 | 0.73 | 0.55 |

An increasing warming climate resulting in thawing permafrost, which considerably increase(s) infiltration in soil water thus decreasing surface runoff and increasing baseflow production potentially.

Baseflow changes can also attributed to agricultural land use and urbanization which is visible in the trends in the West-Estonia river basin district.

## CHAPTER FIVE

## 5. CONCLUSION

One of the key study goals is to compare the BF with total flow and compare the results with some previously produced results in Estonia and to assess the contribution of base-flow on eleven Estonian rivers looking at the monthly and annual base-flow contributions from tributaries and other sources. This thesis used data of daily runoff from the eleven selected rivers in estimating their BFI which explained the BFI contribution to Estonian rivers.

As a key methodology applied, groundwater runoffs to major Estonian rivers flowing into the Baltic Sea (Gulf of Finland) was analyzed and the baseflow index of each of these rivers which also indicates seasonal baseflow contribution calculated. Daily runoff discharge calculations were done to determine the baseflow and the baseflow index of the eleven selected rivers in order to identify the slow continuous contribution of groundwater to river flow.

Between 1990 to 2020 there were changes in the BFI of these rivers with upward movement mostly in the early and later 2000s with a dip in the mid-2000s. The highest calculated BFI of the 1990s was at Kunda river, Vihterpalu river produced the lowest and the 2000s Loobu river has the highest calculated BFI and Vihterpalu river also having the lowest of this period.

Through the years of study several factors can be associated with the changes in baseflow index trend due variations in the runoff. The effect of global warming mostly effective in the 2000s can account for wavelength movement of the BFI of these rivers during these years of my study. Although, this study did not cover changes in vegetation, and groundwater usage previous studies of baseflow monitoring globally has describe changes in baseflow contribution to river flow at catchments as a result of these activities. An indebt climatic properties and BFI relationship study was not done to determine the courses of event, but the knowledge of weather change due to global warming was declared as a potential player in the variation of the baseflow during this period of study. A distinct spatial pattern in the BFI of these rivers was recognized. An increasing high runoff during the wet season has potentially set up a high groundwater flow during the dry weather periods in these catchment areas. Most catchment areas had reduced BFI between 2007 to 2010 which brings me to agreement with Tan, Lui, and Tan 2020 that the decrease seen in their study of Northern Europe catchments that due to climate change and vegetation there has been reduction in the BFI over time.

Future studies can potentially make use such data to assess specific hydrological questions and to support work pertaining to water resources planning and management. Future analysis of baseflow’s impact needs other factors including precipitation, evapotranspiration, snow melt land use, and land cover change should also be considered to understand and approximate nutrient transportation in baseflow to provide some control of non-point and point source pollutant discharge.

Groundwater abstraction in Estonia has reduced due to environmental regulations, however a more in-depth studies on baseflow will provide proper water resource management owing to the fact that wetland is a popular land cover in most regions and an increasing longer winter in the last two years will mean that more groundwater could be discharge to river flow during snow or glacier melts.

# CHAPTER SIX

## 6.SUMMARY

The baseflow index of the studied rivers provides an understanding of the daily discharge of these rivers as a result of slow continuous flow of groundwater from precipitation or rainfall, snow melt, etc, and these named sources are most often regarded as temporary storage sources in the watershed. The result of the baseflow index over the thirty years period of this study shows the long-term contribution of groundwater from delayed source to the total flow of these rivers vis-à-vis their changes in output with respect to the various climatic season runoffs. The role of the climate change or global warming phenomena is also recognized by explanations to provide a partial background justification for changes in the annual baseflow and runoff during this period of the study.

The eleven rivers covered by this study were selected because they make up a large part of the Estonian hydrological network with importance to their respective uses and their catchment sizes. Most importantly these rivers discharge into the Baltic Sea at the Gulf of Finland. The Baltic Sea sensitive to pollution, thus with the understanding the BFI of these rivers discharging into the Baltic Sea an advantage is provided when studying or monitoring nutrient loads discharging into the Baltic Sea per annual over the various seasons.

The daily runoff data for the calculation of the baseflow index was collected from the “Historical Observation Data” bank of the Estonian Weather Service and with the use of calculation method based on the “Low Flow Estimation” and macro computing program developed at the Tallinn University of Technology by Anatoli Vassiljev.

A table provided in the result and discussion presents the annual BFI of each river over the thirty years of study. These data show the percentage of groundwater from delay sources in the total flow of the river. Excel graphs of various climatic seasons presents an understanding of the rise and fall in monthly runoff which explains the BFI during the various seasons, as the BFI representing an increase in streamflow is usually lower vice versa to a decreasing streamflow.

The impact of climate change to these results are also recognized to this effect.

This shows the percentage of slow continuous groundwater contribution to these rivers which can be helpful to future study of each river annual discharge flow percentage into the Baltic Sea at the Gulf of Finland. Global warming impact on climatic seasons especially winter snow cover duration and spring rainfalls has impacted the BFI of the recent decades. This finding is important to the monitoring of Estonia hydrogeological happenings.

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