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Assessment of surface water quality and quantity in Great Zab river catchment, in the Kurdish region of Iraq

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ASSESSMENT OF SURFACE WATER QUALITY AND QUANTITY IN GREAT ZAB RIVER CATCHMENT, IN THE KURDISTAN REGION OF IRAQ

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DEDICATION

To the soul of my son Lawi Ismaiel

06-10-2013

ABSTRACT

The Great Zab River catchment is a major left-bank tributary of the River Tigris and drains a substantial part of the Kurdistan Region, an autonomous region of Northern Iraq. The average annual rainfall in the Great Zab river basin varies from more than 1000 mm/year northeast of the catchment to about 300 mm/year in the southwest. In this study, monthly, seasonally and annually precipitation, temperature and discharge trends of stations in the Great Zab catchment from 1960–2012 were analysed and interpolated. The Mann-Kendall trend test was applied to examine the precipitation, temperature and discharge data. Positive and negative trends at significance levels of 95 and 99% were detected. Water supply was calculated from precipitation stations of catchment using water balance. Water demand for domestic and agricultural sectors were estimated using available secondary data. Within Kurdistan, the water resources of the Great Zab River catchment are under pressure from population increase and are utilized for potable, domestic, agricultural, and industrial supply. As with many parts of the world, effective management of water resources within Kurdistan is hindered by a lack of water quality data and established background concentrations.

This study therefore represents the first regional survey of river water chemistry for the Great Zab River catchment and presents data on the spatial and temporal trends in concentrations of As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, Li, Mn, Mo, Ni, Pb, Sr, Zn, NO3−, SO42−, F−, Cl−, and PO43−, in addition to pH, electrical conductivity, dissolved oxygen and turbidity. As a tool for underpinning the management and monitoring of water quality, background concentrations were defined for the Great Zab catchment using three methods. The influences of geogenic and anthropogenic controls upon spatial and temporal trends in water chemistry are also evaluated. The influence of geogenic loading from underlying bedrock was identifiable within the observed spatial trends, with the most notable differences found between waters sampled from the relatively more volcanic-rich Zagros Zone to the north and those

sampled from the lower catchment underlain by younger clay-, sand- and siltstones. The greatest anthropogenic influence, identifiable through elements such as Cl- and NO3-, is present in the more highly populated lower catchment. The background concentrations identified in the Great Zab catchment would be those expected because of geogenic loading with some anthropogenic influence and represent a more conservative value when compared to those such as the World Health Organization Maximum Admissible Concentration. However, background concentrations represent a powerful tool for identifying potential anthropogenic impacts on water quality and informing management of such occurrences.

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CHAPTER 1: INTRODUCTION

1.1. BACKGROUND TO THE STUDY

Water resources are under relentless pressure due to population growth, rapid urbanization, industrialization and Environmental concern (Arya and Gupta, 2013). Human and ecological use of instream water requires that both the quantity and the quality of water be considered (Chang, 2008; Masamba and Mazvimavi, 2008). Pollutants entering a river system typically result from many transport pathways including, atmospheric deposition, discharge from tributary channels, groundwater inflow and point and diffuse source inputs associated with human activity (Ouyang et al., 2006; Nouri et al., 2011). Since pathways are spatially-seasonally dependent, spatial and seasonal changes in surface water quality must be considered when establishing a water quality management program (Ouyang et al., 2006). Anthropogenic impact on natural environments, and especially on aquatic ecosystems, are currently a topic of increasing concern (Kumar and Pal, 2010). Deterioration of river and lake water quality is common in many aquatic systems and potential causes are associated with various point and non-point sources of pollution (Carpenter et al., 1998). Human activities have affected the river systems in numerous ways, for example, through urbanization, agricultural development, land drainage, pollutant discharge, flow regulation dam construction and canalization. In addition river water quality may vary depending on morphological features, vegetation and other activities in a river basin (Brezonic et al., 1999).

In many countries, the availability of water in terms of both quality and quantity is being severely affected by population growth, urbanization, agricultural and industrial development (White, 1998; Al Radif, 1999). As a result, some countries are now in a permanent state of water deficit, and in other countries, that is the case at critical times of the year or in years of low water availability (Mostert, 2003). According to the United Nations Environment

Program (UNEP) the whole Middle East region is suffering from water scarcity, which is attributed to large temporal and spatial variations in most of the hydrological parameters, especially the rates of precipitation and evaporation. The most significant parameter causing environmental stress is rainfall pattern, which influence the generation and dependability of freshwater availability in terms of its amount, frequency and distribution (Kumar, 2012) (Fig 1.1). The IPCC (2007) reported that climate change will further increase the variability of rainfall, contributing to greater uncertainty and complications in the planning and management processes of the water sector. In addition to natural water scarcity, human activities are contributing to the depletion and deterioration of resources through increases in water demand in all sectors and pollution of remaining resources. High population growth, increasing rates of urbanization and economic activities have placed extensive pressure on the already limited water resources.

These issues concerning water quality and quantity are further amplified by water shortage in the arid and semi-arid regions of the Middle East (Assaf, 2009; Jagannathan et al., 2009). The Kurdistan region in Northern Iraq is not an exception from the rest of the Middle East, similar water quantity and quality challenges apply to this region (Heshmati, 2009). The Kurdistan region has faced a rapid change in the structure of its population, urbanization and economic expansion. Significant demographic changes and economic development programs resulted in the shortage and pollution of water resources (Stevanovic & Iurkiewicz, 2009). Both factors, contribute to pollution from municipal waste, mining and industry, and agricultural runoff, all of which further degrade water quality and thus the amount of quality water sources, further exacerbating the quantity of usable waters (Ali, 2004; Aziz, 2008; Toma, 2013). All of these factors clearly indicate that water is a highly valuable resource for human beings, but also recognise that good management is crucial for its preservation in quantity and quality.

The main factors affecting water quality are inadequately treated domestic sewage and insufficient controls on the discharge of agriculture and industrial waste water (El- Fadel et al., 2002; Abdulwahid, 2013). Furthermore, the absence of a comprehensive surface water quality monitoring programme has resulted in lack of adequate surface water data and information, which in turn constrains proper decision making (Alobaidy et al., 2010). Surface water status is further complicated portions of surface water originate from outside the region, with no binding agreement for sharing water resources between the riparian countries, or the implementation and monitoring of the existing agreements (El-Fadel, 2002). The relevant literature comprises of few and outdated articles on water resources management. Therefore, research into water issues in the context of water resources in the Kurdistan region is considered one of the most important issues and demonstrates a clear researchable constraint.

1.2. JUSTIFICATION FOR THE STUDY

Water has a vital role to play in supporting to socio-economic development in the Kurdistan region, the success of regional development efforts will depend heavily on the availability of water resources and its quality. The region is potentially rich in water resources, however there is lack of development towards sustainable management of water resources. Water resources in the Kurdistan region, especially in the last two decades have suffered from remarkable stress in terms of water quantity and quality (Alobaidy et al., 2010). Ensuring that water is available in the right quantities and quality for domestic, agriculture and industrial uses is a key focus for water investment and management activities.

The growth of population, urbanization and economic expansion undoubtedly led to increasing demands of water. It has led to the decline in the per capita availability and use of water resources and raises the state to a scarcity level in some places of the region (Abdulwahid, 2013). Furthermore, the inefficiency in water management, lack of knowledge, rules and legislations and the inability of policy-makers to monitor development has led to pollution of water (Heshmati, 2009). The results obtained from this study may provide the decision-makers with sufficient information and data about the state of surface water resources in the area to achieve better hydrological and water management. The current study is being undertaken in an attempt to increase the scientific evidence-base for water resource management.

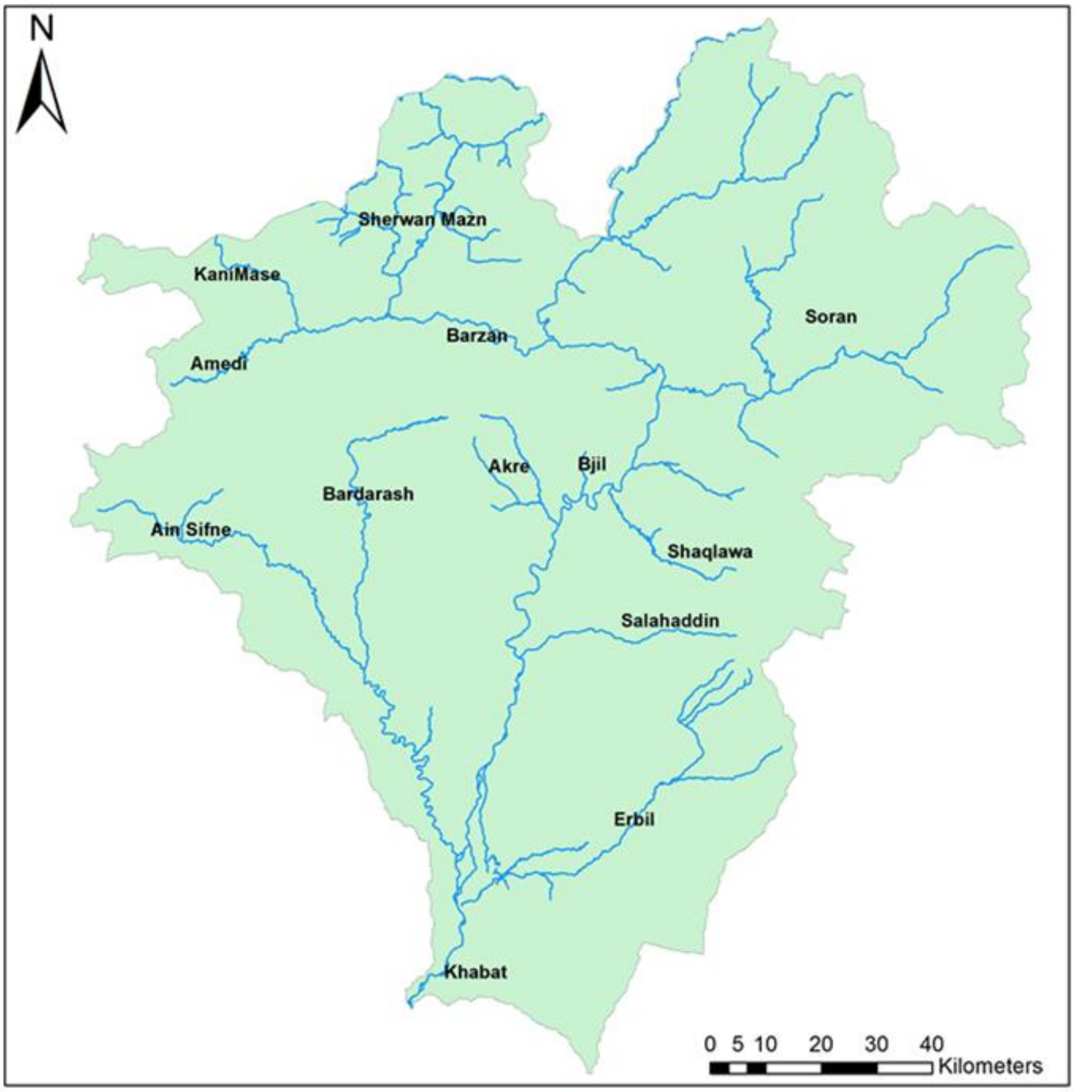


Figure 1.1 Great Zab catchment and main cities

1.3. OVERALL AIM AND MAJOR OBJECTIVES

The overall aim is to understand and evaluate the quality and availability of river water, with respect to the Great Zab River Basin in the Kurdistan region. Specifically, this study has the following objectives:

Objective 1: Collate available hydrological and climatic (hydroclimatic) data for the study catchment (Kurdistan region), notably for rainfall and river flow.

Objective 2: to quantify the temporal and spatial trends in hydroclimatic variables in the study area.

Objective 3: to produce a primary geochemical assessment of river water chemistry with the Kurdistan Great Zab River.

Objective 4: to evaluate spatial and temporal trends in water quality, identify the magnitude of any pollution present and to establish background water quality for the Great Zab for a range of parameters.

Objective 5: to undertake a water balance analysis of supply and demand for surface water resources in the study area.

1.4. THESIS STRUCTURE

This thesis comprises eight chapters presented below. Chapter 1 (Introduction) provides a brief background to the study area and outlined the justification and overall aim and objectives of the study. Chapter 2 presents a review of the literature that provides an overview and context for Integrated Water Resources Management (IWRM) and River Basin Management (RBM), their historical development and explores why we need to manage water resources. It is also review the scientific literature pertaining to the water resources management in the Kurdistan region.

Chapter 3 describes the study area in terms of its location, physical setting of the Great Zab Catchment, climate and rainfall, hydrology and geology vegetation and land use.

Chapter 4 evaluates the temporal and spatial variations of water quality data, and assesses the water quality standards.

Chapter 5 focuses on determining (ambient) background water quality conditions in the Great Zab River catchment, which may be used as a baseline for water quality assessment and resource management.

Chapter 6 evaluates the spatial and temporal trends of hydroclimatic variables in Great Zab catchment.

Chapter 7 undertakes a water balance analysis for water supply and demand in the Great Zab catchment.

Chapter 8 provides an overall discussion of the results of this study and provides a conclusion and recommendations and opportunities for future research in the light of the findings of this study.

CHAPTER 2: LITERATURE REVIEW

2.1 DRIVERS OF WATER RESOURCES MANAGEMENT

The combination of both naturally occurring conditions and human actions creates pressure on water resources. The increased demands on water supply created by human activities within river basins for the purposes of agricultural growth, industrialization, urbanization, domestic development, and other activities are approaching or exceeding the amount of water available in many catchments (Al Radif, 1999). These pressures have caused a reduction in the per capita usage of the limited fresh water resources in many countries to a scarcity level (Gleick, 2000). They have also resulted in the degradation of the quality of water in many areas of the world (JØnch-Clausen& Fugl, 2001). The United Nations (2009) expects that the population of the world will have increased by another 3 billion people in 2050 and most of this population growth will take place in drier regions (Al Radif, 1999). Continued growth in population and economic activity will lead to further increase in water demands and pollution, and thus to increased competition and conflict over limited water resources (JØnch-Clausen& Fugl, 2001; Molle, 2009). Presently more than 2 billion people are affected by water shortage in over 40 countries, where per capacity supply is less than 1,700 m^3 per year (UN-Water, 2007).

The World Resources Institute (WRI) estimates that some 40 % of the world's population, or 2.8 billion people, live in river basins under "water stress" (Fig 2.1 and 2.2). Approximately, 1.2 billion live under condition of physical water scarcity, which occurs when more than 75% of river flows are withdrawn and is an issue in countries like India and China (UN, 2009; OCHA, 2010). The remaining 1.6 billion people live in areas of economic water scarcity where human, institutional, and financial capital, limit access to water even though water in nature is available locally to satisfy human demands (Mehta, 2012). This means that more than 80 % of the water naturally available to agricultural, domestic, and industrial users is withdrawn annually, leaving businesses, farms and communities vulnerable to scarcity. Periodic and often serious, droughts only make the situation worse. Stressed river basins can severely threaten regional water security and economic growth, and may even contribute to political instability especially if a basin does not have adequate water management plans in place (WRI, 2014).

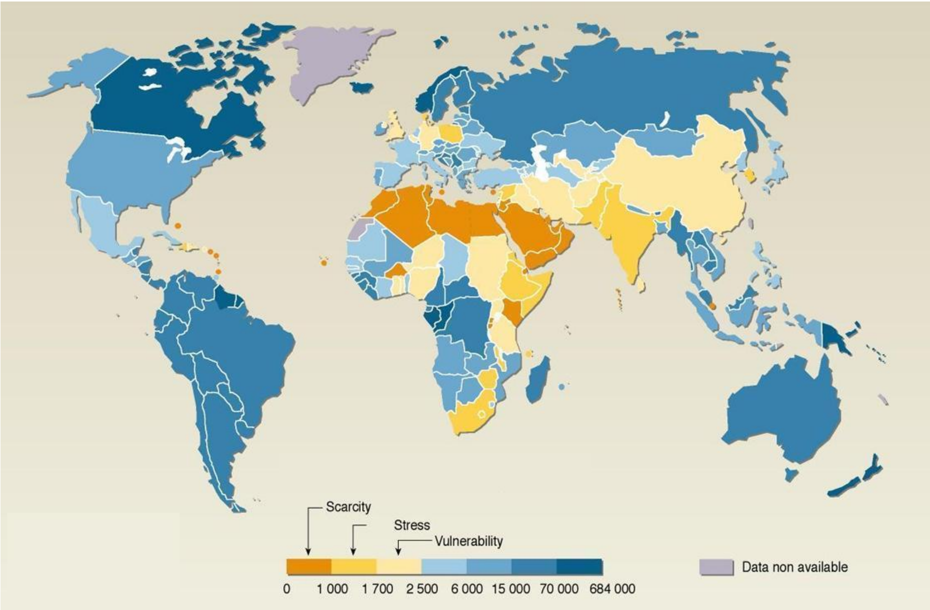


Figure 2.1. Freshwater availability, cubic meters per person per year (UN, 2007).

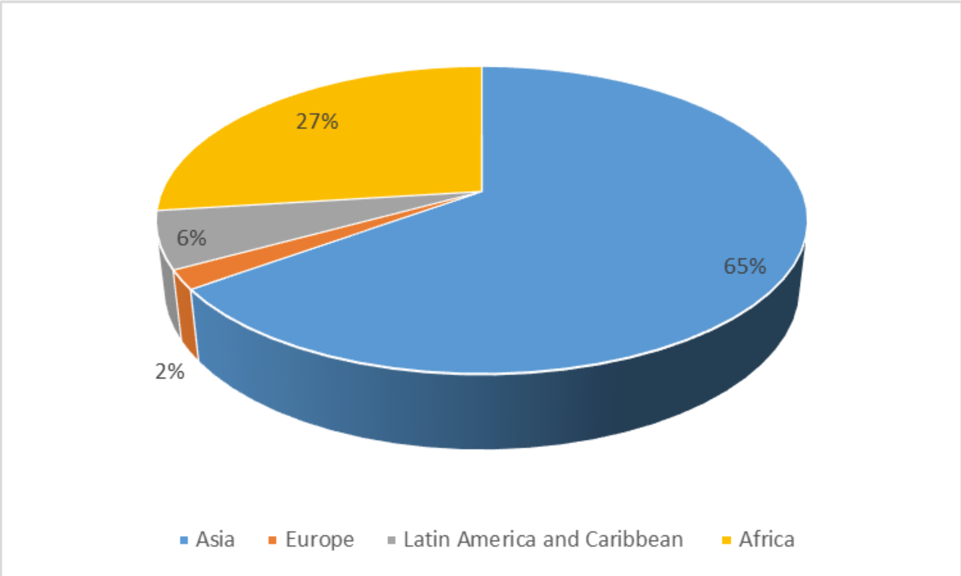


Figure 2.2 Water supply distribution of unserved populations (UN, 2003).

Water quality is as important as water quantity to meet basic human and environmental needs, yet it has arguably received far less investment, scientific, support, and public attention in recent decades than water quantity (Mehta, 2012). According to the World Bank (2004) about 2 million tons of waste per day, comprising human waste, agricultural wastes, and industrial wastes, containing a wide-range of potentially harmful substances, are deposited in water courses. Furthermore, half the population of the developing world are exposed to polluted sources of water (Cap-Net, 2008). Globally, the primary water quality issue for most freshwater is eutrophication, a result of high nutrient loads, mainly phosphorus and nitrogen, which substantially impedes beneficial uses of water (Zamparas and Zacharias, 2014). Major nutrient sources include municipal and industrial sewage discharges, runoff from fertilizers and manure applied to agricultural land from diffuse sources in catchment areas (Howarth et al., 2000). Lakes and reservoirs are particularly susceptible to the negative impacts of eutrophication because of their complex dynamics, relatively longer water residence times and their role as an integrating sink for pollutants from their drainage basins Nitrogen concentrations exceeding 5 milligrams per litre of water often indicate pollution from human and animal waste or fertilizer runoff from agricultural areas (UN, 2012). In addition, water quality can be impacted by a range of other inorganic (e.g. metals) and organic pollutants (Geissen et al., 2015).

Stakhiv (1998) and Charlton & Arnell (2011) conclude that climate change is also another significant contributor to an already difficult situation for many water poor developing countries. In many parts of the world, water availability has severely limited environmental, social and economic development (Vörösmarty et al., 2000). These water poor conditions are prevalent in much of Southern Asia and Sub Saharan Africa, the Middle East and around the Mediterranean (Arnell, 2004; Mehta, 2012; Bouwer, 2000). Recent estimates suggest that climate change will account for about 20 % of the increase in global water scarcity (UN- Water, 2007). The world's rapid population growth over the last century and climate change has been a key factors in increasing global water usage, however demand for water is also rising because of urbanization, economic development, and improved living standards (Al Radif, 1999). Gleick (2000) indicated that between 1900 and 1995, for instance, global water withdrawal demand increased by over six times, more than double the rate of population growth. In the meantime, increasing air temperatures are anticipated to have adverse impacts on water resources, including decreasing snow pack and raising evaporation, which affects the volume of water availability (Lobell & Field 2007). The occurrence of water shortages expected in the summer, could induce a reduction in soil moisture levels and result in agricultural drought (Sun et al., 2008). Water availability may decline to meet crop requirements in summer irrigation and water deficits will occur earlier in the growing season, particularly in drainage basins that lack reservoirs. Furthermore, increasing surface temperatures are anticipated to mean that precipitation will increasingly be received as rain in winter, with a decreasing proportion of snow-pack formation and associated water storage (Peterson and Keller, 1990; Doll, 2002).

In addition to the above, ‘transboundary water’ is also another complicating factor to increase water problems. Globally two hundred and sixty three rivers basins cross international boundaries (Wolf et al., 2003; UN- Water, 2008). Some of these rivers basins are shared by two countries others by several countries. Transboundary water users may mutually affect each other, as demand for water increases, competing claims over shared water may increasingly lead to disputes or even conflict among riparian countries (Rahman et al., 2004). Wolf et al. (2003) argued that in view of increasing demand for water, tensions over transboundary water are likely to increase in some regions, such as Middle East and southern and central Asia e.g. the Rivers Nile, Tigris, Euphrates and Jordan. The current and the predicted trends indicate that water problems of the future will continue to become increasingly more and more complex, and will be more interconnected with other social-, economic-, environmental-development-related issues at local, national and sometimes at international levels (Biswas, 2004; Bouwer, 2000). The need to develop more sustainable practices for the management and efficient use of water resources, as well as the need to protect the environmental ecosystems where these resources are located, has led to essential shifts in awareness and public concern over the past decade. The overall objective for water management, which adopts integrated approaches, is to satisfy the freshwater needs of all countries for their sustainable development (Al Radif, 1999; Bouwer, 2000). Water is an economic, social and environmental 'commodity' as water becomes relatively scarce it will become increasingly important to reallocate available supplies to its most valuable uses (Stakhiv, 1998).

2.2 CONCEPTUAL FRAMEWORK OF IWRM

If integrated water resources management (IWRM) is understood to mean coordinated planning, development, management and use of land, water and related natural resources within hydrologic boundaries, then clearly it is not a new idea (Watson, 2004). Many aspects of the IWRM concept have been known for several decades, with arguably a key turning point reached in 1992 when the so-called 'Dublin Principles' for water management were developed and Agenda 21 was published following the United Nation Conference on Environment and Development (the Earth Summit) in Rio de Janeiro, Brazil (Mitchell, 2004). A decade later the concept of IWRM has been the object of extensive discussions as to what it means in practice (Salman, 2004). Also during this period, new organizations such as the World Water Council (WWC) and the Global Water Partnership (GWP) urged governments to pursue a more integrated approach to the management of land, water and related natural resources (Watson, 2004). In recent years, a number of conferences have been held to give specific guidelines for promoting IWRM (Rahman et al., 2004). Hooper (2003) noted that IWRM has been proposed and is now practiced as a method of water management incorporating land and water resources planning and management (see Fig 2.3).

Heinz et al. (2007) and Saravanan et al. (2009) argued that IWRM aims to address a variety of water management objectives and interests, such as water supply, water quality, flood control, conservation of aquatic ecosystems, integration also can improve management of water-related conflicts. In 2002, at the Johannesburg World Summit on Sustainable Development (WSSD), the Technical Advisory Committee of the Global Water Partnership (GWP) defined IWRM “as a process for coordinating the development and management of water, land and related resources in a way that maximizes economic and social welfare equitably, without compromising the sustainability of vital ecosystems”. This underlined that water should be managed in a basin-wide context, under the principles of good governance and public participation (Rahaman & Varis, 2005). The European Commission (2003) stated that IWRM expresses the idea that water resources should be managed in a comprehensive manner, coordinating all aspects and tasks of water extraction, water control and water- related service delivery so as to bring sustainable and equiTable benefit for all those dependent on the resources.

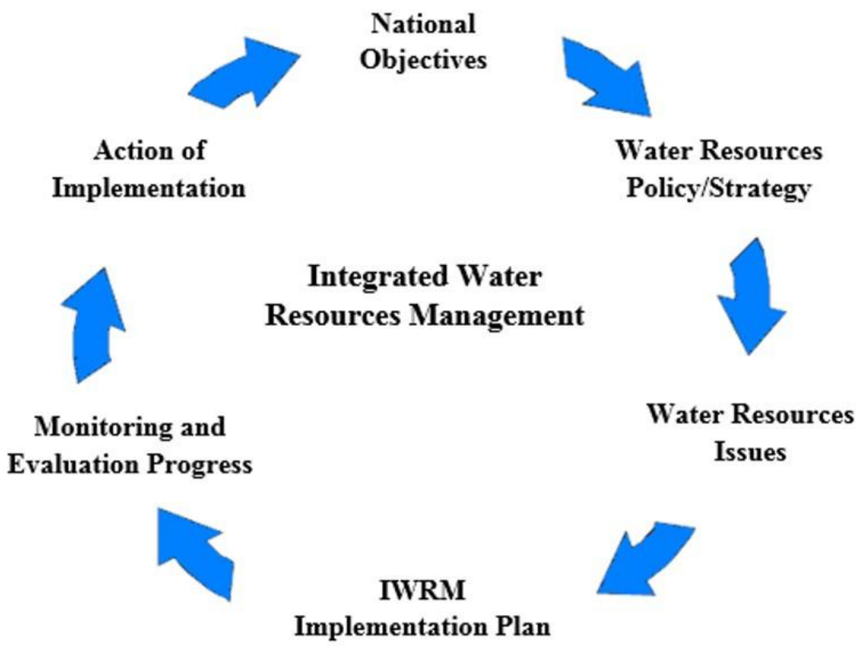


Figure 2.3 Stages in IWRM planning and implementation. Twomlow et al. (2008).

According to Ramsar's (2010) guidance, integrated river basin or river catchment (the land area between the sources and the mouth of a river, including all of the lands that drain into the river), is considered a significant geographical unit for the management of water resources. JØnch-Clausen and Fugl (2001) argued that IWRM is a proposed management approach which aims at coordinating policy making, planning and implementation in an integrated manner. It recognises the complex issues that arise from managing international water systems, and the need for a cross- sectoral, cross institutional and cross boundary approach to address these.

Calder (1999) has stated that IWRM involves the coordinated planning and management of water, land and other environmental aspects and is the way forward for the efficient, equiTable and sustainable development and management of water resources. Furthermore, Cap-Net (2008) stated that IWRM is a systematic process for the sustainable management and development of water resource use in the context of social, economic and environmental objectives. It has been stated by Moriarty et al. (2004) that IWRM is a process of getting from some existing state to some visualised and preferred future state, by following commonly agreed principles or best practice in managing water through the involvement of all relevant stakeholders. Pangare et al. (2006) has noted that IWRM is a participatory planning and implementation process, based on sound science, which brings together stakeholders to determine how to meet society's long term needs for water, while maintaining essential ecological services and economic benefits.

Van Hofwegen and Jaspers (1999) argued that IWRM "is the management of surface and subsurface water in a qualitative, quantitative, and environmental sense from a multi-disciplinary and participatory perspective. There is a focus on the needs and requirements of society at large with regard to water at the present and in the future, thus aiming at maximum sustainability in all senses". Jones et al. (2006) has reported that Integrated Water Resources Management (IWRM) and Integrated River Basin Management (IRBM) are both approaches that seek to achieve more sustainable environmentally and socio-economically use of water resources as a response against the shortcomings of traditional of water supply. The World Wildlife Fund (WWF, 2005) defined IRBM “as a process of coordinating conservation, management and development of water, land and related resources across sectors within a given river basin, in order to maximise the economic and social benefits derived from water resources in an equiTable manner while preserving and, where necessary, restoring freshwater ecosystems." Often IWRM includes the concept of river basin management (RBM), i.e. the idea that water resources should be managed within the hydrological unit of the watershed area or river basin (Barrow, 1998). Molle (2009) has identified the river basin or catchment as a clear concept, as uncontroversial as the physical determination of a catchments, in other words as a unit for the planning and management of water resources by communities. Therefore, all essential components need to be included into the planning process for the watercourse and their catchments (Jaspers, 2003; Hooper, 2003; Molle, 2009). This approach can be called Integrated River Basin Management (IRBM) (Lee& Dinar, 1996). In view of the close relationship between IWRM and IRBM, and for the purpose of simplicity and clarity, IWRM is the term will be used in the remainder of this study.

2.3 HISTORICAL DEVELOPMENT OF WATER RESOURCE MANAGEMENT

Planning and managing the use of water by rivers basin units is a concept developed in the 20th Century (Teclaff, 1996). The development of water resource management around the world has taken many different forms and directions since the dawn of civilization (Gleick, 2000). Water resources management in major river basins such as Tigers-Euphrates, Nile, Yellow, Indus rivers goes back thousands of years (Teclaff, 1996). Irrigation began to from a strong link between humans and water resources in the sixth millennium BC; two important river basin civilizations, Mesopotamia and then Egypt, manipulated water to sustain settled agriculture; both irrigation and elementary flood control were practised (Newson, 1997). As early as the third millennium BC, the Chinese had acquired a comprehensive understanding of river and the hydrological cycle, with a clear explanation of how rivers are generated from clouds and water vapour (Newson, 1997). The Romans and later the Arabs founded sophisticated infrastructures for hydraulic management, but their conceptual understanding on river basins and hydrology remained limited (Molle, 2009). Dooge (2001) argued that conceptual progress in western countries remained limited for a long time and was in particular obstructed by the idea that some water was sourced from an ocean within the earth. The Western conceptual development of a river basin as a natural spatial unit only developed in the second half of the 18th century, when scientific and technological development, paralleled by industrialization, projected the river basin as the place of human conquest of nature (Molle, 2009). By the beginning of the 19th century, water science had developed significantly. Progress was made regarding knowledge in sanitation, hydrology, hydraulics, topography, and geology, which provided the basis for a better understanding of the concept of water resources (Rahaman & Varis, 2005).

Around the middle of the nineteenth Century, the river basin became a vital resources and its management gradually shifted from the local level to the regional or national level, with its growing contribution to the industrial revolution (Downs & Gregory, 2004). The second half of the 20th century was characterized by flood control projects on a large scale and more associated with actions driven by local environment circumstances and agriculture growth, prompted by the necessity for self-sufficiency (Brookes et al., 1983). Downs and Gregory (2004) have advocated that the modern development of water resources has proceeded from single-purpose projects through multipurpose schemes, towards more integrated river basin planning, which began particularly with the United Nations proposals in 1970. Embid (2003) claims that Spain was probably the first country to manage water resources at a basin level and many individual projects in the past have applied different aspects of IWRM. However, the widespread and systematic application of these principles with a more comprehensive approach to water resources management is a recent phenomenon. The next milestone in the development of the IWRM concept was at UN Conference on Water in Mar del Plata (Argentina) in 1977. It is believed that this conference gave birth to the first international coordinated approach to IWRM and provided a platform for discussions on various aspects of water management (Rahaman& Varis, 2005; Stalnacke& Gooch, 2010). Later, Global Consultation on Safe Water and Sanitation was held in New Delhi during 1990. The Dublin Conference on Water and Environment of 1992 and UN Conference Environment and Development of 1992 held at Rio de Janeiro (Brazil) put together a comprehensive water resources management approach for sustainable development (Molle, 2009).

In the relevant literature of the last two decades, Young et al. (1994) and Essaw (2008) have argued that the International Conference on Water and the Environment held in Dublin, Ireland in 1992, was the most all-embracing conference dealing with global water management issues since the Mar del Plata meeting in 1977. Moreover, Fox (2009) stated that river basin development promoted modernization and regional development in the latter decades of the Twentieth Century and the early years of the twenty first century concern for the ecological and social impacts. In recent years, a number of conferences have been held to give specific guidelines for promoting IWRM such as the Second World Water Forum & Ministerial Conference held in The Hague (2000), The International Conference on freshwater, Bonn (2001), the World Summit on Sustainable Development, held in Johannesburg (2002), and International UN-Water Conference held in Zaragoza 2012/2013. In all conferences, representatives from all over the world have shared their views on new approaches for the development and management of water resources (Rahaman et al., 2004; JØnch & Fugl, 2001; Salman, 2004). Also during this period, new organizations such as the World Water Council (WWC) and the Global Water Partnership (GWP) urged governments to pursue a more integrated approach to the management of land, water and related resources (Watson, 2004). Furthermore, Watson (2004) explained that IWRM can be applied to the management of the different elements of the water systems, to the broader environment, social and economic systems within a river basin. Within Europe at least, the latest important milestone in the development of the concept was in December 2000, and the ratification of the European Water Framework Directive (WFD). The Directive takes a holistic and comprehensive approach towards water management as it covers the relevant components of water: namely, inland surface water, groundwater, transitional water, and coastal water, and for the first time, surface water and groundwater are managed within "river basin" in an integrated manner at the European level (Salman, 2004).

2.4 ANTHROPOGENIC EFFECTS ON WATER RESOURCES

Anthropogenic activities have a significant negative impact on the quality and quantity of water resources (Foley et al., 2005). There are three main factors contributing to water scarcity namely: direct water pollution, water consumption, and (anthropogenic) climate change (Foley et al., 2005). These factors have significant influences on the reduction of water quantity and quality (Olivera and DeFee, 2007). Water resources use can be divided in two major types: in-stream use and off-stream use. In-stream use consists of dams and hydrological power, swimming and paved roads for transportation that contribute to the reduction of water quality (Foley et al., 2005). Another type of water consumption is off-stream use refers to water that are withdrawn for household use, industry use, irrigation, livestock watering, thermal and nuclear power which will not be returned to its abstraction location. The most direct impact of urbanization on ecosystems is altering the hydrologic cycle that controls the ecosystem energy and matter flows (DeFries and Eshleman, 2004). Indeed, water resources in urban environments around the world are increasingly stressed due to population rise, rapid land use change (Foley et al., 2005; Olivera and DeFee, 2007). Surface waters are most vulnerable to pollution among fresh water sources of the aquatic environment.

Surface water quality is a matter of serious concern today. Rivers due to their role in carrying off the domestic and industrial wastewater and run-off from agricultural land in their vast drainage basins are among the most vulnerable water bodies to pollution (Singh et al., 2005). Not only anthropogenic influences such as industrial activities and wastewater disposal cause their pollution but natural processes such as erosion and weathering of rocks in catchment are equally or sometimes more responsible in determining the quality of water (Jarvie et al. 1998). Pollution due to industrial activities and wastewater disposal is a constant sources, while erosion from catchments depend on external factors and may vary according to the natural factors such as precipitation and run-off generation (Olivera and DeFee, 2007). Human activities generally affect the distribution, quantity, and chemical quality of water resources. The range in human activities that affect the interaction of ground water and surface water is wide (Tiwari et al., 2015).

The increase nitrogen concentrations are produced especially by non-point sources of pollution such as agricultural discharge to the river, while the presence of phosphorus is mainly due to domestic wastewater disposal in river (Tiemeyer et al., 2006). Both eventually leading to eutrophication of the water body (Singh et al., 2005). Since rivers have remained as the main source of water for agricultural, industrial, and urban needs in most part of the world, therefore, conservation and scientifically reliable information about their quality are important. This information can also serve as a helpful tool in designing and implementing effective river management schemes. Inputs of metals and organic contaminants to the surface water occur from three common sources: domestic, commercial and urban runoff. A review of available literature has quantified the extent and importance of these various sources and the inputs from different sectors. In general, urban runoff is not a major contributor of potentially toxic elements to surface water (Sin et al., 2001). Inputs from paved surfaces due to vehicle road abrasion and tyre and brake-lining wear have been identified and losses from Pb painted surfaces and Pb and Zn from roofing materials represent localised sources of these elements (Abdel-Ghani and Elchaghaby, 2007). The presence of organic matter in surface water is determined by solid degradable waste such as crop, food wastage and humans and animals wastes (Khan et al., 2017).

The behaviour of metals in the natural water is a function of the substrate sediment composition, the suspended sediment composition, and the water chemistry (Mohiuddin et al., 2012). During transport, heavy metals may experience many changes in their speciation due to precipitation, dissolution, sorption, and complexation phenomena (Akcay et al., 2003), which affect their behavior and bioavailability (Nicolau et al., 2006). Generally, behavior of heavy metals in the aquatic environment is strongly influenced by the association of metals with various geochemical stages in sediments (Morillo et al., 2004). Geochemical speciation and distribution of metals in the defined chemical fraction been used in predicting the potential contamination, bioavailability and mobility (Islam et al., 2015). Therefore, it is essential to assess the concentrations and distribution of heavy metals in the river's environment.

2.5 OVERVIEW OF SURFACE WATER RESOURCES IN KURDISTAN REGION

The quantity and quality of water drives all human activity and that of most other organisms as well. Human activities such as agriculture, industrial production, hydropower generation, sanitation, and transportation are highly dependent on the availability of water (Al Radif, 1999). Bucknall et al., (2007) stated that the Middle East region is facing rapidly increasing water problems with withdrawing close to 80% of their total renewable water resources, which limits the possibility for future technical fixes to address growing populations and economic demand for water. In addition, per capita water resources are one sixth of the global average and set to decline by half by 2050 (UN, 2016). In the Middle East, water withdrawal as the percentage of renewable water supplies falls within the highest in the world, although the renewal rate is rather low because the region is arid and semi-arid (ESCAP, 2010). According to Bou-Zeid et al (2002) 9 out of 14 Middle Eastern countries experience water shortages, with the others rapidly approaching this status, a trend that may be exacerbated by predicted future changes in climate and population growth. Alobaidy et al. (2010) point out that the Middle East is one of the most vulnerable regions to the global climate change. Water resources in the Middle East are being affected by climate change and variability weather events and the Kurdistan region is not an exception from the rest of the Middle East (Heshmati, 2009).

Al-weshah (2002) and Assaf (2009) argued that the water scarcity in Middle East is expected to intensify due to climate change and variability, excessive growth in demand driven by explosive growth in population, economic development and improvement in living standards, the meagre surface water resources in these regions are already exploited and significantly polluted. According to UNESCO (2009) Iraq's hydrological system has undergone dramatic change over the past 30 years, driven primarily by pressures related to rising demand for a resource of increasingly limited supply, and a shortage of surface water in Iraq in recent years which has diminished to critical levels. The Tigris River Basin, one of the primary sources of surface water in Iraq and the Kurdistan region, discharge has fallen to less than a third of normal capacity, with national storage capacity dropping to around 9 % of full capacity in 2009 (UNESCO 2009). Heshmati (2009) argued that the availability of water in the Kurdistan Region considerable spatial and temporal variability. The increase in population, urbanization and expansion of economic activities undoubtedly leads to increasing demand of water use for various purposes. Alobaidy et al., (2010) identified that water resources in the Kurdistan Region, especially in the last two decades have suffered from remarkable stress in terms of water quantity and quality due to different reasons, such as the dams built on the Tigris River and its tributaries in the riparian countries, global climate changes, local severe decrease of annual precipitation rates and the improper planning of water uses in the region. Stevanovic & Iurkiewicz (2009) stated that the last drought cycle of 1999-2001 dramatically affected water resources in the region. The discharge of many rivers decrease and the yield of much important spring water were reduced and the water Table in some areas was significantly lowered.

In the Kurdistan region, population growth rate is 2.7% per annum and approximately 5 million people inhabit the territory of around 40,643 km^2 (Travaglia & Dainelli, 2003). Approximately half live in the three main cities and administrative centre, Erbil capital city, Sulaimaniya, and Dohuk. In the last two decades, the urban areas have become overcrowded and these cities meet their demands for water by using water from surface water resource. Stevanovic and Iurkiewicz (2009) argued that the dispersion of the rest of the population to thousands of small villages spread all over the territory is one of the main problems for water management in the region. Moreover, living standards in the region improved considerably and have increased stress on water resources in the region. According to Ministry of Planning, KRG (2011) the quantity of water produced on a daily basis is 924,600 m^3, while daily demand equates to about 1.25 million m^3. Therefore, the present water deficit is 325,400 m^3 per day, i.e. 26% of total demand and 35% of total quantity produced at present. Stevanovic & Iurkiewicz (2009) stated that population growth is directly affecting availability of water resources. It has led to the decline in the per capita availability and use of water resources. In addition, the rapid growth of the urban population has put intense pressures on water resources and raises the scarcity level in many places of the region. Heshmati (2009) concluded that the Kurdistan Region faced a rapid change in the structure of its population and urbanization. The comprehensive demographic changes and development programs resulted in the shortage and pollution of water resources. Furthermore, Alobaidy et al. (2010) argued that urbanization is now growing so fast that the population and government will soon face many environmental problems. In major cities, current water supply systems will soon be insufficient to meet the increased demand and sanitary improvement. Water quality is also affected by the quantity and quality of supplies coming from different sources. El-Fadel et al., (2002) and Galbraith, (2006) stated that the main factors affecting the water quality are inadequately treated domestic sewage and insufficient controls on the discharge of agriculture and industrial wastewaters.

Abdulwahid (2013) noted that the water pollution by different substances, the absence of specialized institutions, untreated sewage, are among the major environmental challenges facing water resources in the region. Furthermore, Alobaidy et al., (2010) stated that the absence of a comprehensive surface water quality monitoring programme has resulted in lack of adequate surface water data and information, which in turn constrains proper decision making. Ensuring water quality is a key component of ensuring sufficient water supply as part of water resources management. Effective management of water resources through legislative control on water quality is currently being restricted by a lack of national water quality guidelines (Shareef and Muhamad, 2008).

Heshmati (2009) pointed that the rural inhabitants are closer to the sources of water and unlikely to have access to water distribution and treatment systems. Despite the closeness to water sources and access to greater quantity the quality of drinking water is often much lower than in urban areas due to contamination and the lack of treatment facilities. According to Ministry of Planning/KRG (2011) there is a discrepancy with regard to water service level at the urban and rural areas. PoTable water shortfall rate in the urban areas was down to 6.9%, while the shortfall rate in the rural regions was much higher 38.3%.

2.6 PREVIOUS STUDIES ON ASSESSMENT OF WATER QUALITY IN GZRB

A number of water quality assessments have been conducted in various areas of the Kurdistan region. The most common assessments were found to be the measurements of basic physical parameters (such as pH, temperature, dissolved oxygen and conductivity) and chemical parameters, specifically nutrient concentration (such as total nitrogen and phosphorus). These are demonstrated by basic physical and chemical measurements of water quality in the region. Physical and chemical parameters are mostly used to assess water quality, while the assessment of metals concentrations appears more uncommon. Toma (2011) noted that there are significant seasonal variations in some physico-chemical parameters and as a whole most of the parameters are different, the study has revealed that electrical conductivity varied from 435-485 µs/cm, pH it varies from 7.2 in Dokan Lake to 8.4 in Derbendikhan Lake. Rasheed (1994) made an ecological investigation on 17 sites of various aquatic ecosystems within Erbil province. Three sites have been selected along water course of Bastora River and showed that dissolved oxygen and biochemical oxygen demand were ranged between 6.36-11.99 $mg.l^{-1}$ and 0.1-3.04 $mg.l^{-1}$ respectively.

Aziz (2006) conducted 100 filter runs on Great Zab water by using a pilot-plant, and compared his result with the effluent water of Erbil water project. Al-Naqshbandi (2002) reported that NO^3 concentration was ranged between 0.24-6.7 $mg.l^{-1}$ in his limnological study at Ifraz site. Whereas the maximum turbidity value 186 Nephelometric Turbidity Units was recorded in Great Zab River during May 2002, while EC value was ranged between 272-407 $µs.cm^{-1}$ (Aziz, 2004). Furthermore, Aziz (2006) assessed water quality of Great Zab River at Ifraz site for irrigation and drinking purposes and observed that BOD5 values never exceed 4.6 $mg.l^{-1}$.

Toma (2011) made a limnological study on Derbendikhan lake were carried out seasonally over period of 4 season and observed that the highest value of calcium and magnesium reached to 70mg/L and 34mg/L respectively, minimum value of sodium was 7.0 mg/L and maximum value of potassium was 1.4 mg /L, Sulfate value ranged from 125-175mg/L, minimum value of chloride was 24mg/L. Higher value of nitrite, phosphate and silicate was 0.86µgN-NO2/L, 25µgP-PO4/L and 0.5µgSi-SiO2/L respectively.

Shareef et al., (2009) described physico-chemical properties of drinking water from water treatment plants on Great Zab. He showed that values of pH of river water (6.5-8.4) and drinking water (7.1-7.5) samples were within WHO acceptable limit (Table 2.1), making it marginal for irrigation and drinking purposes. Values of EC of water samples from selected sites were (195-250 ms/cm) lower than the acceptable level recommended by WHO (2004). Ali (2010) surveyed two sites on Great Zab River within Erbil province. He reported that DO concentration was ranged between (4.2 to 12.35 $mg.l^{-1}$), hydrogen ion concentration (from 6.3 to 8), EC (from 255 to 821 $\mu s.cm^{-1}$), BOD5 (from 0.6 to 24 $mg.l^{-1}$), COD (from 15 to 294 $mg.l^{-1}$), ammonium level (from 0.51 to 1.66 µg $NH4-N.l^{-1}$), nitrite (from 29.1 to 71.3 µg $NO2-N.l^{-1}$), nitrate (from 112.9 to 327.4 µg $NO3-N.l^{-1}$), reactive phosphate (from 195.7 to 558 µg $PO4-P.l^{-1}$) and calcium concentration (from 24.7 to 72 $mg.l^{-1}$).

Abdulwahid (2013) identified the pH value of spring water of Delizhiyan spring and Shawrawa River within Soran District is varied from 6.4 to 8.13, indicating that the water sample are almost neutral to sub-alkaline in natural, while the electrical conductivity and total dissolved solid value in spring water and river were ranged between 300 to 1455 $\mu S/cm^{-1}$ and 150 to 727 $mg.1^{-1}$ respectively. Shekha (2016) reported that generally results of most water quality parameters revealed that Great Zab River were within permissible level for drinking water consumption, while it regarded as safe water type for all kinds of crops.

Table 2.1 WHO maximum acceptable concentration and world median for range of parameters

Parameters	WHO MAC	World median
Li	-	0.2[1]
Ca	-	[1]12 mg l^{-1}
Cr	50	0.7[1]
Mn	400	4[1]
Fe	300	40[1]
Co	-	0.3[1]
Ni	70	0.3[1]
Cu	2000	3[1]
Zn	3000	15[1]
As	10	4[1]
Sr	-	500[1]
Mo	70	0.5[1]
Cd	3	0.02[1]
Ba	700	20[1]
Hg	6	0.05[1]
Pb	10	3[1]
Cl^-	[2]250 mg l^{-1}	[3]7.8 mg l^{-1}
$SO4^{2-}$	[2]250 mg l^{-1}	[4]8.3 mg l^{-1}
F^-	1.5 mg l^{-1}	[3]0.1 mg l^{-1}
NO_3^-	50 mg l^{-1}	[3]1 mg l^{-1}
PO_4^{3-}	-	[3]0.03 mg l^{-1}

Alobaidy et al. (2010) assess water quality of Dokan Lake and found that the pH was varied from 6.45-8.20, average DO concentration level of 8.12 mg/L and BOD was 3.20 mg.l^{-1}, while the conductivity value was ranged between 189.33-540 µS/cm. Toma (2011) studied several limnological parameters of Dokan Lake. The result of the study shows conductivity was in the range of 240-430 μS/cm, TDS was 161 to 280 mg/L, pH range was 7.3 to 8.0. Dissolved oxygen ranged between 5.5 to 9.2 mg/L. Calcium and magnesium concentrations varied from 30 to 52mg/L and 14 to 24 mg/L, respectively. Potassium and sodium ranged between 3.8-6.0 mg/L and 1.1-2.2 mg/L, respectively. Sulfate value varied from 130-224 mg/L and ranged between 18-25 mg/L for chloride. High value of nitrate was recorded. From all published research available in Kurdistan region, it is obvious that catchment-wide investigation in the whole surface water quality has been neglected and to date, only a few studies, covering small areas, have been conducted on metal concentrations within surface waters. Therefore, catchment-wide geochemical assessment of water quality is needed to inform the integrated management of water resources in the Kurdistan Region.

CHAPTER 3: STUDY AREA

3.1 LOCATION OF STUDY AREA

The Great Zab River originates in Turkey from the mountainous area of east of Lake Van (Fig 3.1) where it springs at an altitude of 4,168 m above sea level (Ali, 2011). The river is 407 km long (290 in Iraq) and is one of the main tributaries of the Tigris river, flowing into the Iraqi Kurdistan, north of the Erbil plain between latitudes 36° and 38°N and longitudes 43°18’ and 44°18’E (Sissakian, 2013; Aziz, 2008). The whole river basin has an area of 26306 km^2 with a sizeable part outside Iraq, mostly in Turkey (Table 3.1). In Iraq, the catchment is mostly located in the region of Kurdistan (Rasheed, 2008; Abdulla & Al- Badranih, 2000). It is the most important river basin in Kurdistan Region as it covers approximately 33 % of the whole Kurdistan area (around 50330 km2) including the capital city of Erbil (ESCWA-BGR, 2012). The discharge of this river is about 70 % relative to that of the River Tigris before they join together about 49 km south of Mosul towards Sharqat town.

Table 3.1. Partitioning of the Great Zab River basin area at regional and national level (km^2)

	Iraq		Outside Iraq		
	In KR	Outside KR	Turkey	Iran	Total
Catchment area	16998	216	9309	5	26307
	16880		9427		
Proportion of the river basin	63 %	1 %	36 %	Insignificant	100 %

Although integrated water management takes into account the whole river basin from the origin of the river to the outlet to the Tigris, mostly political and practical reasons oblige to restrict the study area. The area of the river basin outside Iraq, in Turkey, and in Iran, due to political issues between Iraq/Kurdistan, Turkey and Iran make difficult to access to the data in these parts, it was decided to consider Turkey and Iran as an input for the study area.

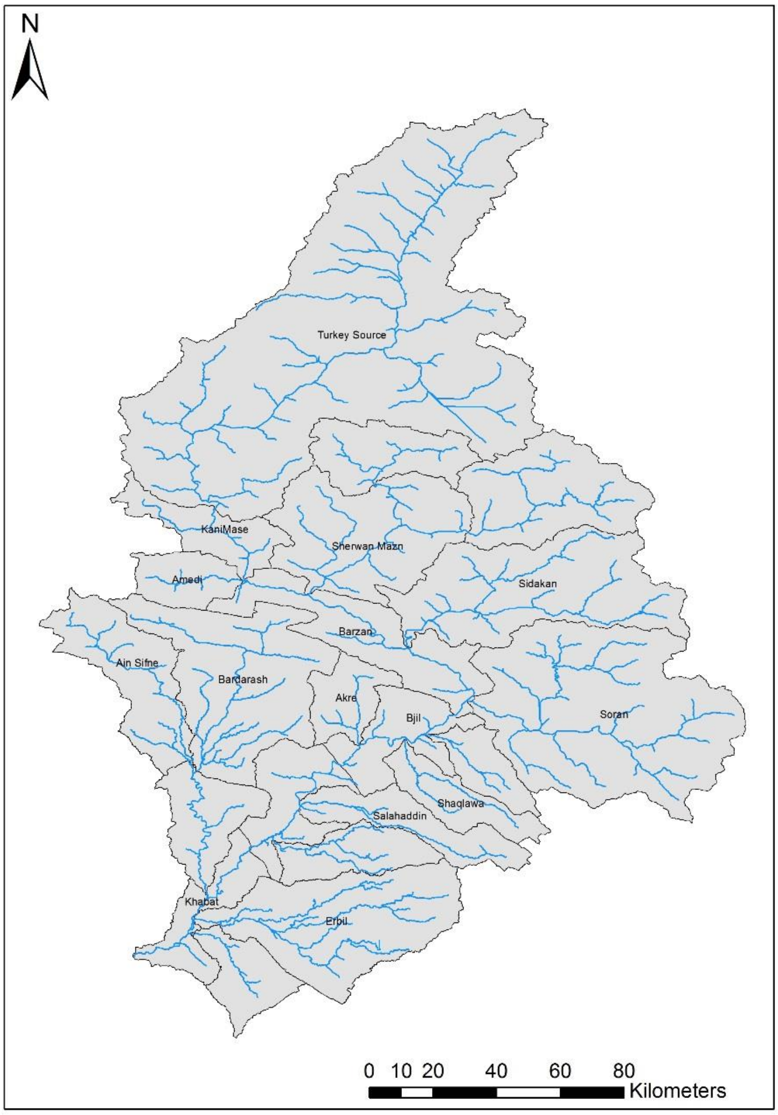


Figure 3.1 Great Zab catchment and study area

3.2 HYDROLOGICAL CHARACTERISTICS

3. 2.1 River basins and hydrographic network

Great Zab River flows generally northeast to southwest from the mountainous area in Turkey to the outlet to the Tigris River 49 km south of Mosul city (Shareef, and Muhammad, 2008). The river rises in the mountains that lie in the centre between Ormia Lake in Iran and Wan Lake in Turkey (Fig 3.1). Then it flows in northwest direction across the Iraqi border beside Amedi, afterward it flows in southeast direction parallel to the Iraqi Turkey borders until it combines with Shemdianan River that flows from the heights close to the Iran-Iraqi borders.

It flows again in a northwest direction until it combines with Rawanduz near Bekhme (UNICEF, 2000). Its flow was diverted at Bekhme because of the construction of the dam that was not completed. From the junction with Rawanduz River the flow direction changes to southwest then it flows through a range of hills with different heights until it combines with Tigris River. Many tributaries supply the main river (Fig 3.2), of which two are transboundary, namely Shemdianan (from Sheen) and Haji Bak (from Chama River), which delimits a portion of the boundary between Turkey and Iraq. Four main tributaries are totally located in Kurdistan Region (three on left bank: Shemdianan, Rukuchuk, Rawanduz, and one on right bank: Khazir). In addition, there are seven secondary tributaries.

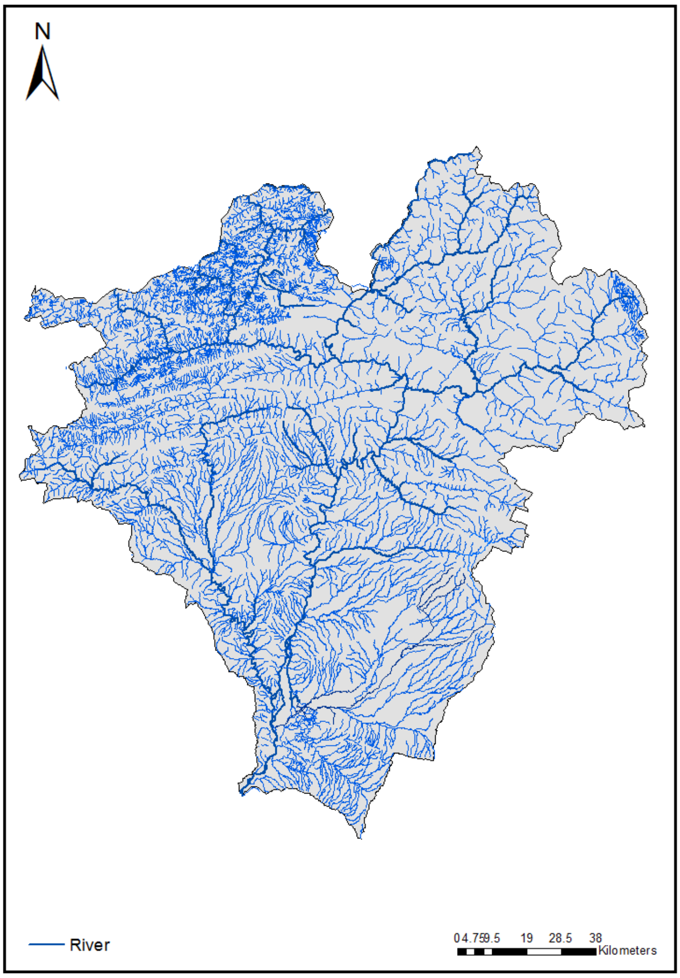


Figure 3.2 Hydrographic network in study area

The hydrographic network of the Great Zab divide into two main networks, first the Great Zab River, which drains all the water from the streams and tributaries and second the permanent and seasonal streams and tributaries. Four tributaries supply most of water into the Great Zab River, with Table 3.2 providing an overview of the catchment area of these main tributaries.

Table 3.2 River Basins in Great Zab.

River Name	Catchment area (km^2)	Average annual runoff (m^3/s)
Shemdianan	3341	15
Rukuchuk	1844	32
Rawanduz	2956	34
Khazir	3303	12

Because of an undulating topography, the hydrographic network includes many thalwegs (lowest points of a stream bed or a valley). These streams are seasonal, which drain water to the Greater Zab in the rained season and are dry in summer season. In order to analyse water resources and uses in the study area, it was decided to divide the whole basin into 22 sub-basins (Fig 3.3). Division is made according to topography, hydrology and according to the location of main infrastructures for water management. The Greater Zab is one of the few unregulated rivers in the region as no dams have been built on the river to date. However, both riparian countries have plans to exploit the Greater Zab. Iraq has planned two dams in the Great Zab catchment: the Bekhme and Mandawa Dams. The aim of the project was to create a large reservoir that would be used to supply irrigation water and hydropower to the mainly Kurdistan region in the northern Iraq. However, construction was suspended in 1990 due to the outbreak of the Gulf War.

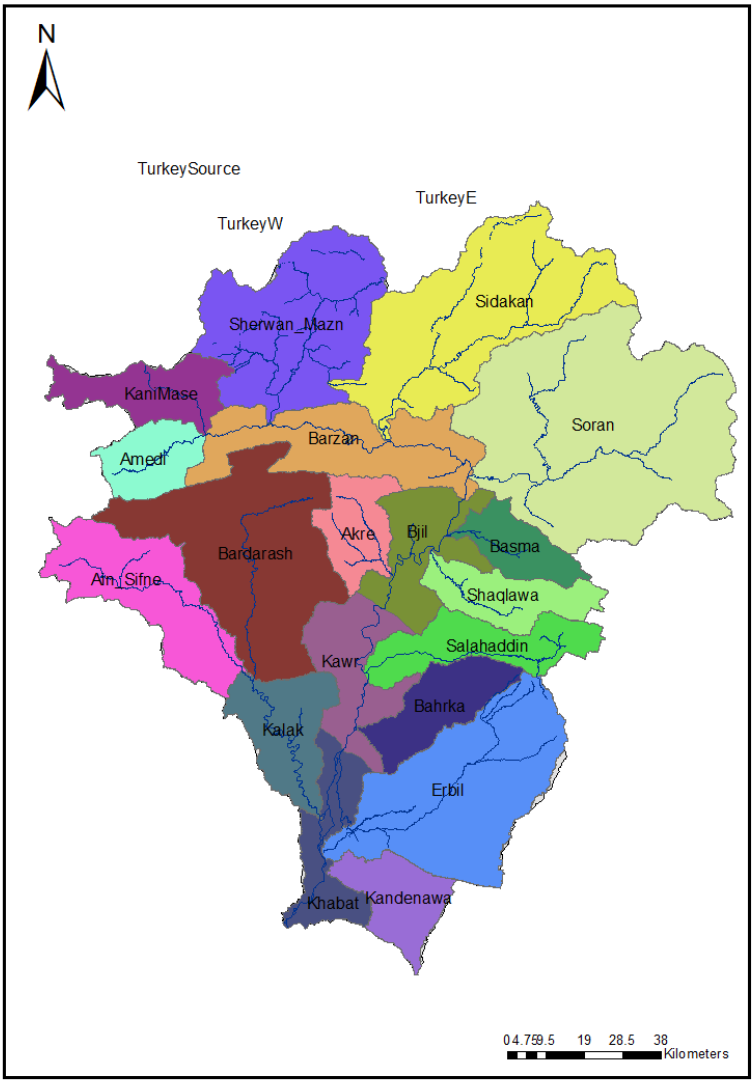


Figure 3.3 Major sub-basins in study area

The headwater are characterized by a steep topography (Sissakian, 2013). The Great Zab rises in the highlands of the Zagros Mountains which consists of parallel limestone folds rising to elevations of over 3,000 masl (Travaglia & Dainelli, 2003). The valleys including that of the Great Zab and the south- western foothill zone are filled with gravel, conglomerate, and sandstone (Aziz, 2008; Stevanovic and Iurkiewicz 2009). In this area geomorphology is rather uneven surface with steep slopes and narrow valleys and vegetation cover is widespread, constituted of both grasses and forests (Travaglia & Dainelli, 2003).

The river and its tributaries are primarily fed by rainfall and snowmelt (ESCWA-BGR, 2012) particularly in the highlands of the Zagros Mountains, with cold winter temperatures and annual precipitation in excess of 1,000 mm (Toma, 2013). From there, the river flows into the foothill zone of the Zagros, where rainfall drops to less than 350 mm per year at the confluence with the Tigris (Abdulla & Al- Badranih, 2000). Rainfall and snowmelt result in a flow regime with a higher flow season in spring (Rasheed, 2008). The Great Zab River supplies the Tigris River with an average annual flow volume of 12.7 billion cubic meters measured at Eski Kalak gauging station and 12 billion cubic meters further upstream at the Bekhme Dam for the period of record 1930-2011. According to some estimates, 33% of the Tigris flow at Baghdad originates from the Great Zab (ESCWA-BGR, 2012).

Table 3.3 Summary of annual flow volume statistics for the Great Zab (BCM/year)

River	Station (drainage area, km^2)	Period	Mean	Minimum	Maximum	CV[a] (-)
Great Zab	Eski Kalak (16998)	1932-2012	12.7	3.7	23.6	0.31

Source: Compiled based on data provided by Saleh (2010); Ministry of Agricultural KRG (2012).

3.2.2 Relief and hydrological zones

Elevations within the Kurdistan region range between 3600 metres and less than 200 metres and hence cover a wide range of climatic zones (Abdulla & Al- Badranih, 2000). The average elevation of the Greater Zab basin (including the part outside of Iraq) is about 2300 metres upstream of the Iraqi border and about 1700 m for the entire basin upstream of Eski Kalak (Stevanovic and Iurkiewicz, 2009). According to Sissakian (2013) and Stevanovic and Iurkiewicz (2009), the alignment of the main rivers is roughly rectangular with respect to the major geological (tectonic and lithological) boundaries and mountain ridges. Great Zab river basin therefore includes three major hydrological zones:

1. A high mountain zone (equivalent to the geological “thrust zone”) with limited groundwater storage, but high precipitation and significant snow storage. The area is sparsely inhabited (even partly uninhabited due to security issues) and characterised by steep slopes and narrow valleys (Abbas et al., 2016; Sissakian et al., 2015).

2. A karstified zone that drains the major karstic-fissured aquifers of the region. The relief is dominated by elongated mountain ridges that are often crossed by the rivers through narrow gaps which offer suitable sites for dam construction (Sissakian, 2013). From a hydrological perspective the area is heterogeneous, with phenomena such as canyons, dry valleys and, on the other hand, large springs (yielding several m^3/s throughout the year) which are fed by large subterranean karst systems. Depending on the tectonic situation several basins and plains are embedded in this zone (Soran basin); this is the main population centre of the zone (Abdulwahid, 2013).

3. The lowland plains, with a typical elevation between 300 and 600 m. The area is partly agricultural land, partly eroded ‘badland’ and includes both densely populated (around the regional capital Erbil) and low density inhabited areas (Abbas et al., 2016). Significant parts of the plains are made up of the highly productive Bakhtiari aquifer, which is partly covered by fluvial deposits and terraces or less permeable layers. Groundwater resources, which are mostly of good quality but limited due to low precipitation (300 to 500 mm/y), are being used intensively through several thousand deep wells. Most of the lowland tributaries are seasonal wadis, i.e. without permanent baseflow during the dry season (Sissakian, 2013).

3.3 PHYSICAL CHARACTERIZATION

3.3.1 Topography and limits of topographical basins

In the Great Zab River basin three major tectonic zones can be distinguished (Sissakian, 2013): (Fig 3.4) the Zagros Zone in the north (along the border with Turkey and Iran), the imbricated high folded zone in the central part and the foothill zone in the south (Stevanovic and Markovic, 2004). Generally, these tectonic zones are associated with corresponding major morphologic units: mountainous ranges, anticline ridges / foothill pediments and fluvial accumulation plains (Stevanovic and Iurkiewicz, 2009; Sissakian et al., 2015).

- The foothill area (or plain), where Erbil is located. It is the lowest elevation area, where the geological layers show smooth folds of recent alluvial and alluvial sediments (average elevation 400 m) (Travaglia & Dainelli, 2003).
- The imbricated high folded zone area in the north and northeast of the foothill, showing a succession of anticlines and synclines. This area is rich in karstic springs, by place with high yields (Sissakian, 2013).
- And the Zagros area and Suture Zone, further to the north and north-east towards the border with Turkey and Iran. The suture zone corresponds to the thrust of the sea-floor plate over the European plate at the Upper Cretaceous period. Average elevation is over 2000 m (Al-Basrawi and Al-Jiburi, 2014; Stevanovic and Markovic, 2004).

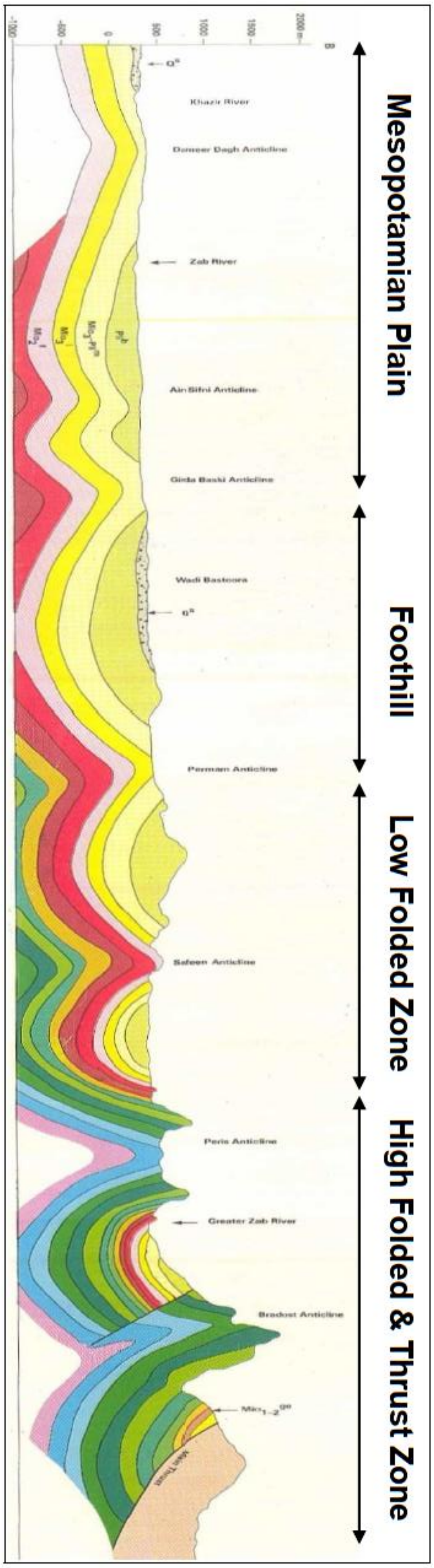


Figure 3.4 Cross section from Foothill zone (left) to the Zagros zone (right)

3.3.2 Geological Setting

The Kurdistan region of Iraq is geologically part of the extensive alpine mountain belt of the near east. The Taurus- Zagros belt developed during the collision of the Afro-Arabian continent with the Eurasian continent (Ameen, 1992). The Taurus- Zagros includes two main zones: the thrust zone and the folded zone (Karim et al., 2011). The thrust zone forms the Suture Zone of the collided plates and occurs as a narrow strip in the north, just outside the border between Kurdistan region and Turkey, and in the northeast, along the border between the Kurdistan region and Iran (Stevanovic & Iurkiewicz, 2009). The folded zone is much wider (~200 km) and can be subdivided according to the intensity of folding into two main parts: the imbricated folds zone, which consists of relatively narrow zone of intensely faulted and thrusted large folds near the thrust zone border, and the simple folded zone, which is much wider and consists of smaller and less disrupted folds (Travaglia & Dainelli, 2003; Karim et al,. 2011; Issa et al., 2014). The simple folds are further subdivided into two subzones: the high mountain zone, which consists of a series of relatively large mostly asymmetric anticlines separated by narrow synclines, and the foothill zone, which consists of a series of relatively small and narrow anticlines separated by wide synclines (Ameen, 1992; Othman and Gloaguen, 2013).

The thrust zone mainly consists of the oldest formations, from the pre-Triassic and Jurassic periods to the late Teriary period Nawprdan, Walsh Formations (Issa et al., 2014; Stevanovic & Iurkiewicz, 2009). In the high folded zone, the oldest formations belong to the Middle and Upper Jurassic. The important “Bekhme” karstic aquifer is hosted by sediments accumulated during the late Lower Cretaceous phase (the Aptian and Albian ages) as well as during the lower and middle part of the Upper Cretaceous (Aqra, Bekhme, Qamchuga, and other formations) (Stevanovic & Markovic, 2004). In the folded zone Triassic to Pliocene units outcrop, mainly sedimentary rocks, with a predominance of limestones and dolomitic limestone (Sissakian, 2013). These formations are significant, because of the intensive karst phenomena and the large volume of potential groundwater storage (Stevanovic & Iurkiewicz, 2009). Recent Quaternary deposits (alluvium, terrace and colluvium) fill the valleys and follow the main riverbed in the northern and central part, and cover the older Tertiary formations in the plains (Travaglia & Dainelli, 2003). Based on detailed field geology and with the support of satellite images and aerial photographs, Stevanovic and Markovic (2004), define the most important active geomorphological processes prevailing in Iraqi Kurdistan region. They mentioned karstic, fluvial and slope (delluvial, prolluvial and colluvial) processes, besides traces of the Aeolian process. Structural relief forms caused by inner, endogenic forces, and exposed by activity of different exogenic forces are also abundant (Karim et al,. 2011; Stevanovic & Iurkiewicz, 2009).

3.3.3 Groundwater

In the higher mountains area, groundwater is discharged from the main karstic aquifers (Bekhme and Pila Spi aquifers) into springs (Stevanovic & Iurkiewicz, 2009; Travaglia & Dainelli, 2003). In the inter-mountain basins, groundwater also enters stream-beds through overlying unconsolidated deposits. Most of this spring-water is probably diverted upstream for irrigation and water supply purposes (ESCWA-BGR, 2012). In the plain area of Zagros zone groundwater from the Bai Hassan- Mudadia Aquifers discharges prevailingly into the main Great Zab tributaries (Stevanovic & Iurkiewicz, 2009). The source of the Great Zab lies at an altitude of approximately 3000 masl in the Zagros Mountains east of Lake Van in Turkey. No information is available on the contribution of transboundary flow to the discharge of the Great Zab, nor on proportions of seasonal runoff and base flow from aquifer discharges in the upper catchments of the river system. Extensive groundwater drainage into the Great Zab occurs in the Erbil area in the foothills zone (ESCWA-BGR, 2012).

On the plain of the region, the groundwater is tapped by numerous wells. A few thousand water wells with a depth ranging from 100 to 200 m operate for different purposes in the surroundings of the regional capital Erbil alone. To the north, in the hills, the spring water from relatively water-rich karstic aquifers is used as the main source for drinking purposes, and supplies the traditional gravity irrigation schemes (Stevanovic and Markovic, 2004). Discharge through springs represents the main drainage of the karstic aquifers. Various factors such as the contact of water-bearing layers and impermeable rocks, and the presence and distribution of tectonic elements, control the outlet locations, while climatic conditions and resources of the aquifer system actually dictate the amount of water discharged through springs. Most of the large springs are located in the High Folded zone (Stevanovic & Iurkiewicz, 2009).

3.3.4 Soils

The soils of the Kurdistan region and the study area are the result of weathering, erosion and sedimentation, and soil-forming processes during Quaternary period (Berding, 2002). In the mountain valleys, foothills and adjacent plains, several meters of fine textured sediment forming fertile deep soil lie on top of a bed of gravel (Al-Naish, 2011). Litho soil, shallow medium chestnut soil and rendzina soils are dominant from the great soil groups in mountainous area (Sissakian, 2013). Shallow to deep chestnut soils exist in the valleys, whereas the foothills have mainly brown soil (Bapeer et al., 2010). According to Berding (2003), the soils in the plains and foothills zone are generally deep and regarding texture, remarkably homogeneous. The sand, silt and clay contents vary within rather narrow limits and the vast majority of soils have silty clay loam over silty clay. The silt content is typically higher than the clay content with 50-65% silt, 30-45% clay and 5-10% sand being representative (Bapeer et al., 2010). Only on more recent alluvial deposits (lower terraces) close to the rivers, is the texture more variable and includes sandy and loamy soils (Mulder et al, 2015). Where the Aeolian/fluviatile cover is thin or has been eroded the underlying gravel (and cobble) beds are exposed (Solecki, 2005). The gravel and cobble content of the soils may then change over short distances from nil to more than 40%. Gravelly/ cobbly soils are estimated to occupy less than 10% of the plains (Abdulla & Al- Badranih, 2000). As a whole the soils in Kurdistan region are calcareous and originated from limestone and dolomite of different formation (Mulder et al, 2015). There are also scattered spots of blue Marle, red mud and chalky soils that belong to Kolosh, Gercus and Shiranish Formations, but parent material, slope, runoff, soil depth and maturity affect soils variability (Al-Basrawi and Al-Jiburi, 2014). The brown mountain and hill soils are prevalent in the Kurdistan region, showing the effect of higher precipitation and eroded material of rocks, modified by the richer plant cover, these brown soils are fertile (Mulder et al, 2015).

3.4 CLIMATIC CHARACTERISTICS

The climate of the Kurdistan region is semi-arid continental, hot and dry in summer, and cold and wet in winter. The hottest months are June, July, August while the coldest months are December, January and February (Bozkurt and Sen, 2013). The climate of the region is characterized by clear seasonal differences, caused mainly by changes in the type of atmospheric circulation during the year, and by the intensity of the insulation (Stevanovic, 2001). In the cold season, this part of north Iraq is influenced more by the Mediterranean front. As a result of the contrast between the cold European air and warmer masses of air from northern Africa, a frontal zone of high pressure develops over the Mediterranean area; disturbances of cyclonic character occur frequently along this zone (Bozkurt and Sen, 2013; Othman and Gloaguen, 2013). Some barometric depressions stray to the east and break through these high-pressure areas, reaching the region. This does not occur frequently, however, and the precipitation on the cold front is short and boisterous. In summer, the thermal differences between the air masses are much less, and the circulation systems, which support them, are weaker (Stevanovic & Markovic, 2004).

According to the Koppen system of climate classification, the mountainous areas of Kurdistan Region can be described as being of type DSa, which indicatives a cool wet climate in the winter and dry season in the summer with a yearly rainfall of between 800 and 1000 mm (Othman and Gloaguen, 2013) (Fig 3.5). Whereas, the plains and valleys of the region describe as CSa Mediterranean climate characterized by rainy winter and dry hot summers with a yearly rainfall of between 300 and 700 mm (Travaglia & Dainelli, 2003). The annual rainfall in the region varies. Precipitation occurs from October to May, increasing from SW to NE, reaching its maximum at the highest altitude of the mountains ranges (Mudler et al., 2015). The topography also has a great influence on the rainfall distribution (Evans, et al., 2004; Alijani, 2008). The average annual rainfall ranges from 250 mm in Khanaqin to more than 700 mm in Zakho, 900 mm in Rawanduz, 1000 mm in Akri and 1200 mm in Penjwin (Hussein, 2010; Al-Basrawi and Al-Jiburi 2004). These rainfall amounts indicate that rainfall increases as one move towards the north and northeast because of the higher elevations (Stevanovic & Markovic, 2004; Abdulla & Al- Badranih, 2000). Since the rainfall is the main climatic parameter Kurdistan region can be divided into three different regions based on precipitation rates, as follows:

- The zone where annual rainfall exceeds 550 mm/year: This zone is mainly agricultural due to secured rainfall. The area of this zone is around 1.5×109 m^2 of rain fed land, and more than 8.0×109 m^2 of forestlands and good quality pastures (UNDP, 2011). As a result of the sufficient quantities of rain, the cultivation of crops such as wheat, barley, chickpeas, lentils, winter vegetables is possible in areas such as: Rawanduz, Choman, Shaqlawa, Koya, Mergasur in the Erbil Governorate; and Amedi, Akre, Zakho, Sheikhs in Duhok Governorate (Ahmad, 2001).
- The zone where annual rainfall ranges between 350 and 550 mm/ year: This zone covers an area of 3.5 × 109 m^2 of exploit able farmland with around 4.0 × 109 m^2 of

pastures and forests (UNDP, 2011). Winter sowing of all kinds of crops is usually undertaken in this zone. Due to the uncertain level of rain and to the recurrent droughts, two complementary irrigations are usually necessary, one at the beginning of the planting season before germination and one before the maturity of the grains. This zone includes the central districts of Erbil and Duhok Governorates (UNDP, 2010).

- The zone where the annual rainfall is less than 300 mm/year: This zone is the dry zone, and it covers 2.0×109 m^2 (UNDP, 2011). In this zone, agriculture cannot depend on rain and an average of three to five complementary irrigations are required between sowing and the maturity of the crops. This area includes the rest of the districts of the governorates of Erbil, and Duhok (FAO, 2001; Saeed, 2001).

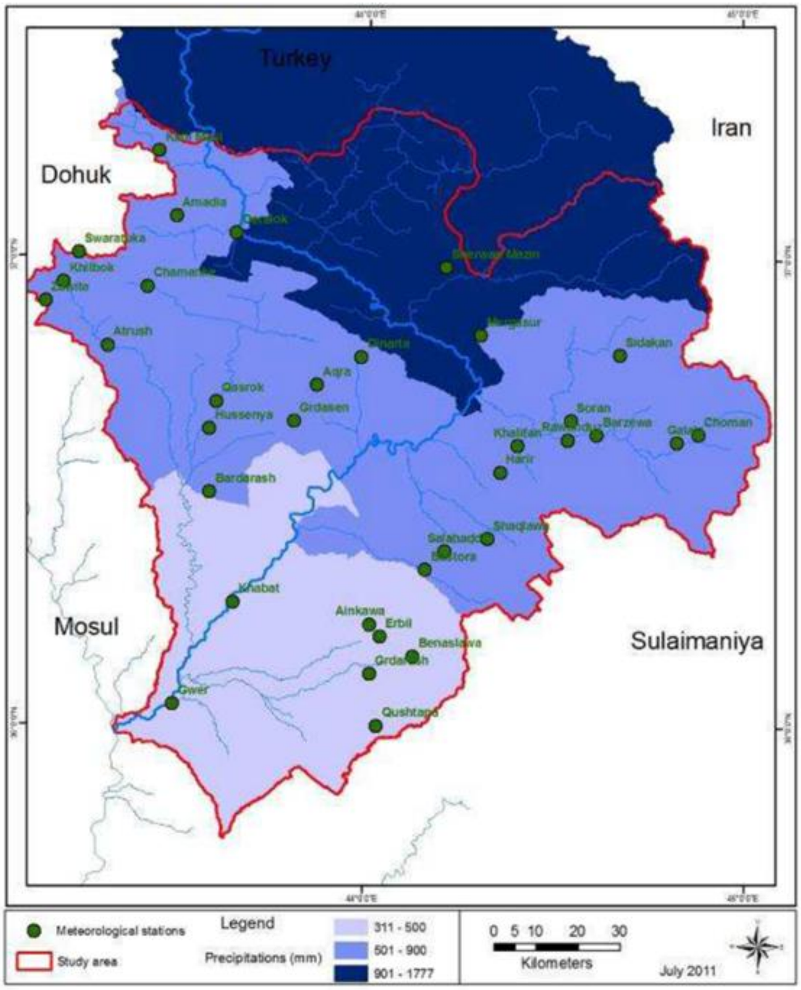


Figure 3.5 Precipitation zones in study area

The mean annual rainfall in the Erbil plain for the period 1961-1990 was 425 mm/year while observed yearly values range between 200 to 700 mm (Fadhil, 2011). Rainfall reduction has been observed recently during the winter and springtime of 1998-1999, the observed rainfall was three times lower than average (Heshmati, 2009). Comparison of data collected by FAO throughout the three Governorates for October 1999- April 2000 shows a reduction of about 40 percent to the mean rainfall for this period of the year (Mulder et al,. 2015). The mean annual air temperature in the Kurdistan region is high approximately 20˚C although slightly lower than in the south and middle of Iraq. January is the coldest month of the year, but generally the mean temperature does not fall below 5°C (Heshmati, 2009). However, the temperature can drop to minus 5°C, but only in northern and northeastern parts of the region. The mean temperature in July and August exceeds 30°C, the hottest months, mean highs are 39-43°C, and often reach 50°C. Mean winter high temperatures are 7-13°C, and mean lows are 2-7°C (Stansfield, 2003; Abdulla & Al- Badranih, 2000).

The direction of the wind often is from north to east. When the summer wind blows this causes drought and erosion. During summer, the atmosphere is dusty and hot but during winter, the climate is cold with snowfalls and frost (Saeed 2001; and Ahmed 2001). In winter, in the region winds from northern sectors prevail, while in summer, western and south-western winds occur most frequently (Saeed, 2001). Generally, the average wind velocity in the individual months of the year does not exceed 5 m/s. The average annual air humidity is 40-45%, and exhibits a high seasonal diversity. In January, humidity approaches approximately 70% while it drops to below 20% in July and August (Ahmad, 2001). In addition, the climate is greatly affected by the dusty and warm wind that blows from the southern and western desert of Iraq, Jordan and Saudi Arabia. Dust storms raise the daily temperature to a maximum value of more than 45˚C (Heshmati, 2009).

3.5 NATURAL FOREST AND VEGETATION

An FAO survey of the forestry sub-sector in 1999 indicated that the forest area in northern Iraq covered 1.9 million hectares, or about 36% of the region. The tree cover of the region's mountain slopes reaches elevations of 600m to 2000m and is dominantly made up of oak woodlands and some oak forests, holding medium-sized trees, often with a wide spread crown (Solecki, 2005). The high Zagros is characterized by three different ecozones: the area above the treeline at 1,800 metres where shrubs and herbs dominate, the area between 1,800 and 610 metres that was in the past dominated by open oak forest (*Quercus aegilops*), and the wetter and sometimes marshy river valleys (UNDP, 2011). Other trees besides oak that can be found in the forested zone including juniper at higher elevations; ash, hawthorn, maple and walnut at intermediate elevations; and pistachio and olive trees in lower, drier areas (Wright, 2007). In the foothill zone, many areas are now cultivated, but there remain small patches of natural vegetation dominated by herbs of the genus *Phlomis* (FAO, 2001).

The trees are a major source of income and essential in the livelihood of the mountain population small farmers. In the villages more than anywhere else, the trees are regularly used for firewood and pollarded to provide winter fodders for livestock or branches for roof construction and light summer huts. The Oak also meet the needs of the local population for building material, home and agricultural implements. In agricultural fields some interesting species are used for protection against wind and water erosion, such as *Prosopis stephaniana* and *Glycyrrhiza glabra* (Berding, 2003). The growing period for most crops continues beyond the rainy season and to a large extent, crops mature on moisture stored in the soil profile (Saeed, 2001). The forestry sector in Kurdistan Region is no well developed. The successive wars and drought events have severely affected the natural ecosystems. The local communities manage natural forests in a traditional management system. Some forests are protected by law, and guarded by the local " Peshmerga". The protection is limited to a series of interdictions (grazing, harvesting) with no planning and management.

3.6 HUMAN CHARACTERISTICS

3.6.1 Population size and growth rates

Data indicates that the region's population increased from about 3,910,329 million inhabitants in 2003 to 4,382,167 million inhabitants in 2008, at an increase rate of 12.07%. In 2009, population was 4,698,790 million, with an increase rate of 7.05%, compared to 2008 and 19.96% in comparison to that of 2003 (Ministry of Planning, KRG 2011). Population is expected to rise to about 5,601,227 million in 2016, if the growth rate remained the same as in the past five years, in terms of birth and mortality rates and other relevant changes (Heshmati, 2009). This absolute increase is a natural result of population growth rise, which maintained the same high pace over the past two decades, due to adoption of a series of programs and measures aimed to encourage reproduction by offering material and moral incentives, such as encouraging early marriage. Annual growth population growth rates by governorate, based on the figures released by the Kurdistan Region Statistics Office and the result of Iraqi Household Socio Economy Survey, was 3.2% in Erbil, 3.1% in Sulaymaniyah and 2.6% in Duhok, with an overall annual growth rate of 3%. After 2003, the region experienced a transformation stage, characterized by certain changes which impacted the population's demography. These changes were evident in a group of demographic indicators, like increased overall reproduction rate to 4% in 2006 in the region as a whole, 4.9% in Erbil, 4.1% in Duhok and 2.9% in Sulaymaniyah, which exceed the internationally recognized world rate of 2.6% (Ministry of Planning, KRG 2011). Other indicators are high birth rates of 29.9 per on thousand inhabitants for 2004-2009, based on Ministry of Health figures, coupled with a relative stability and a slight rise in infant mortality rate to 11.5 per one thousand live birth, during the same period (Ministry of Planning, KRG 2011). The population growth rate has been maintained and is expected to stand at 3% or slightly more in the medium and long term, assisted by the rising birth rates and stable mortality rate, and achieved through expanded preventive and medical services (Ministry of Planning, KRG 2013).

There is an intensive internal migration towards the cities (Erbil, Sulaymaniyah and Dohuk) and their suburbs. This exerts a pressure, which in the absence of proper land use planning and adequate infrastructure, results in major environmental problems, and aggravates the effects of drought. The increase in the urbanisation level and the fact that a high proportion of the displaced population is not willing to return to the native villages, is directly affecting the agriculture and forestry sector and the sustainability of the rural areas. On one hand the increase in the urbanisation level will mean an increase in the urban extension, which will be at the expense of the peri-urban lands and of some orchards and agricultural fields. It also implies a higher demand on water in urban settings. On the other hand, the migration towards the cities and the abandonment of the villages and agricultural fields in rural areas, will lead to the destruction of the traditional livelihood systems, including water related systems, such as Kahrezs, natural springs and wells. Such an increase also means an increasing need to improve the urban environment by providing more green spaces, and thus an increasing need of water resources.

3.6.2 Drinking water and sanitation

Ministry of Municipalities and Tourism, in particular the General Directorate of Water and Sewerage, is in charge of provision of water and sanitation. They have to provide services to a little part of the population dispersed in numerous small villages and to a fast growing urban population concentrated in a few towns. Most of the households obtain their drinking water through pipes. Drinking water is supplied by a mix of surface and groundwater for instance 5000 wells are used for drinking purposes in Erbil governorate, Erbil city gets 40% of its drinking water from wells. While in the mountain area, main intakes for drinking purposes all come from surface and springs resources (Ministry of Planning, 2013).

3.6.3 Legal and institutional framework

The ministry of Municipalities and Tourism of the Kurdistan Regional Government (KRG) manages the water supply system in the three governorates of the region. The operations are entirely financed from the Kurdistan Region Government and are managed by local directorate. The overarching responsibility for planning in KRG lies with the Ministry of Planning, while the Ministry of Health providing the environmental standards that monitor data respectively. Moreover, the water security stability responsibilities are the task of Ministry of Agricultural and Water Resources. The water and sanitation directorate of each KR's governorate self-performs its services without involving the private sector. Although, National Development Strategy (NDS) is at the central point of the Ministry of Planning and Development corporation activities in KRG play a pivotal role in placing policies at a national level. The regional development strategy also plays a critical and foundational role for formulation and implementation of the national development strategy through laying the ground for the generation of policy options, the prioritisation of objectives, and determining the consequences of water strategies.

CHAPTER 4: SPATIAL AND TEMPORAL TRENDS OF WATER QUALITY IN GREAT ZAB RIVER BASIN

4.1 ABSTRACT

This study presents data on the spatial and temporal trends in concentrations of As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, Li, Mn, Mo, Ni, Pb, Sr, Zn, NO_3^-, SO_4^{2-}, F^-, Cl^- and PO_4^{3-}, in addition to pH, electrical conductivity, dissolved oxygen and turbidity. Surface water samples were collected from 62 sites and grouped upon major underling geological unites identified in Great Zab catchment. The best water quality is in the upper parts of the Great Zab catchment, while lower catchment shows greatest anthropogenic influence, identifiable through elements such as Cl^- and NO_3^-. The result indicate that concentrations of Ca, Li, Mo are higher in the winter than summer whilst concentrations of Zn, SO_4, F^-, Cl^-, and PO_4 are higher in the summer than winter. The most frequent differences were found between water chemistry in samples collected from the Zagros and foothill zones, with 13 parameters showing a statistically significant difference. Five and 7 parameters, respectively, showed statistically significant differences between the Zagros and imbricated/high-fold zones and imbricated/high-fold and foothill zones.

4.2 INTRODUCTION

Worldwide deterioration of surface water quality has been attributed to both natural processes and anthropogenic interferences, including hydrological change, climate change, land use change, and the effects of industrial, municipal and agricultural inputs (Ravichandran, 2003; Melina et al., 2005; Gantidis et al., 2007). Information on water quality and pollution sources is essential for the implementation of integrated water resources management (Crosa et al., 2006; Sarkar et al., 2007; Zhou et al., 2007). In addition, due to the seasonality of river discharge regimes, assessing spatial and temporal variations of river water quality at a catchment level has become an important aspect for the physical and chemical characterization of aquatic environments (Ouyang et al., 2006; Sundaray et al., 2006). Water quality is defined in terms of the chemical, physical and biological parameters and the quality of surface water may vary temporally and spatially even when there is no anthropogenic influence present (Lawson, 2011). Research on spatial and temporal variations of river water quality has been conducted in many basins (e.g. Arya and Gupta, 2013; Aziz, 2004; Chang, 2008; Khan et al., 2017; Singh, 2005; Ouyang et al., 2006). Studies investigating the spatial and seasonal variability of water quality have reported that water quality issues, such as eutrophication, are highly dependent on land use patterns and influence from catchment runoff (Caccia and Boyer, 2005; Zhang et al., 2007). Additionally, anthropogenic point sources can have impacts upon water quality at a range of magnitudes, dependent upon the nature of the inputs (Rostami et al., 2018).

Spatial and temporal monitoring of river water quality has been used as one of the important tools for water quality assessment (Singh et al. 2005; Shrestha and Kazama 2007). Like most developing countries, Kurdistan is experiencing rapid industrialization, urbanization and population growth, especially during the last 20 years (Alobaidy, 2010). Unfortunately, this has not been coupled with the development and implementation of environmental safety procedures and legislation, resulting in many environmental problems arising from various pollutants emanating from industry, agricultural practices and untreated urban sewage (see Fig 4.1 and 4.2). The Great Zab catchment exemplifies these challenges and is coupled with a general lack of a systematic assessment of the spatial and temporal trends in river water quality in the catchment that may be used to inform IWRM. Therefore, this chapter presents the results of the investigation into spatial and temporal trends in water quality in the Great Zab River catchment with respect to selected cations, anions and physico-chemical parameters.

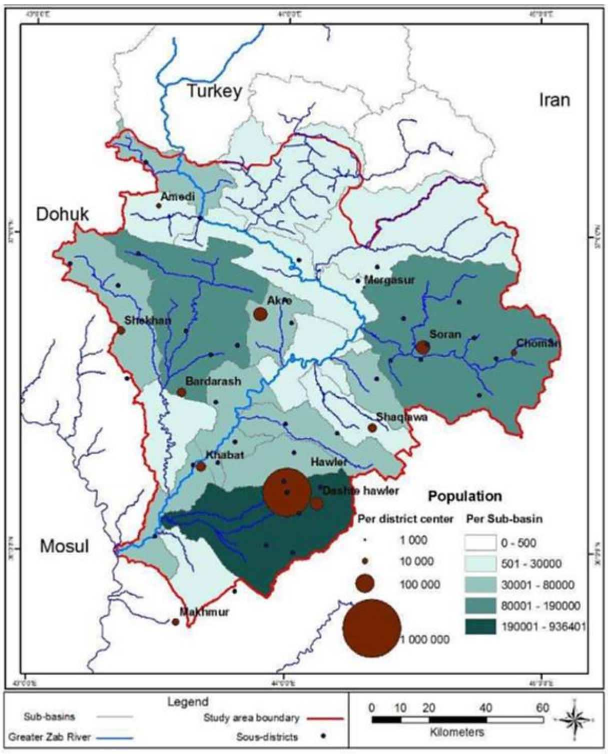


Figure 4.2 Distribution of the population

Figure 4.1 Agricultural Zones

4.3 METHOD AND MATERIALS

The basic requirements of any sampling method are that it is rapid, inexpensive and easy to apply consistently over the spatial and temporal scales of interest that it is statistically representative and robust and that is standardized within both the current study and in relation to any relevant previous work (Herr and Gray, 1995).

4.3.1 Sampling site selection and sampling frequency

The number of samples collected and distance between samples in a particular river were dependent upon river length and accessibility. Accessibility to the surface drainage network in the Great Zab River Basin is spatially variable. Therefore, for larger rivers such as the Rivers Great Zab, Rezan and Rwanduz, where access was generally more difficult, sample sites were spaced between 5 and 40 km, but generally not more than 30 km apart. However, for smaller rivers (tributaries) with easier access, such as Bastora, and Komel Rivers, sample sites will spaced between 1-10 km apart with generally equidistant spacing. For all sample sites, the selection of sample locations was focused particularly on bridge crossings that granted better access to the rivers (c.f. Bird et al., 2010). In total, samples were collected from 62 sites (Fig 4.3) during winter (20/01/2014) and summer (15/06/2014). Sample locations were also chosen in order to effectively characterise the influence of major tributary streams, with samples taken upstream and downstream of the confluence and with at least one sample being collected from the tributary itself. Samples were collected at sufficient distance downstream of tributary confluences to ensure thorough mixing (Rösner, 1998), with the downstream sample collected at a distance equal to at least 5 trunk stream channel widths (c.f. Bird, 2004). In addition, water was collected from one site repeatedly over four consecutive days in order to provide an indication of shorter-term variability in geochemical conditions.

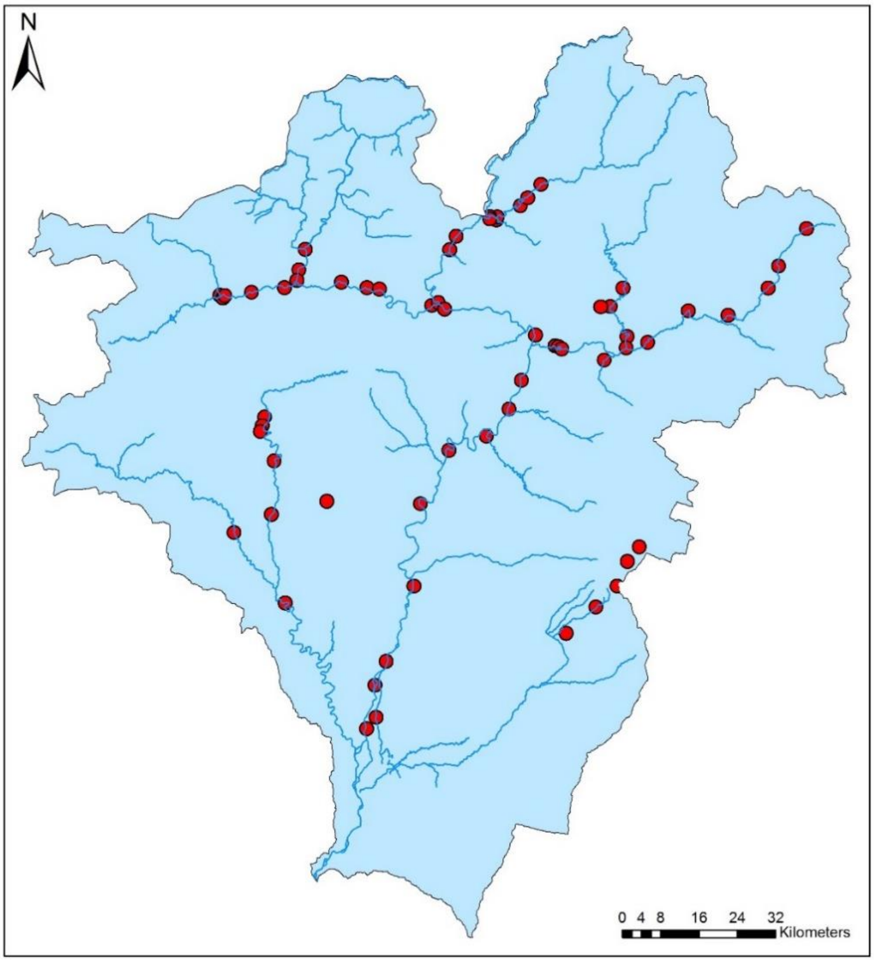


Figure 4.3 Location of Samples

4.3.2 Sampling method

4.3.2.1 Sample collection

The grab sampling method was used to collect surface water samples following recommendations of the Environmental Protection Agency (EPA, 2013), ensuring the reliability and accuracy of results. If safe, the sampler was wade to mid-stream in a well-mixed section of small streams (Fig 4.4). If it is unsafe or not practical to sample at mid-stream especially for larger streams then an area of unrestricted flow that can be sampled from shore are used. Collection bottles of 500ml capacity are used for initial sample collection. The container rinsed with river water and emptied downstream of the sampling site. This process is performed three times to flush out any contamination ensuring any sediment was not stirred up in the process. The water was collected by inverting the un-capped bottle and submerging it to half the water column depth and allowing the bottle to fill completely, taking care not to disturb any sediment on the riverbed. Collecting samples 20 cm below the surface was done to avoid and surficial films on surface waters, which have been shown to be potentially enriched in metals relative to carrier waters due to organo-complexing (Pojasek and Zajicek, 1978), however the turbulent nature of many streams sampled would reduce the likelihood of these forming.

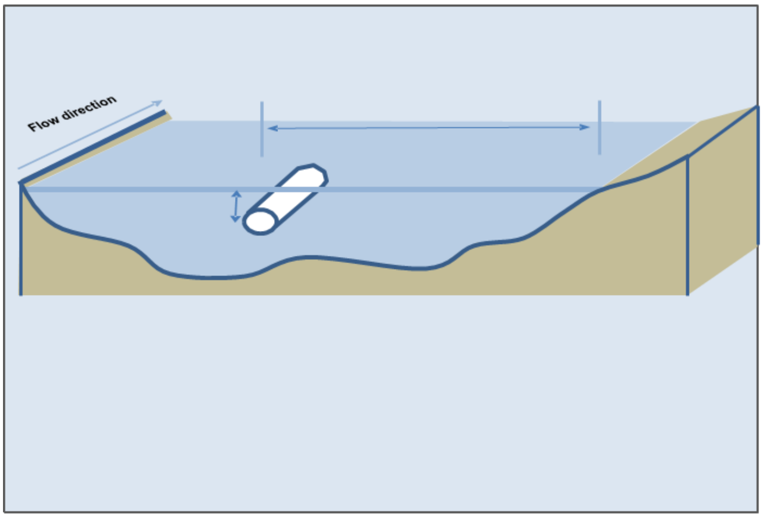


Figure 4.4 shows the methodology used to ensure high quality samples.

4.3.2.2 Sample filtration

Water samples collected for analysis by ion chromatography (IC) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) ideally should be collected in plastic containers, such as polystyrene or polypropylene bottles, as glass bottles can contribute ionic contamination when performing trace analysis (Jackson, 2000). In addition, appropriate storage and preservation of the samples is required, in order that the final sample analysis is representative of the analyte concentration present when the sample was originally taken from the field (Madrid & Zayas, 2007). Following the recommendation of EPA (2013), once the river water samples are collected, samples were filtered through a 0.45μm cellulose nitrate filter membrane using a plastic syringe that was pre-washed in sample water (Fig 4.5). Then samples were stored in 30 ml Nalgene bottles that had been acid washed for 24 hours with 10% HCl prior to use. Bottles were 'pre-washed' twice with the filtered sample before the final sample was retained.

Figure 4.5 shows the methodology used for filtration and samples preservation.

Filtration is a vital step in sample preservation and separates constituents dissolved in the water from detritus and other solids that may change the chemistry of the sample before it can be analysed (Aiken & Leenheer, 1993). In the field of water quality, it is also employed to distinguish between suspended and dissolved components (Khan and Subramania-Pillai., 2006). A variety of filter membrane pre sizes have been used in environmental studies, however, a pore size of 0.45 microns is commonly used for many constituents (Madrid & Zayas, 2007). The use of 0.45 μm membranes has a number of advantages as highlighted by Carter (2007) and Stumm and Morgan (1996); particles not retained by 0.45 μm filters do not settle in natural waters within days and are transported with solutes, and in addition most bacteria and other organisms are retained, averaging that the filtered sample is often nearly sterile and less subject to microbially-driven changes.

4.3.2.3 Sample acidification and storage

Various physical, chemical and biological processes can affect a sample from the time of collection to that of analysis. The use of appropriate preservative methods to maintain sample integrity will prevent or minimise these effects (EPA, 2000). Water once filtered, 3 drops of HNO_3 were added to each sample; bottles were then stored in the dark at about 4°C prior to transportation back to the laboratory for analysis. The addition of HNO_3 ensures that metal concentrations are not altered prior to analysis, through loss of dissolved concentrations due to precipitation or adsorption onto container walls or micro-particulates, e.g. colloids within the sample (Jarvis, 1992). Furthermore, this acidification helps combat bacterial activity which may degrade or alter the sample (Jarvis, 1992).

4.3.3 Field measurements

Some variables must be measured in the field either in situ or soon after the sample has been collected. Field analysis is necessary for water temperature, pH, EC, DO and turbidity (WHO, 1996). In addition, the coordinates of each of locations sampled using Global Position

System (GPS) personal navigator (GARMIN eTrex H model). Whereas some studies have determined these parameters upon return of water samples to the laboratory, it can be argued that more advantage and potentially accurate measurements are made in the field at the time of sampling (Bartram and Ballance, 1996).

4.3.3.1 Hydrogen ion concentration (pH)

It was measured directly in the field by using portable pH-meter (HANNA instrument model HI 991003). The instrument was calibrated before sampling with standard buffer solution (pH, 4 and 7). This instrument was supplied with an automatic temperature corrector. The measurement was taken after temperature stabilizing for a few minutes according to APHA (1998).

4.3.3.2 Electrical Conductivity (EC)

Electrical conductivity of water was measured directly in the field by using portable EC-meter (HANNA instrument model HI 8733). The instrument was calibrated before sampling with a standard 12.880 μS solution. The results were expressed as $\mu S.cm^{-1}$.

4.2.3.3 Dissolved Oxygen (DO)

It was determined using a PDO-520 dissolved oxygen meter. The results were expressed as $mg.l^{-1}$.

4.3.3.4 Turbidity

Turbidity of water was measured directly in the field by using portable Turbidity meter (HANNA instrument model HI 93703). The instrument was calibrated before sampling with a standard buffer solution (0 and 10 NTU). The results were expressed as NTU.

4.3.4 Laboratory methods

Water samples were analysed for the following: As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, Li, Mn, Mo, Ni, Pb, Sr, Zn, NO_3^-, NO_2^-, SO_4^{2-}, F^-, Cl^-, and PO_4^{3-}. These parameters have been selected depending on the main objectives of this study and from environmentalist and public health view points. Details on the methods used are given in the following sections Along with, where necessary, a review of more technical and theoretical concepts relevant to the techniques used. Laboratory procedures in this method statement have been derived from the standard procedures recommended by APHA (1998).

4.3.4.1 Sample analysis by ion chromatography

Concentrations of NO_3^-, NO_2^-, SO_4^{2-}, F^-, Cl^-, and PO_4^{3-} were determined by ion chromatography (IC) (Metrohm 850 Professional) at Bangor University. IC is an analytical technique for the separation and determination of ionic solutes in and can be classified as a liquid chromatographic method, in which a liquid permeates through a porous solid stationary phase and elutes the solutes into a flow-through detector. A Thermo Fisher AS22 anion exchange column was used for the separation of NO_3^-, NO_2^-, SO_4^{2-}, F^-, Cl^-, and PO_4^{3-}. The mobile phase was 4.5 mM sodium carbonate/1.4 mM sodium bicarbonate and flow rate 1.2 ml/min. Suppression was achieved using a Metrohm Supressor Module, supplied with a 150 mM sulphuric acid/0.1 M oxalic acid/acetone mix and ultrapure water. Inorganic anions were detected using a suppressed conductivity detector. All solutions were prepared in ultrapure water with a specific resistance of (18.2) MΩ•cm (Millipore, Molsheim, France). Calibration solutions were prepared in-house, using AnalaR grade chemicals (sodium fluoride, sodium chloride, sodium nitrite, potassium bromide, sodium nitrate, potassium dihydrogen phosphate, sodium sulphate), according to the concentrations presented in Table 4.1. The concentrations used for the calibration curve and the quality control of the analyses are presented in Table 4.1. Accuracy and precision generally found to lie with ±10 % limit of acceptance defined by

Hamilton (1980) and Ramsey et al. (1992) and utilized by numerous environmental studies e.g. Macklin et al. (2003); Bird (2016).

Precision was calculated as the coefficient of variation (Equation 4.1) and accuracy as the difference between measured and certified values expressed as a percentage of the certified value.

$$Coefficient\ of\ variation\ (\%) = \left(\frac{Standard\ deviation\ of\ replicates}{mean\ concentration\ of\ replicates}\right) \times 100 \qquad \text{(Equation 4.1)}$$

Table 4.1 Analytical quality control data.

Anion	Concentrations of anions (mg L^{-1}) Calibration Curve					% Accuracy	% Precision
Nitrate	40	10	2	0.4	0.2	4.4	2.5
Nitrite	2	0.5	0.1	0.02	0.01	-	4.5
Fluoride	2	0.5	0.1	0.02	0.01	3.5	5.8
Chloride	400	100	20	4	2	11.5	3.4
Sulphate	200	50	10	2	1	7.9	2.1
Phosphate	2	0.5	0.1	0.02	0.01	0.5	1.9

4.3.4.2 Sample analysis using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS)

Concentrations of As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, Li, Mn, Mo, Ni, Pb, Sr, Zn were determined by ICP-MS (Agilent Technologies 7700) at the Department of Geography and Earth Sciences, Aberystwyth University. Samples were analysed in 10 ml aliquots containing an internal Ru calibration standard at an effective concentration of 100 µg L^{-1}. In addition, a calibration solution containing all analyte elements at 100 µg L^{-1} was used in order to calibrate the mass spectra. ICP-MS has many advantages over other solution-based analytical techniques such as flame atomic absorption (FAAS) and atomic emission (FAES) spectroscopy, as it use a 10,000 k plasma flame instead of gas burning in air, and then uses a mass spectrometer to separate and quantify those ions (Jarvis and Jarvis, 1992b). ICP-MS technique was commercially introduced in 1981 following the development of a concept from the early 1970s, and it has gained general acceptance in many types of laboratories (Hall, 1992a). Geochemical analysis labs were early adopters of ICP-MS technology because of its superior detection capabilities, precision, and sensitivity particularly for the earth elements (Warra and Jimoh, 2011). ICP-MS is ideally suited to the analysis of waters given that samples may be analysed directly without the need for preconcentration (Beauchemin et al., 1987; Gabarino and Taylor, 1987; Jarvis, 1997). ICP-MS has been widely used in a number of different fields including drinking water, wastewater, natural water systems, hydrogeology, geology and soil science, mining, food sciences, and medicine (Wang et al., 2010; Warra and Jimoh, 2011).

The reason for the popularity of ICP – MS over other techniques such as FAAS, FAES and ICP – Atomic Emission Spectroscopy (ICP – AES) are: superior sensitivity, simpler spectra, the ability to give isotopic information and that potentially up to 70 elements may be measured simultaneously in less than 2 minutes using less than 2 ml of sample solution (Hall, 1992b; Pearce, 1992). Table 4.2 shows the analytical quality control for a range of cations elements.

Table 4.2 Analytical quality control data.

	Certified (mg^{-l})	Measured (mg^{-l})	% Accuracy	% Precision
As	60.5±0.7	40.5	33	6.6
Ba	544.2±5.8	504	7.3	1.9
Ca	32300±110	34100	5.6	3.6
Cd	6.6±0.07	5.7	13.8	n.d.
Co	27.1±0.32	20.4	24.5	1
Cr	20.4±0.24	15.9	21.7	1.8
Cu	22.8±0.31	39.6	74	1.8
Fe	98.1±1.4	97.6	0.5	4.9
Hg	-	-	-	n.d.
Li	17.4±1.7	9.3	46.3	0.9
Mn	38.9±0.45	34.9	10.4	3.6
Mo	121.4±1.3	120.9	0.4	0.7
Ni	62.4±0.69	62.4	0	0.7
Pb	19.6±0.21	18.7	4.8	n.d.
Sr	323.1±3.6	298.6	7.6	0.2
Zn	78.5±2.2	32.3	58.8	2.2

4.3.4.3 Sample introduction

Conventionally, a sample solution is nebulised into the plasma ‘flame’ where it rapidly undergoes desolvation (removal of the solvent from the liquid sample), vaporization to the molecular level and dissociation into atoms, some of which are ionised (Jarvis and Jarvis, 1992a). Plasma is a partially ionised gas (Hall, 1992a), with most ICP systems using an Ar plasma formed from an Ar gas pumped at approximately 0.8 l s^{-1}. Argon is preferred as a plasma gas as it is: a) inert and will not easily chemically react with samples, b) has a high 1st ionisation energy, therefore allowing the effective ionisation of almost all elements, and c) because it has a moderately low thermal conductivity averaging heat is retained within the plasma (Jarvis and Jarvis, 1992a). Once a stream of ions has been generated they are focused through a series of ion lenses into a mass analyser, which retards the ion beam and based upon element mass allows ions of each element to pass into the mass spectrometer in a set order. The mass spectrometer measures elemental concentration as raw ion counts; this can then be scaled against the internal Ru calibration standards and processed to give elemental concentration in solution.

4.3.4.4. Potential for spectral interferences

Interferences are associated with the formation of molecular and doubly charged ion species whose mass-charge ratio (m/z) coincides with isotopes of interest (Tan and Horlick, 1986). These species arise due to the presence of compounds derived from: a) the plasma gas (e.g. Ar+, ArN+), b) acids used in sample preparation (e.g. ArCl+), and c) associated matrix elements (e.g. 54Fe+ on 63Cu+, 65Cu+, 64Zn+ and 66Zn+) (Hall, 1992a). Fortunately, almost every element has an isotope that is free from spectral overlap (Hall, 1992a).

4.4 RESULT

In order to analyse the data, the statistical software SPSS was used, performing a one-way ANOVA with post hoc Tukey tests to show exactly where significant relationships lie. Confidence limits of 0.05 were used these methods are in line with those performed by other studies (Aziz, 2006; Crosa et al., 2006; Araove, 2009; Ali, 2010; Lawson, 2011; Toma, 2013; Andem et al., 2014). The average water temperature across all catchments in winter was (10.36°C ± 0.34) whereas in summer the water temperature was (18.66°C ± 0.58). The pH of river water ranges from mildly acidic (5.6) to mildly alkaline (8.9). The turbidity of water (1.7-65 NTU) indicates that in general river water in Great Zab River catchment contains relatively low concentrations of suspended organic and inorganic material. Electrical conductivity ranges from 200 to 1028 µS cm^{-1} with a median value of 375 µS cm^{-1}. However, the numerical values of electrical conductivity show that for the upper and lower catchment areas the electrical conductivity value was higher in the winter when compare to summer. Opposite trends were observed with respect to the middle catchments where the numerical values for the electrical conductivity were higher in the summer and lower in the winter season.

The dissolved oxygen concentration was higher in summer when compare to winter. The median Cl^- concentration in the Great Zab (6.7 mg l^{-1}) is largely similar to the world median concentration of 8.3 mg l^{-1}. In order to establish whether water chemistry differs significantly between summer (lower flow conditions) and winter (higher flow conditions), data collected in February 2014 and June 2014 were compared using a one-way ANOVA on log-transformed data, using a significance threshold of $\alpha = 0.05$. Results (Table 4.3) indicate that concentrations of Ca, Li, Mo are higher in the winter than summer (statistically significant at $\alpha = 0.05$), whilst concentrations of Zn, SO_4^{2-}, F^-, Cl^-, and PO_4^{3-} are higher in the summer than winter (statistically significant at $\alpha = 0.05$). Seasonal differences for other analytes were not statistically significant.

Table 4.3 Results of a one-way ANOVA for temporal trends.

Parameter	P value (Seasonal)
As	N/A
Ba	0.486
Ca	**0.000****
Cd	0.224
Co	0.986
Cr	0.719
Cu	**0.487***
Fe	0.224
Hg	N/A
Li	**0.029****
Mn	0.223
Mo	**0.036****
Ni	0.256
Pb	N/A
Sr	0.642
Zn	**0.031***
NO_3^-	0.180
$SO4^{2-}$	**0.000***
F^-	**0.000***
Cl^-	**0.017***
PO_4^{3-}	**0.000***
Turbidity	0.769
DO	**0.000***
EC	0.563
pH	**0.000****

Bold indicates significant at $\alpha = 0.05$
*Denotes mean summer concentration is higher than mean winter concentration
**Denotes mean winter concentration is higher than mean summer concentration

In order to evaluate the spatial trends in water quality, samples were grouped based upon the major underlying geological units identified in the Great Zab catchment. The groups were identified as: (1) Zagros zone, (2) the imbricated/ high-fold zones and (3) the foothill zone

(Fig 4.7). The grouping by underlying geology reflects the importance of geogenic loading in determining surface water chemistry (Drever 1997). Log-transformed data were analysed using a one-way ANOVA, using a significance threshold of $\alpha = 0.05$.The most frequent differences were found between water chemistry in samples collected from the Zagros and foothill zones, with 13 parameters showing a statistically significant difference (Table 4.4). Five and 7 parameters, respectively, showed statistically significant differences between the Zagros and imbricated/high-fold zones and imbricated/high-fold and foothill zones (Figure 4.6). The greater statistical similarity of water chemistry sampled in the imbricated/ high-fold and foothill zones will reflect the greater similarity in bedrock geology between these areas compared with the Zagros zone.

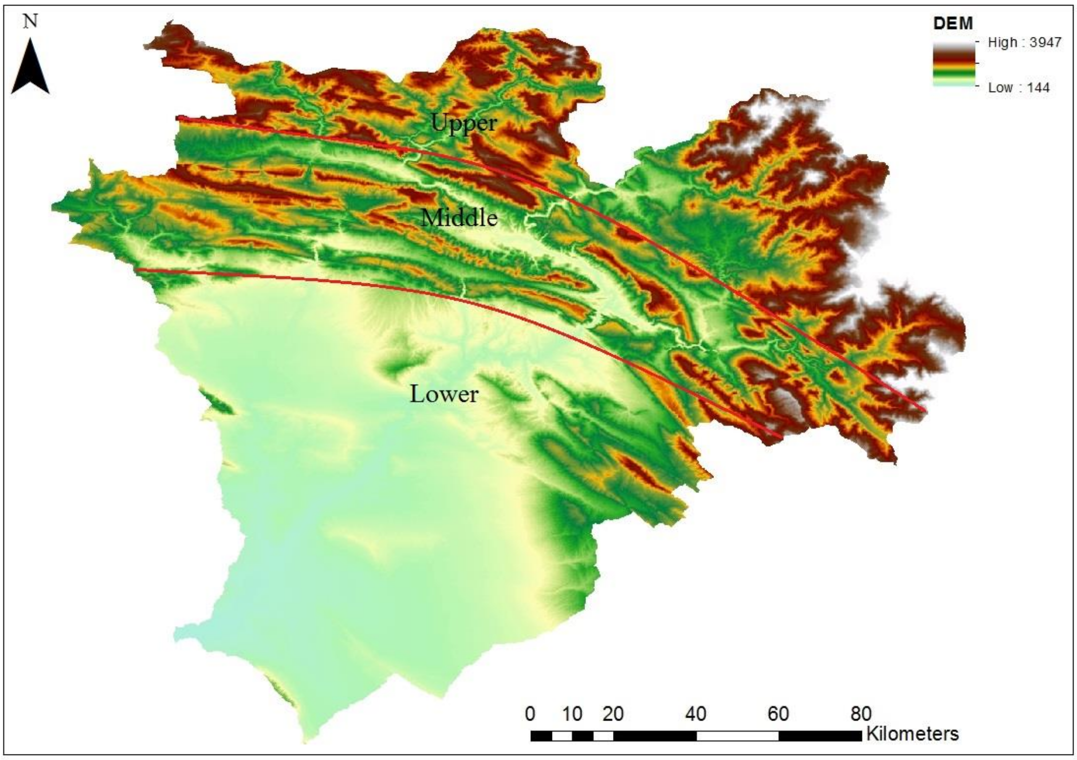


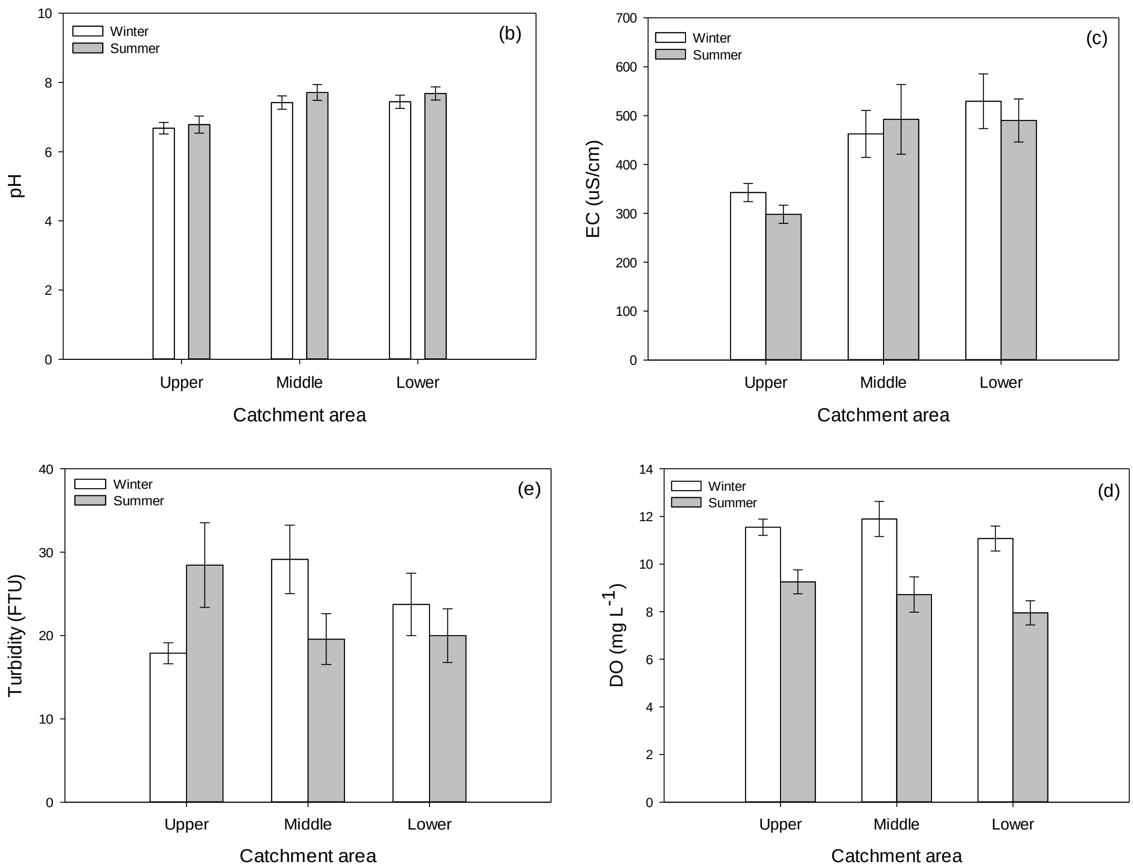
Figure 4.6 Zones in catchment area. Upper = Zagros Zone, Middle = Imbricated/High-folded Zone and Lower = Foothill Zone.

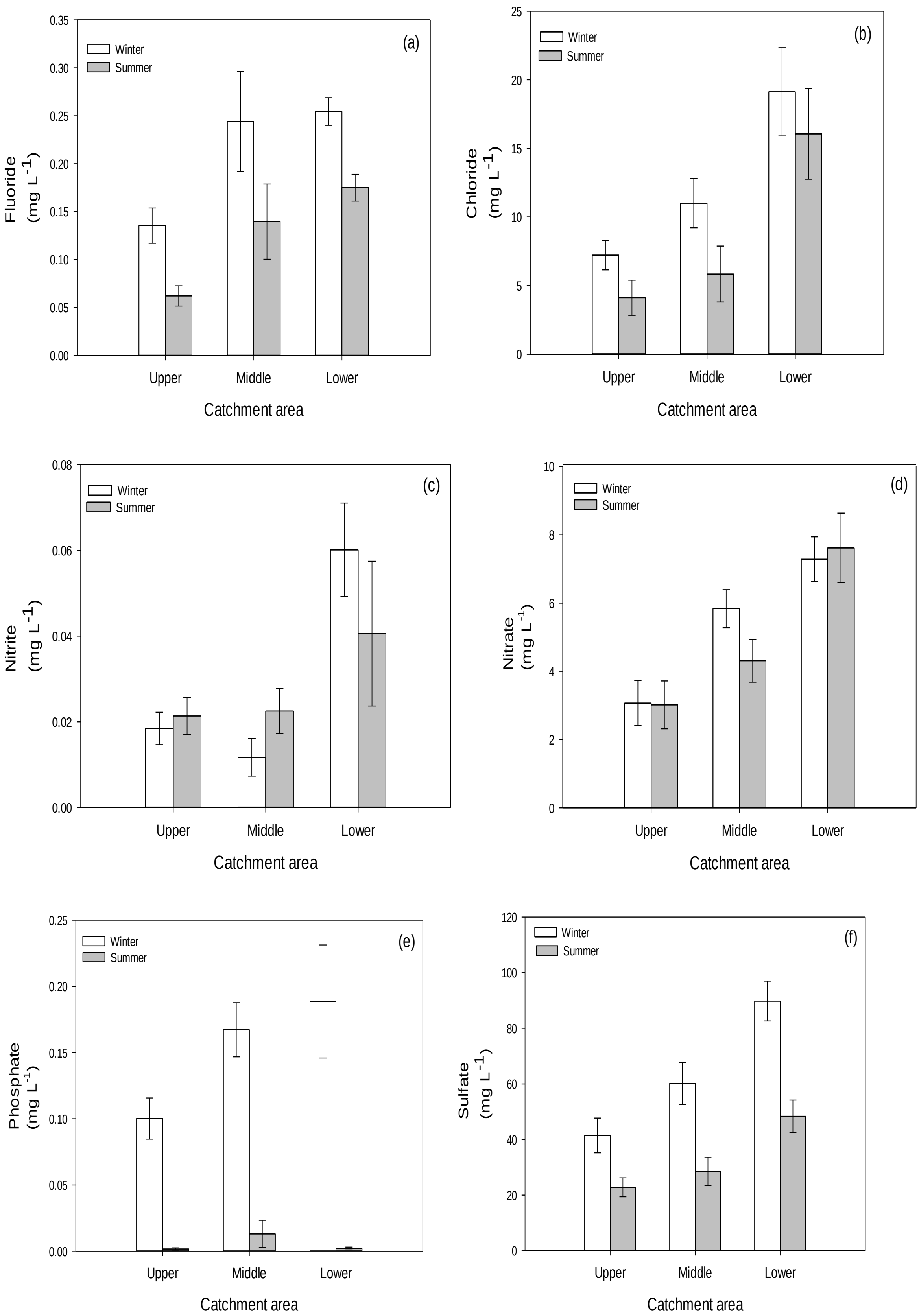
Table 4.4 Results of a one-way ANOVA for spatial trends.

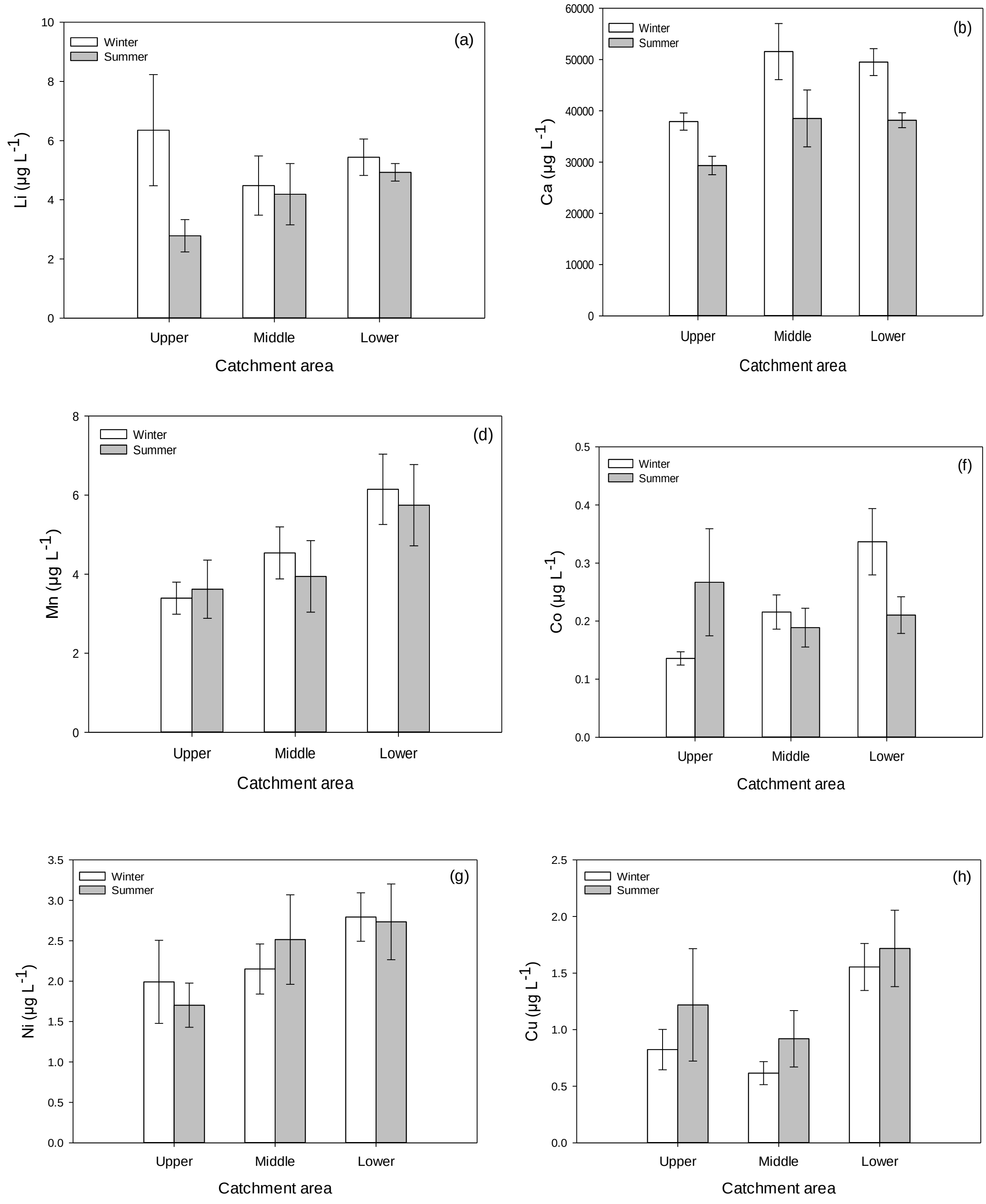
Parameter	P value (Spatial)		
	Z[1] vs I/HF[2]	Z v FZ[3]	I/HF v FZ
As	N/A	N/A	N/A
Ba	0.888	**0.000**	**0.000**
Ca	**0.009**	**0.001**	0.625
Cd	0.210	0.944	0.275
Co	0.711	0.299	**0.025**
Cr	0.063	0.653	0.270
Cu	0.210	0.772	0.500
Fe	0.233	0.455	0.726
Hg	N/A	N/A	N/A
Li	**0.000**	**0.000**	0.855
Mn	0.980	0.455	0.726
Mo	**0.000**	**0.000**	0.596
Ni	0.169	0.946	0.212
Pb	0.424	0.708	0.792
Sr	**0.019**	**0.001**	0.441
Zn	0.311	0.801	0.629
NO_3^-	0.746	**0.000**	**0.000**
$SO4^{2-}$	0.651	**0.000**	**0.000**
F^-	**0.024**	**0.005**	0.734
Cl^-	0.771	**0.008**	**0.000**
PO_4^{3-}	0.886	0.735	0.936
Turbidity	0.650	0.963	0.764
DO	0.801	0.996	0.686
EC	0.119	**0.021**	0.626
pH	0.413	**0.014**	**0.000**

Bold indicates significant at $\alpha = 0.05$
a Zagros zone
b Imbricated/high-fold zone
c Foothill zone

The influence of geology on water chemistry is exemplified by Ca and Sr concentrations; these are found to be significantly higher in waters within the imbricated/highfold and foothill zones than in the Zagros zones (Table 4.4). Average Sr concentrations in water with the imbricated/ high-fold (542 µg l^{-1}) and foothill zones (683 µg l^{-1}) are at least twice as high as in the Zagros zone (243 μg l^{-1}). Average Ca concentrations are c. 10 mg l^{-1} lower in the Zagros zone compared to the imbricated/high-fold and foothill zones. This reflects the abundant carbonate bedrocks, notably limestone and dolomitic limestone, which are the main sources of Sr to stream water in particular, whilst the bedrock of Zagros zone is relatively carbonate poor. Chloride and NO_3^- show a statistically significant difference between the foothill zone (the lower Great Zab catchment) and the two upstream zones. Concentrations of Cl^- and NO_3^- are significantly higher in the lower catchment, as indicated by mean concentrations of 14.2 and 6.8 mg l^{-1}, respectively, which are twice as high as those for the Zagros and imbricated/high-fold zones upstream. Chloride and NO_3^- are two substances for which higher concentrations in river water, and particularly within-catchment variability, can be the result of anthropogenic inputs, such as from agricultural activity in the case NO_3^- (Randall and Mulla 2001).




(a)
Winter
Summer
Fluoride (mg L-1)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Upper
Middle
Lower
Catchment area
(b)
Winter
Summer
Chloride (mg L-1)
25
20
15
10
5
0
Upper
Middle
Lower
Catchment area
(c)
Winter
Summer
Nitrite (mg L-1)
0.08
0.06
0.04
0.02
0.00
Upper
Middle
Lower
Catchment area
(d)
Winter
Summer
Nitrate (mg L-1)
10
8
6
4
2
0
Upper
Middle
Lower
Catchment area
(e)
Winter
Summer
Phosphate (mg L-1)
0.25
0.20
0.15
0.10
0.05
0.00
Upper
Middle
Lower
Catchment area
(f)
Winter
Summer
Sulfate (mg L-1)
120
100
80
60
40
20
0
Upper
Middle
Lower
Catchment area


(a)
Li (µg L-1)
Winter
Summer
Upper
Middle
Lower
Catchment area
(b)
Ca (µg L-1)
Winter
Summer
Upper
Middle
Lower
Catchment area
(d)
Mn (µg L-1)
Winter
Summer
Upper
Middle
Lower
Catchment area
(f)
Co (µg L-1)
Winter
Summer
Upper
Middle
Lower
Catchment area
(g)
Ni (µg L-1)
Winter
Summer
Upper
Middle
Lower
Catchment area
(h)
Cu (µg L-1)
Winter
Summer
Upper
Middle
Lower
Catchment area

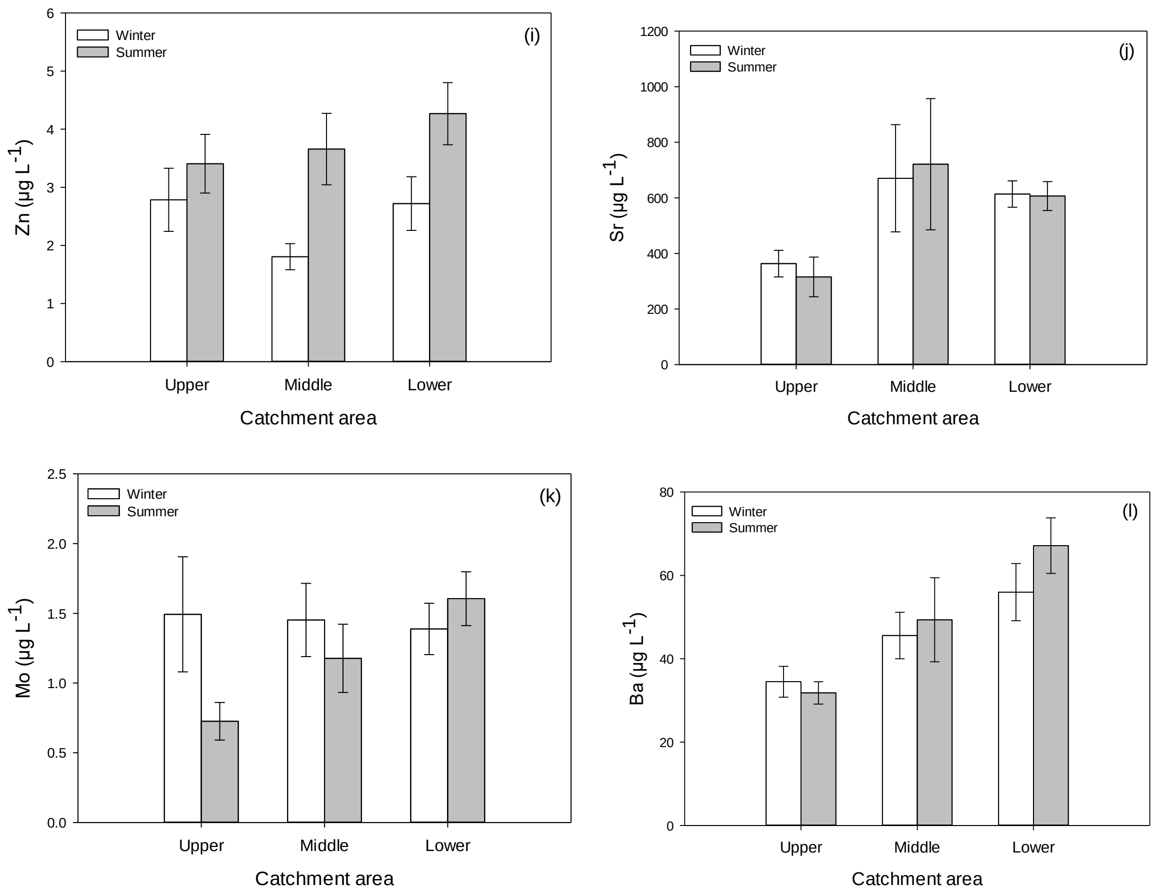


Figure 4.7 Seasonal variation for range of parameters concentration in different catchment areas (error bars represent standard deviation of the mean).

4.5 DISCUSSION

Higher concentrations of a number of elements during winter (generally higher discharge conditions) in the Great Zab catchment suggest enhanced delivery from the riparian zone via a combination of surface and sub-surface flows. While higher concentration for other elements during summer (generally lower discharge conditions) due to a lower degree of physical dilution that occurs during periods of low discharge. The relationship between water quality and river discharge is a potentially complex scenario. Previous studies (e.g. Garbarino et al. 1995) have reported generally higher concentrations of metals under low flow conditions due to a lower degree of physical dilution that occurs during periods of low discharge. In addition, higher discharge conditions can result in a reduction in dissolved concentrations due an increase in sorption process due to higher suspended sediment concentrations. However, conversely other studies (e.g. Gundersen and Steinnes 2001) have demonstrated that periods of higher discharge can yield higher metal concentrations due to enhanced delivery of substances to the river channel from run-off and the potential activation of point sources. What is apparent is that different elements can display different relationships with discharge, as noted in a study of Southeast Asian rivers by Chanpiwat and Sthian-nopkao (2014). Importantly, the amount of anthropogenic activity is greatest in the lower Great Zab catchment, the part of the catchment containing the highest Cl^- and NO_3^- levels. Whilst geogenic inputs are important in explaining largescale variability in water chemistry, the spatially variable influence of anthropogenic activity is an important contributor to the water chemistry of the Great Zab catchment.

Water temperature is an important factor to consider when assessing water quality. In addition to its own effects, water temperature influences several other parameters and can change the physical and chemical properties of water (Ezzat et al., 2012; Oyem et al., 2014). In the study area, with an overall average water temperature of 14.51±0.55°C temperature values for this present study showed marked seasonal variation. Water temperature change depends mainly on the climatic conditions, sampling times and the number of sunshine hours. Air and water temperatures were positively correlated during studied seasons. This indicated that the water temperature is affected only by the ambient air temperature, pointing to the absence of any source for thermal water pollution. The seasonal variation of pH values observed in this study is in agreement with results of previous studies conducted by (Dublin-Green, 1990; Ekeh and Sikoki, 2003; Ansa, 2005; Araove, 2009; Singh et al., 2013). The pH of Great Zab River water during of most the study period was mildly alkaline (average of 7.28 ± 0.09). This result is in agreement with Maulood et al. (1980) they reported that Iraqi inland water is regarded to be on the alkaline side of neutrality. The mildly alkaline pH will primarily reflect the influence of bedrock geology in the catchment, and the results are agree with the finding that recorded by Ali (2010) in the same river and Abdulwahid, (2013) on the Delizhiyan springs and Shawrawa River within the study area. The seasonality in the pH of Great Zab water may be related with input loads of pollutants in the river system (Sahu et al., 1995).

The results of EC value for Great Zab River came in accordance with the known conductivity values for Iraqi inland waters (Amin and Aziz, 2005; Ganjo and Aziz, 2006; Toma, 2013). The varied differences in electrical conductivity between the Zagros zone and the Foot Hill zone, may be due to accumulation of salt ions due to increasing distance from their sources. Turbidity is a visual property of water and indicates a reduction of clarity that may be because of suspended particles (Jayalakshmi et al., 2011). The turbidity of water is caused by suspended matter like clay, silts, organic and inorganic matter, plankton and other microscopic organisms (Tanwar and Tyor, 2014). It can be noticed that turbidity is higher in winter season (23 NTU), potentially due to enhanced surface runoff, which causes an increasing in suspended solids in the river water. A possible explanation for this trend may be due to the influx allocutions organic and inorganic materials from the surrounding catchments area during the rains. According to Khan and Chowdhury (1994) high values of turbidity during rainy seasons may be due to heavy load of silt into the river water from feeder streams. The results obtained from this study showed a higher turbidity level than that recorded by Aziz (2006) in the same river. While, it was lower than that found previously by Ali (2010).

The seasonality in the DO of Great Zab water is in agreement with results of Shrestha and Kazama (2007) and Malik and Husain (2008) who reported that at high temperature, which is usually observed in summer season, the solubility of oxygen decreases while at lower temperature winter season it increases. Probable source of high F^- in Great Zab waters seems to be that during weathering and circulation of water in rocks and soils, fluorine is leached out and dissolved in ground water (María and Laura, 2015). The increase in fluoride levels in the dry season in lower part of catchment may be attributed to the absence of runoff to the river which may cause dilution, and hence in that period the river flow is mainly from groundwater (old water) containing more fluoride ions.

The difference in fluoride levels in the headwater compared to other sampling areas of the river indicates the main point source pollution of fluoride in the river. Cl^- is a naturally occurring major anion found in all natural waters. However, its concentration remains quite low and is generally less than that of sulphates and bicarbonates, therefore, the chloride concentration serves as an indicator of water pollution (Vaishali, and Punita, 2013). More importantly, sewage water and industrial effluent are generally rich in Cl^- and hence the discharge of these wastes results in high chloride level in fresh water (Maheshwari et al., 2011). The high content of Cl^- in the aquatic systems may be partly responsible for the stimulation of excessive plant growth. However, as oxygen supply is gradually reduced via hypoxic conditions the accumulation of large amounts of organic matter tends to increase possibly through anaerobic decomposition, which in turn may lead to eutrophication as well as anoxic conditions (Jayalakshmi et al., 2011).

High contents of chloride at middle catchment areas could be due to mixing of surface water with groundwater containing high concentrations of chloride, or could be related to wastewater discharges with high chloride during a low-flow period (Eneji et al., 2012). In the lower catchment, the high concentration of Cl^- can be attributed to the mixing of sewage water, industrial and fertilizer effluents in surrounding agricultural areas, which build up high amounts of organic and inorganic ions like Cl^-. Similar results were reported by Ali (2010) working on the same river which he attributed to anthropogenic sources. The high level of NO_2^- at Foot Hill zone may be due to domestic sewage input to the river from the surrounding village and agricultural runoff, similar results were reported by Ali (2010) and Srinivasan and Natesan (2013). Phosphates come from fertilizers, pesticides, industry and cleaning compounds, whilst natural sources include phosphate containing rocks and solid or liquid wastes (Jayalakshmi et al., 2011).

In addition to the weathering of phosphorous-bearing rocks and subsequent leaching of phosphate ions into water bodies, the occurrence of phosphate ions in the various sampling sites of Great Zab River is likely due additional input from agricultural land nearby or due to activity of phytoplankton and human and industrial effluent loads (Al-Mussawi et al., 1995). These results are in agreement to the findings of Ali (2010), Hassan (1997) and Al-Mussawi et al., (1995). Sulfate occurs naturally in water because of leaching from gypsum and other common minerals (Shrinivasa and Venkateswaralu, 2000). Discharge of industrial wastes and domestic sewage in waters tends to increase its concentration (Vaishali, and Punita, 2013). Sulfates when added to water, tend to accumulate to progressively increasing concentration (WRC, 2003). Generally, Kurdistan region inland waters contain naturally high concentrations of sulfate, explained by the relatively abundance of gypsum in the bedrock (Abdulwahid, 2013). The results of high concentration of sulfate in Great Zab waters come in agreement with the results of previous studies by Ahmad (2014), Abdulwahid (2013) and Al-Lami et al., (1999).

The average value of trace metals concentration in the water samples collected during this study reflects that the nature of pollution in our area of study is mainly due to agricultural and sewage discharge. Calcium is the most abundant cation from both a seasonal and geographic standpoint within the study area. Results for calcium concentrations were similar to that reported by Aziz (2004). The Calcium enters water by leaching from minerals within catchment. This reflects the abundant carbonate bedrocks, notably limestone and dolomitic limestone, which are the main sources of Sr to stream water in particular, whilst the bedrock of Zagros Zone is relatively carbonate poor.

4.6 CONCLUSION

This study showed a case study targeting the large-scale river system across northern Kurdistan. The study in the mountainous and plain regions provides more insight into the impacts of land uses and anthropogenic factors on water quality and may provide useful action points for catchment management. Given that many world-wide catchments face the growing problems caused by the increasing impacts of land uses and human demand on ecosystem services, the methods and results identified in this study can provide implications on catchment management of other similar regions particularly in developing countries like Kurdistan. The water of least quality was located at lower catchment areas. This result demonstrated the influence of untreated domestic sewage discharge and/or agricultural runoff from Erbil city, an area that includes more than half the population and almost all agricultural lands from the catchment study area. The amount of wastewater discharge is difficult to estimate, however, as the wastewater in rural areas (e.g. Khabat Town) is released at random without the use of a proper sewerage system. In winter the pollution load is more prominent as compared to summer season. The validity of the results obtained from Great Zab River indicated the correlation found between the variables. Spatial and temporal variability of the physico-chemical parameters from this study may be used as future baseline data to monitor and manage any changes with changing land use.

CHAPTER 5: ESTABLISHMENT OF BACKGROUND WATER QUALITY CONDITIONS AND SPATIAL VARIABILITY OF WATER CHEMISTRY IN THE GREAT ZAB RIVER CATCHMENT

This chapter is an amended version of recently published work by the author (Ismaiel et al., 2018) in the journal Environmental Earth Sciences,

5.1 ABSTRACT

The Great Zab River catchment is a major left-bank tributary of the River Tigris and drains a substantial part of the Kurdistan Region, an autonomous region of Northern Iraq. Within Kurdistan, the water resources of the Great Zab River catchment are under pressure from population increase and are utilized for potable, domestic and agricultural and industrial supply. As with many parts of the world, effective management of water resources within Kurdistan is hindered by a lack of water quality data and established background concentrations. This study therefore represents the first regional survey of river water chemistry for the Great Zab River catchment and presents data on the spatial and temporal trends in concentrations of As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, Li, Mn, Mo, Ni, Pb, Sr, Zn, $NO_3^{\,-}$, $SO_4^{\,2-}$, F^-, Cl^- and PO_4^{3-}, in addition to pH, electrical conductivity, dissolved oxygen and turbidity. As a tool for underpinning the management and monitoring of water quality, background concentrations were defined for the Great Zab catchment using three methods. The influences of geogenic and anthropogenic controls upon spatial and temporal trends in water chemistry are also evaluated. The influence of geogenic loading from underlying bedrock was identifiable within the observed spatial trends, with the most noTable differences found between waters sampled from the relatively more volcanic-rich Zagros zone to the north and those sampled from the lower catchment underlain by younger clay-, sand- and siltstones. The greatest

anthropogenic influence, identifiable through elements such as Cl^- and NO_3^-, is present in the more highly populated lower catchment. The background concentrations identified in the Great Zab catchment would be those expected as a result of geogenic loading with some anthropogenic influence and represent a more conservative value when compared to those such as the World Health Organization Maximum Admissible Concentration. However, background concentrations represent a powerful tool for identifying potential anthropogenic impacts on water quality and informing management of such occurrences.

5.2 INTRODUCTION

As noted by Adams and Chapman (2007), compared to organic substances, metals in surface waters pose significant regulatory challenges given that they may be sourced from natural geogenic loading as well as anthropogenic inputs, and that the latter may be highly spatially variable and diffuse in nature. Furthermore, anthropogenic inputs may stem from historical activities long-since ceased (e.g. Alpers et al., 2005). A major step in developing a regulatory framework for surface water quality is the derivation of background concentrations (Oste et al., 2012). Determining a background concentration may be used to set a threshold value, which may allow instances of contamination of water to be identified (Panno et al., 2006). Background can be considered to be a concentration of a substance resulting from natural processes, uninfluenced by human activity (Reimann and Garrett, 2005). Given the spatially variability in factors determining geogenic metal loading to surface waters, ‘global’ background values are therefore of limited use (Oste et al., 2012). As a result, developing regional background concentrations can be seen as preferable. Given the difficulty in finding waters that have no anthropogenic ‘signal’ (Smith et al., 2003), the term ‘ambient background concentrations’ has been developed, whereby concentrations represent natural and low level anthropogenic inputs (Peters et al., 2012). Approaches to defining background concentrations in surface waters have been reviewed by detail by Oste et al. (2012). Ensuring water quality is a key component of ensuring sufficient water supply as part of water resources management. This is particularly relevant to the provision of poTable water supplies. Pressures on water quality have been noted in catchments and regions experiencing population and industrial growth (McDonald et al., 2011; McDonald et al., 2014). The Kurdistan region is experiencing rapid increase in population. This combined with an increased urban population and improvements in living standards have resulted in pressures on water resources through impacts upon water quality (Alobaidy et al., 2010). These pressures are being felt, in conjunction with the threat posed from climate change, across the globe (Vörösmarty et al., 2000). The Great Zab River catchment represents one of the largest catchments in the Kurdistan Region, covering an area of approximately 40,643 km2 and surface waters in the catchment provide water supply to a population of 1.8 million.

Effective management of water resources through legislative control on water quality is currently being restricted by a lack of national water quality guidelines (Shareef and Muhamad, 2008). Whilst there has been some study of water quality in particular parts of the catchment (e.g. Abdulwahid, 2013; Shareef et al., 2009; Shareef and Muhamad, 2008; Toma, 2011a; Toma, 2011b), there has been no attempt to establish baseline water chemistry and define background concentrations that may act as a means of evaluating water quality, and which may form the basis for the development of appropriate legislative guidelines. The aims of this study are therefore to address this knowledge gap by determining ambient background concentrations for the Great Zab River catchment for 16 metals, 5 anions, pH, electrical conductivity (EC), dissolved oxygen (DO) and turbidity and to evaluate the spatial and seasonal trends in water quality within the catchment.

5.3 STUDY AREA

Kurdistan occupies an area of 40,643 km2 and a population growth rate is 2.7%per annum (Ministry of Planning, 2011), notably in the cities of Erbil, the capital city, Sulaimaniya and Dohuk, is placing pressure upon water resources. Stevanovic and Iurkiewicz (2009) report that that population growth has led to the decline in the per capita availability and use of water resources. According to the Ministry of Planning/KRG (2011), the quantity of water produced on a daily basis is 924,600 m3, while daily demand totals approximately 1.25 million m3. Therefore, the present water supply deficit is 325,400 m3 per day, i.e. 26% of total demand and 35% of total quantity produced at present. The Great Zab River catchment covers an area of approximately 40,300 km2, with 13,708 km2 within Kurdistan and the remainder in Turkey. The Great Zab River is a left bank tributary of the River Tigris, with confluence downstream of Mosul. The flow regime of the Great Zab River is strongly influenced by annual snowmelt, with the highest monthly mean discharges occurring in the early summer months (Saleh, 2010). Within Kurdistan, the Great Zab catchment sits within three major geological zones (Figure 1). To the northeast, the Zagros Zone comprises predominantly folded limestones with some felsitic volcanics. The Imbricated and High-fold zones comprise Cretaceous-age carbonates in a range of different formations. A detailed description of these has been produced by Sissakian (2013), however, in summary these formations comprise predominantly limestone that has been variably pervaded by dolomite, marl and shale. The lower portion of the catchment lies within the Foothill zone (Figure 1), dominated by late Miocene to Pleistocene-aged sandstones, siltstone and claystone (Sissakian, 2013). The region at the boundary of the High-fold and Foothill zones comprises a number of formations of generally Paleocene and Eocene age that comprise dolomitic limestones and, particularly to the northwest, thick basaltic lavas (Sissakian, 2013).

5.4 METHODS

Samples of river water were collected from 62 sites in February 2014 and June 2014 (Fig. 5.1). Sample sites were selected to best balance the demands of ease of access and spatial coverage, with sample sites focusing mainly upon road–river intersections (c.f. Bird et al. 2010). In the field, samples were filtered through 0.45-μm cellulose nitrate filter membranes, acidified with 50% HNO_3 and placed on ice in acid-washed Nalgene bottles. Samples were stored below 5 °C prior to analysis. Concentrations of As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, Li, Mn, Mo, Ni, Pb, Sr, Zn were determined by inductively coupled plasma mass spectrometry (Agilent Technologies 7700). Analytical accuracy was assessed through the analysis of the NIST1643 certified reference material and analytical precision through the repeat analysis (n = 10% of total sample number) of a randomly selected sample. Data for analytical quality control are given in (Table 5.1).

Samples were analysed by ion chromatography for their NO_3^{-}, SO_4^{2-}, F^{-}, Cl^{-} and PO_4^{3-} content. A Thermo Fisher AS22 anion exchange column was used for the separation of SO_4^{2-}, F^{-}, Cl^{-} and PO_4^{3-}. The mobile phase was 4.5 mM sodium carbonate/ 1.4 mM sodium bicarbonate and flow rate 1.2 ml/min. Suppression was achieved using a Metrohm Suppressor Module, supplied with 150 mM sulphuric acid/0.1 M oxalic acid/acetone mix and ultrapure water. Inorganic anions were detected using a suppressed conductivity detector. All solutions were prepared in ultrapure water with a specific resistance of (18.2) MΩ cm (Millipore, Molsheim, France). Analytical accuracy of anion analyses (Table 5.1) was assessed through the analysis of standard solutions and analytical precision through the repeat analysis (n = 10% of total sample number) of a randomly selected sample. In the field, measurements of pH (Hanna Instruments HI991003), electrical conductivity (Hanna Instruments HI8733), dissolved oxygen (PDO520) and turbidity (Hanna Instruments HI93703) were taken at the time of sampling.

Table 5.1 Analytical quality control data for laboratory analysis

	Certified	Measured	% Accuracy	% Precision
As	60.5±0.7	40.5	33	6.6
Ba	544.2±5.8	504	7.3	1.9
Ca	32300±110	34100	5.6	3.6
Cd	6.6±0.07	5.7	13.8	n.d.
Co	27.1±0.32	20.4	24.5	1
Cr	20.4±0.24	15.9	21.7	1.8
Cu	22.8±0.31	39.6	74	1.8
Fe	98.1±1.4	97.6	0.5	4.9
Hg	-	-	-	n.d.
Li	17.4±1.7	9.3	46.3	0.9
Mn	38.9±0.45	34.9	10.4	3.6
Mo	121.4±1.3	120.9	0.4	0.7
Ni	62.4±0.69	62.4	0	0.7
Pb	19.6±0.21	18.7	4.8	n.d.
Sr	323.1±3.6	298.6	7.6	0.2
Zn	78.5±2.2	32.3	58.8	2.2
NO_3^-	-	-	4.4	2.5
SO_4^{2-}	-	-	7.9	2.1
F^-	-	-	3.5	5.8
Cl^-	-	-	11.5	3.4
PO_4^{3-}	-	-	0.5	1.9

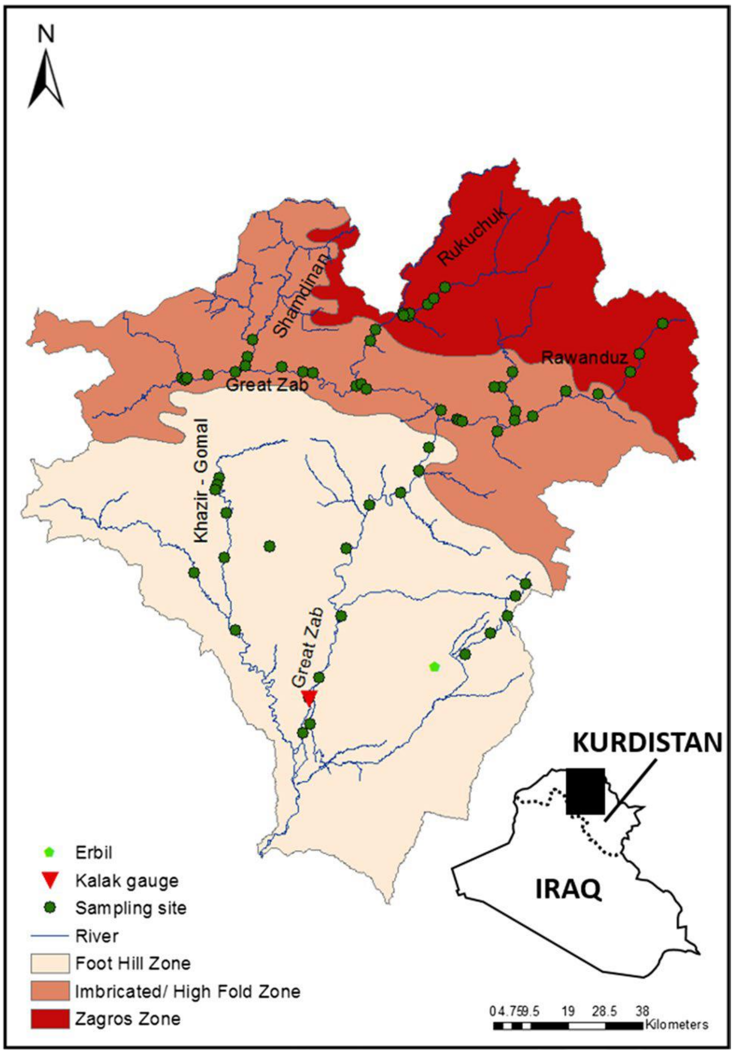


Figure 5.1 Location map showing the Great Zab catchment within Kurdistan, major study rivers, sample sites and major geological units

5.5 RESULTS AND DISCUSSION

5.5.1 Water chemistry

A summary of minimum, mean, median and maximum values is provided for cations (Fig 5.2), anions (Fig 5.3) and (Fig 5.4) pH, EC, DO, turbidity. Global median and World Health Organization (WHO) Maximum Admissible Concentrations (MACs) also plotted in order to provide context for the data from Kurdistan. WHO MACs are appropriate for potable water, which is consistent with the Great Zab River, and provides an indication of water quality in relation to human health. In addition, percentage cumulative frequency plots of the water chemistry data for cations (Fig 5.5) and anions, pH, EC, DO, turbidity (Fig 5.6) show the frequency distribution of the parameters in summer and winter. Arsenic, and Hg were non-detectable in all samples. In comparison to world median values, cation concentrations in the Great Zab catchment vary by metal (Fig 5.2). All Li and Ca concentrations are greater than the world median value, whilst the third quartile concentration for Ba is greater than the world median concentration. Third quartile concentrations for Cu, Zn and Pb are lower than the respective world median concentrations. For metals for which a WHO MAC has been defined, all concentrations in the Great Zab catchment fall below these. All anion concentrations measured in the Great Zab catchment fall below their respect WHO MACs (Fig 5.3). All F^- and NO^-_2 concentrations measured in the Great Zab catchment fall below world median concentrations; however a majority of sites had SO_4^{2-} concentrations in excess of the world median. The median Cl^- concentration in the Great Zab (6.7 mg l^{-1}) is largely similar to the world median concentration of 8.3 mg l^{-1}. The pH of river water ranges from mildly acidic (5.6) to mildly alkaline (8.9). The turbidity of water (1.7-65 NTU) indicate that in general river water in Great Zab River catchment contains relatively low concentrations of suspended organic and inorganic material. Electrical conductivity ranges from 200 to 1028 µS cm^{-1} with a median value of 375 µS cm^{-1}.

A Pearson Product Moment correlation was performed to evaluate bivariate relationships between water chemistry parameters. The full correlation matrix is included as Supplementary Material and Fe, Al and Hg were not include in the analysis due to the high number of non-detectable concentrations. Statistically significant correlations between cations and anions are relatively rare, notable exceptions being between SO_4^{2-} ($r = 0.408$) and NO^-_3 ($r = 0.441$) and Ba; both significance at $\alpha = 0.01$.

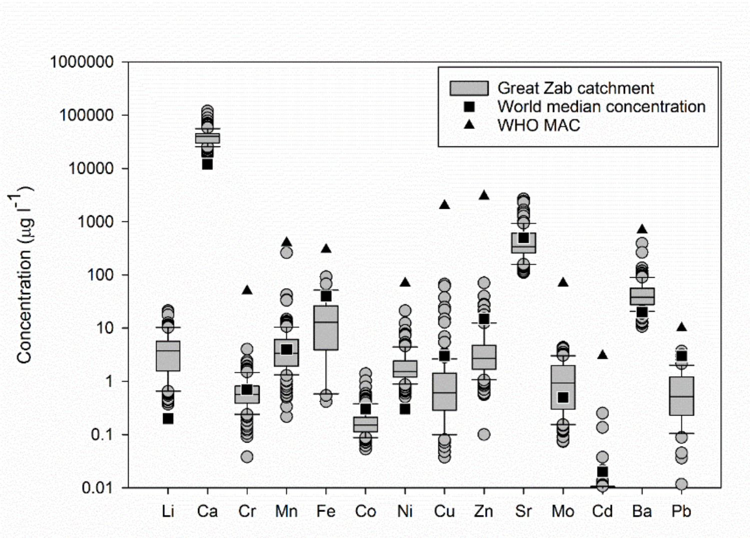


Figure 5.2 A summary of minimum, mean, median and maximum values for Cations

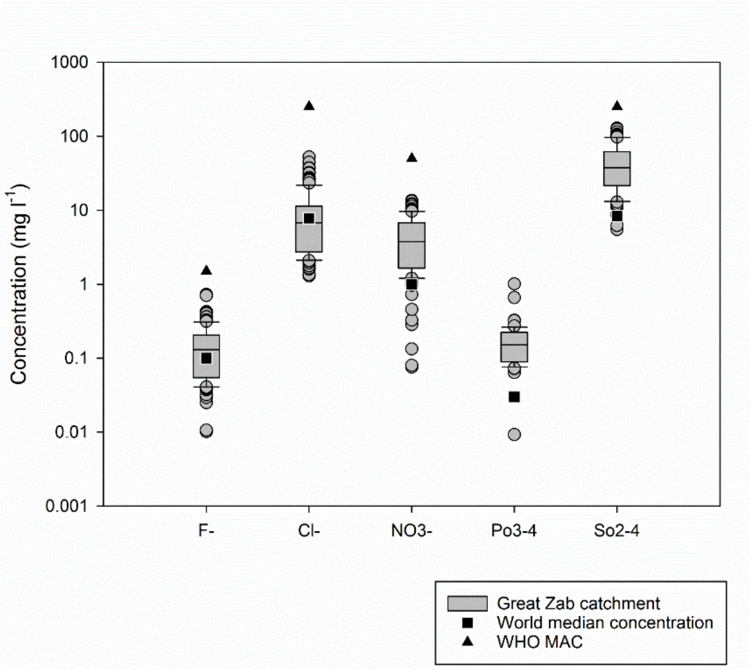


Figure 5.3 A summary of minimum, mean, median and maximum values for Anions

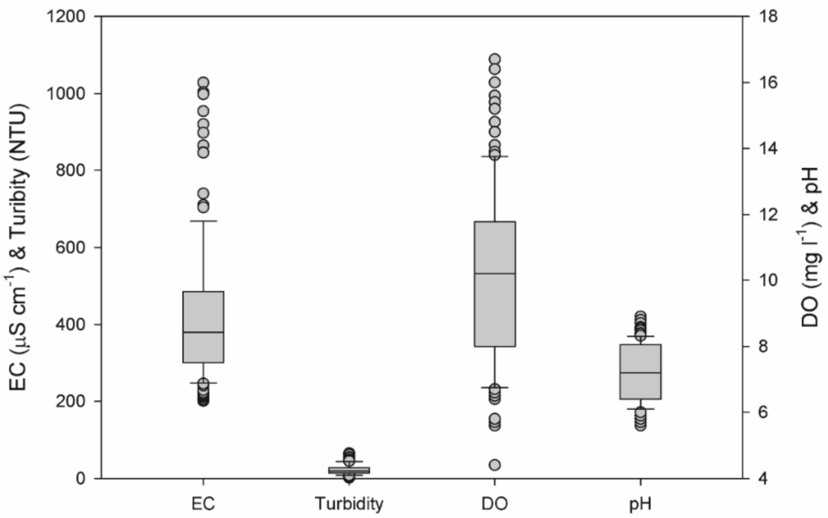


Figure 5.4 A summary of minimum, mean, median and maximum values for EC, DO, pH and Turbidity

Statistically significant correlation between cations and between anions are more frequent. With respect to cations, significant correlations exist between metals in the same groups, such as between the transition metals. Particularly strong correlations exist between Ni and Co (r = 0.801), Cu (r = 0.659) and Zn (r = 0.816). For alkaline earth metals, strong correlation relationships exist between Ca and Sr (r = 0.822) and Ba (r = 0.349). Significant correlations exist between a number of anions, being strongest between F^- and SO_4^{2-} (r = 0.637). There are relatively few significant correlations between elemental concentrations and pH; Ca, Ba, Cl^- and NO_3^- being exceptions. Dissolved oxygen concentrations are correlated with PO_4^{3-} and SO_4^{2-} (α = 0.01). In order to establish whether water chemistry differs significantly between summer (lower flow conditions) and winter (higher flow conditions), data collected in February 2014 and June 2014 were compared using a one-way ANOVA on log-transformed data, using a significance threshold of $\alpha = 0.05$. Results (Table 5.2) indicate that concentrations of Ca, Li, Mo are higher in the winter than summer (statistically significant at $\alpha = 0.05$), whilst concentrations of Zn, $SO_4{}^{2-}$, F^-, Cl^-, and PO4 3− are higher in the summer than winter (statistically significant at $\alpha = 0.05$). Seasonal differences for other analytes were not statistically significant. Higher concentrations of a number of elements during winter (generally higher discharge conditions) in the Great Zab catchment suggest enhanced delivery from the riparian zone via a combination of surface and sub-surface flows.

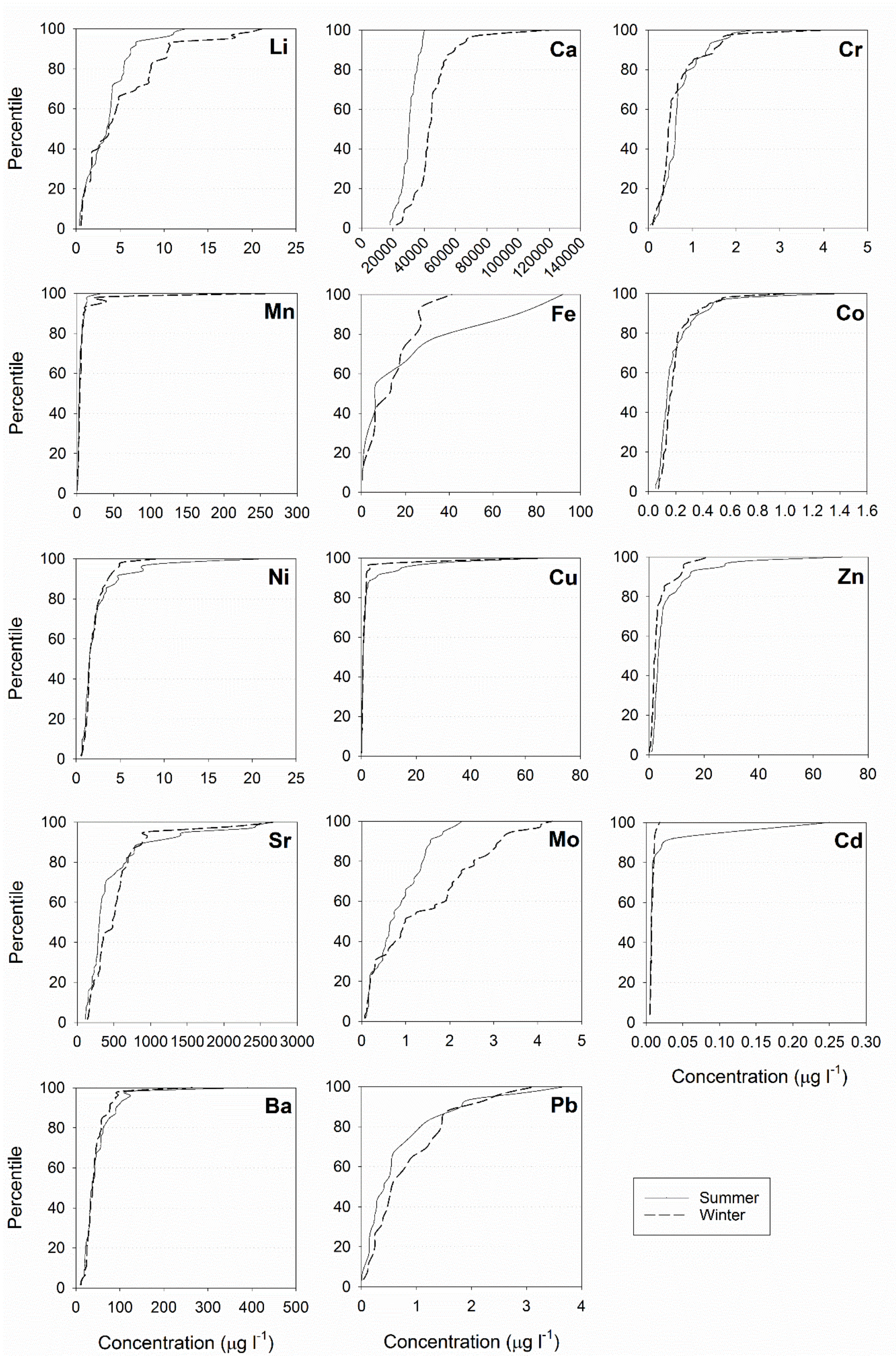


Figure 5.5 Cumulative frequency plots of cation concentrations in the Great Zab catchment during winter and summer seasons

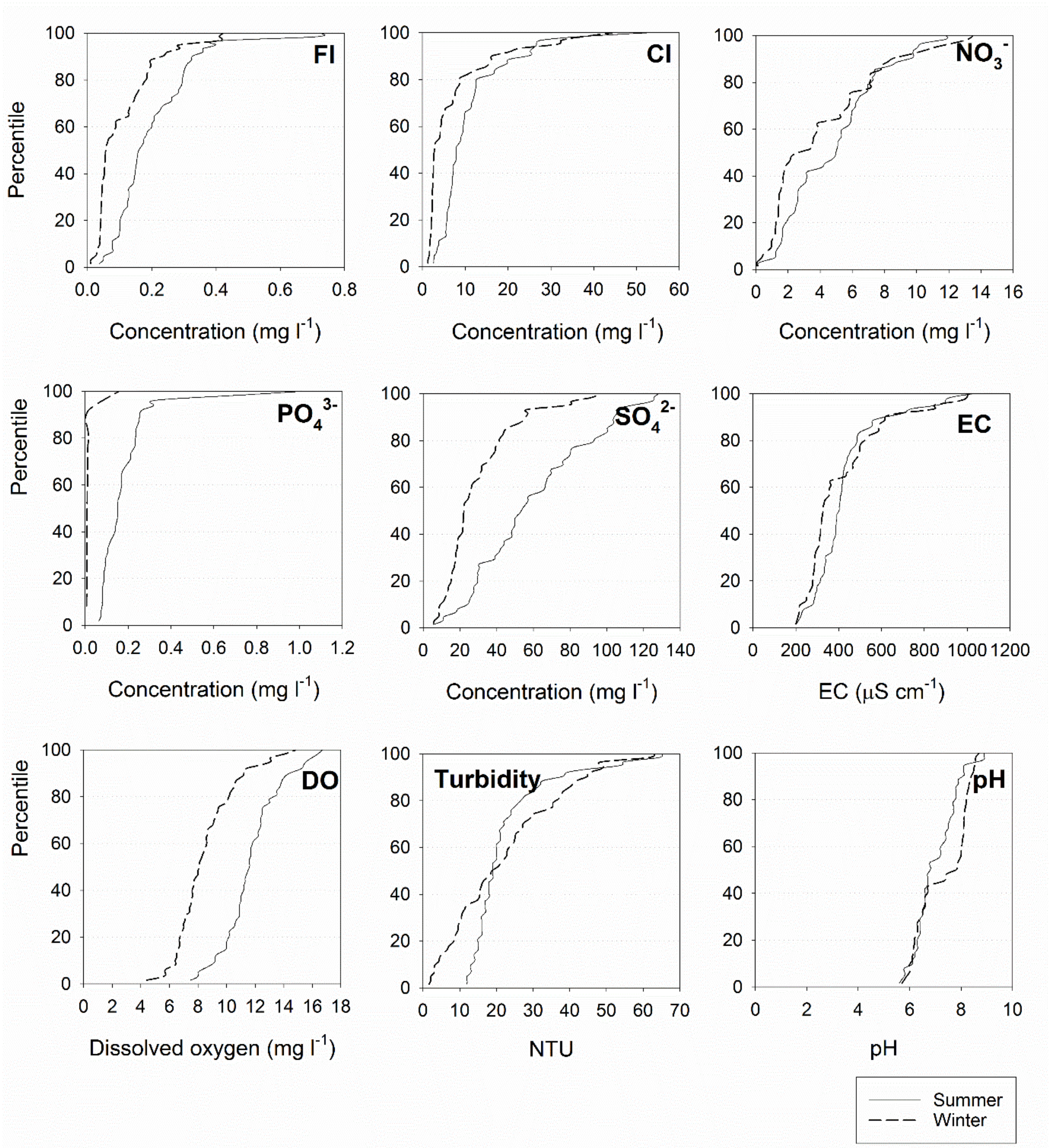


Figure 5.6 Cumulative frequency plots of anion concentrations and pH, EC, DO and turbidity in the Great Zab catchment during winter and summer seasons.

Calcium, Li and $SO_4{}^{2-}$ concentrations have been found to be consistently higher than world median concentrations. The relationship between water quality and river discharge is a potentially complex scenario. Previous studies (e.g. Garbarino et al. 1995) have reported generally higher concentrations of metals under low flow conditions due to a lower degree of physical dilution that occurs during periods of low discharge. In addition, higher discharge conditions can result in a reduction in dissolved concentrations due an increase in sorption process due to higher suspended sediment concentrations. However, conversely other studies (e.g. Gundersen and Steinnes 2001) have demonstrated that periods of higher discharge can yield higher metal concentrations due to enhanced delivery of substances to the river channel from run-off and the potential activation of point sources. What is apparent is that different elements can display different relationships with discharge, as noted in a study of Southeast Asian rivers by Chanpiwat and Sthiannopkao (2014).

In an attempt to evaluate the spatial trends in water quality, samples were grouped based upon the major underlying geological units identified in the Great Zab catchment. The groups were identified as: (1) Zagros zone, (2) the imbricated/ high-fold zones and (3) the foothill zone (Fig. 1). The grouping by underlying geology reflects the importance of geogenic loading in determining surface water chemistry (Drever 1997). Log-transformed data were analysed using a one-way ANOVA, using a significance threshold of $\alpha = 0.05$. The most frequent differences were found between water chemistry in samples collected from the Zagros and foothill zones, with 13 parameters showing a statistically significant difference (Table 5.2). Five and 7 parameters, respectively, showed statistically significant differences between the Zagros and imbricated/high-fold zones and imbricated/high-fold and foothill zones. The greater statistical similarity of water chemistry sampled in the imbricated/ high-fold and foothill zones will reflect the greater similarity in bedrock geology between these areas compared with the Zagros zone. The influence of geology on water chemistry is exemplified by Ca and Sr concentrations; these are found to be significantly higher in waters within the imbricated/highfold and foothill zones than in the Zagros zones (Table 5. 2).

Average Sr concentrations in water with the imbricated/ high-fold (542 μg l^{-1}) and foothill zones (683 μg l^{-1}) are at least twice as high as in the Zagros zone (243 μg l^{-1}). Average Ca concentrations are c. 10 mg l^{-1} lower in the Zagros zone compared to the imbricated/high-fold and foothill zones. This reflects the abundant carbonate bedrocks, notably limestone and dolomitic limestone, which are the main sources of Sr to stream water in particular, whilst the bedrock of Zagros zone is relatively carbonate poor.

Table 5.2 Results of a one-way ANOVA for temporal trends

Parameter	P value (Seasonal)	P value (Spatial)		
		Z[1] vs I/HF[2]	Z v FZ[3]	I/HF v FZ
As	N/A	N/A	N/A	N/A
Ba	0.486	0.888	**0.000**	**0.000**
Ca	**0.000****	**0.009**	**0.001**	0.625
Cd	0.224	0.210	0.944	0.275
Co	0.986	0.711	0.299	**0.025**
Cr	0.719	0.063	0.653	0.270
Cu	0.487	0.210	0.772	0.500
Fe	0.224	0.233	0.455	0.726
Hg	N/A	N/A	N/A	N/A
Li	**0.029****	**0.000**	**0.000**	0.855
Mn	0.223	0.980	0.455	0.726
Mo	**0.036****	**0.000**	**0.000**	0.596
Ni	0.256	0.169	0.946	0.212
Pb	N/A	0.424	0.708	0.792
Sr	0.642	**0.019**	**0.001**	0.441
Zn	**0.031***	0.311	0.801	0.629
NO_3^-	0.180	0.746	**0.000**	**0.000**
$SO4^{2-}$	**0.000***	0.651	**0.000**	**0.000**
F^-	**0.000***	**0.024**	**0.005**	0.734
Cl^-	**0.017***	0.771	**0.008**	**0.000**
PO_4^{3-}	**0.000***	0.886	0.735	0.936
Turbidity	0.769	0.650	0.963	0.764
DO	**0.000***	0.801	0.996	0.686
EC	0.563	0.119	**0.021**	0.626
pH	**0.000****	0.413	**0.014**	**0.000**

[1]Zagros Zone
[2]Imbricated/High-folded Zone
[3]Foothill Zone
Bold indicates significant at $\alpha = 0.05$.
*Denotes mean summer concentration is higher than mean winter concentration
**Denotes mean winter concentration is higher than mean summer Concentration

Chloride and NO_3^- show a statistically significant difference between the foothill zone (the lower Great Zab catchment) and the two upstream zones (Table 2). Concentrations of Cl^- and NO_3^- are significantly higher in the lower catchment, as indicated by mean concentrations of 14.2 and 6.8 mg l^{-1}, respectively, which are twice as high as those for the Zagros and imbricated/high-fold zones upstream. Chloride and NO_3^- are two substances for which higher concentrations in river water, and particularly within-catchment variability, can be the result of anthropogenic inputs, such as from agricultural activity in the case NO_3^- (Randall and Mulla 2001). Importantly, the amount of anthropogenic activity is greatest in the lower Great Zab catchment, the part of the catchment containing the highest Cl^- and NO_3^- levels (see Fig 5.7). Whilst concentrations are below respective WHO MACs, the data exemplify and indicate that whilst geogenic inputs are important in explaining largescale variability in water chemistry, the spatially variable influence of anthropogenic activity is an important contributor to the water chemistry of the Great Zab catchment.

5.5.2 Quantifying background conditions

Establishing background geochemical conditions provides a potentially valuable regulatory tool for evaluating water quality. However, given the difficulty in locating 'pristine' water bodies that have no anthropogenic influence, as reviewed by Peters et al. (2012), a range of approaches have been utilized to quantify background conditions in river catchments. Peters et al. (2012) used a low percentile of water quality data to provide a relatively conservative estimate of background, or what can be termed 'ambient background'. In contrast, other approaches have utilized higher percentile, such as the 90th percentile value (Fraters et al. 2001). To evaluate the potential influence of the approach used, three different approaches were taken. Firstly, background conditions were calculated as the 10th percentile value (Peters et al. 2012) of the whole data set from the Great Zab River catchment (Table 5.3). Secondly, based upon the analysis of Q–Q plots of NO_3^- concentrations, utilized as an anthropogenic marker, and other water quality parameters (Fig. 5.7), the 95th percentile was identified as a point where the distributions differ (Helsel and Hirsch 2002). Therefore, this is indicative of a different sample population above the 95th percentile and can be interpreted as a separation of geogenic and anthropogenic components. Finally, following the method of Davies (1983) background concentrations were estimated using regression analysis of % cumulative frequency curves of log10 concentrations from the sample population (Table 5.3).

Table 5.3 Background conditions defined for the Great Zab catchment. WHO MAC and world median concentrations also given for comparison. Concentrations in µg l^{-1} unless stated.

	10^{th} percentile	95^{th} percentile	Regression analysis	WHO MAC	World median
Li	0.7	11.5	2.3	-	0.2[1]
Ca	26.1 mg l^{-1}	67 mg l^{-1}	22 mg l^{-1}	-	[1]12 mg l^{-1}
Cr	0.2	1.7	0.3	50	0.7[1]
Mn	1.4	14.6	3.6	400	4[1]
Fe	0.8	26.9	2.1	300	40[1]
Co	0.1	0.5	0.1	-	0.3[1]
Ni	0.9	7.2	1.7	70	0.3[1]
Cu	0.2	14.8	0.5	2000	3[1]
Zn	1.2	17.7	8.1	3000	15[1]
As	n/d	n/d	n/d	10	4[1]
Sr	161	1650	154	-	500[1]
Mo	0.2	3.3	0.4	70	0.5[1]
Cd	<0.01	0.01	<0.01	3	0.02[1]
Ba	21	108	21	700	20[1]
Hg	n/d	n/d	n/d	6	0.05[1]
Pb	0.1	1.8	0.2	10	3[1]
Cl^-	2.2 mg l^{-1}	31.5 mg l^{-1}	3.2 mg l^{-1}	[2]250 mg l^{-1}	[3]7.8 mg l^{-1}
$SO4^{2-}$	13.6 mg l^{-1}	105 mg l^{-1}	15.9 mg l^{-1}	[2]250 mg l^{-1}	[4]8.3 mg l^{-1}
F^-	0.04 mg l^{-1}	0.4 mg l^{-1}	0.1 mg l^{-1}	1.5 mg l^{-1}	[3]0.1 mg l^{-1}
NO_3^-	1.2 mg l^{-1}	11.2 mg l^{-1}	6.9 mg l^{-1}	50 mg l^{-1}	[3]1 mg l^{-1}
PO_4^{3-}	<0.01 mg l^{-1}	0.3 mg l^{-1}	mg l^{-1}	-	[3]0.03 mg l^{-1}

[1]Reimann and de Caritat (1998)
[2]Based upon acceptable taste. A health-based limit has not been established.
[3]Ivanov (1996)
[4]Berner and Berner (1996)

Generally, of the three approaches, the 10th percentile concentrations are always the lowest (Table 5.3), with the exception of Ca and Sr, for which the regression derived concentrations are lowest. The 10th percentile concentrations have been described by Peters et al. (2012) as reflecting ambient background conditions that, in relation to the Great Zab catchment, would be expected resulting from natural, geogenic inputs and low level anthropogenic activity. However, utilizing NO_3^- concentrations as an anthropogenic marker suggests that the proportion of the sample population that could be considered as geogenic is much larger, equating to the 95th percentile value and that background concentrations could potentially be established at higher concentrations. Given that background concentrations may be used as an indicator of water quality, the background concentrations can be compared to WHO MACs (Table 5.3). All background concentrations in the Great Zab, determined by the three methods used, are lower than WHO MACs. In some case, background concentrations are orders of magnitude lower, for example in the case of Cu and Zn (Table 5.3). The comparison to WHO MACs suggests that the background concentrations defined by this study can be viewed as conservative if used as a guide for water quality based upon risks posed to human health. It is not suggested that the background concentrations derived here are adopted as a measure to protect human health; however, the concentrations quantified may act as valuable guide for identifying instances for anthropogenic pollution within the Great Zab catchment.

Given that background concentrations may be used as an indicator of water quality, the background concentrations can be compared to WHO MACs (Table 5.3). All background concentrations in the Great Zab, determined by the three methods used, are lower than WHO MACs. In some case, background concentrations are orders of magnitude lower, for example in the case of Cu and Zn (Table 5.3). The comparison to WHO MACs suggests that the background concentrations defined by this study can be viewed as conservative if used as a guide for water quality based upon risks posed to human health. It is not suggested that the background concentrations derived here are adopted as a measure to protect human health, however, the concentrations quantified may act as valuable guide for identifying instances for anthropogenic pollution within the Great Zab catchment. Variations in water chemistry within the catchment would mean that the instances of enrichment above background concentrations varies between waters from the Zagros, Imbricated/High Fold and Foothill Zones. By way of example, comparison of Li, Ba, F^- and NO_3^- concentrations, which have been previously shown to differ significantly between the three zones (Table 5.4), suggests that instances of elevation above background concentrations vary between zone and element (Fig 5.8).

Highest NO_3^- concentrations occur in the Foothill Zone, in waters from the Great Zab River itself, but also its tributaries, the Khazir River and the Gomal. NO_3^- concentrations in 7% of samples from Foothill zone exceed the 95th percentile-defined background value, but samples from the Zagros and Imbricated/High Fold Zones do not. Conversely, Li and F^- concentrations in the Zagros Zone, in 9% and 7% of samples respectively, exceed the 95th percentile-defined background value, with all samples in the two downstream zones falling below. These data further highlight that spatial trends in water chemistry, including the occurrence of relative elevation in concentrations, are likely to reflect both geogenic influences operating at larger spatial scales and site-specific conditions, particularly point sources associated with anthropogenic activity, that vary between different water quality parameters.

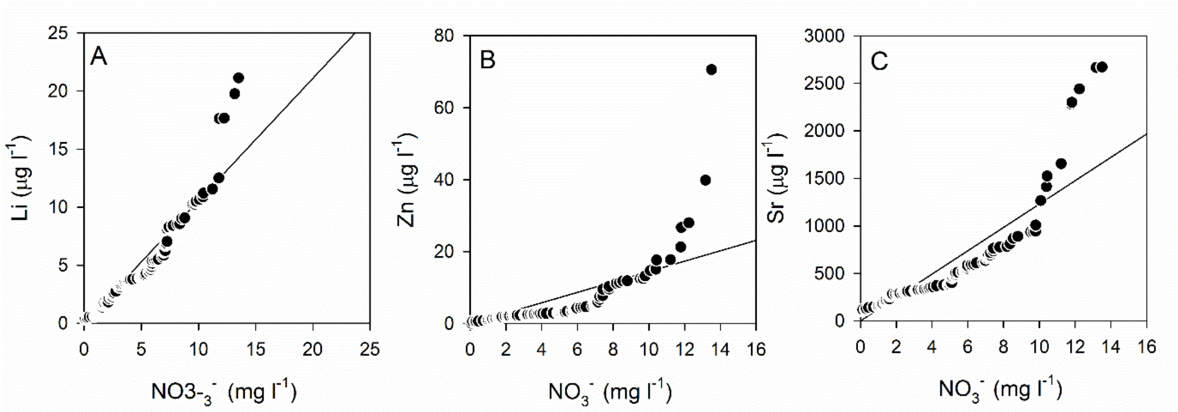


Figure 5.7 Q-Q plots of NO3- (as an anthropogenic tracer) and Li, Zn and Sr concentrations in the Great Zab catchment.

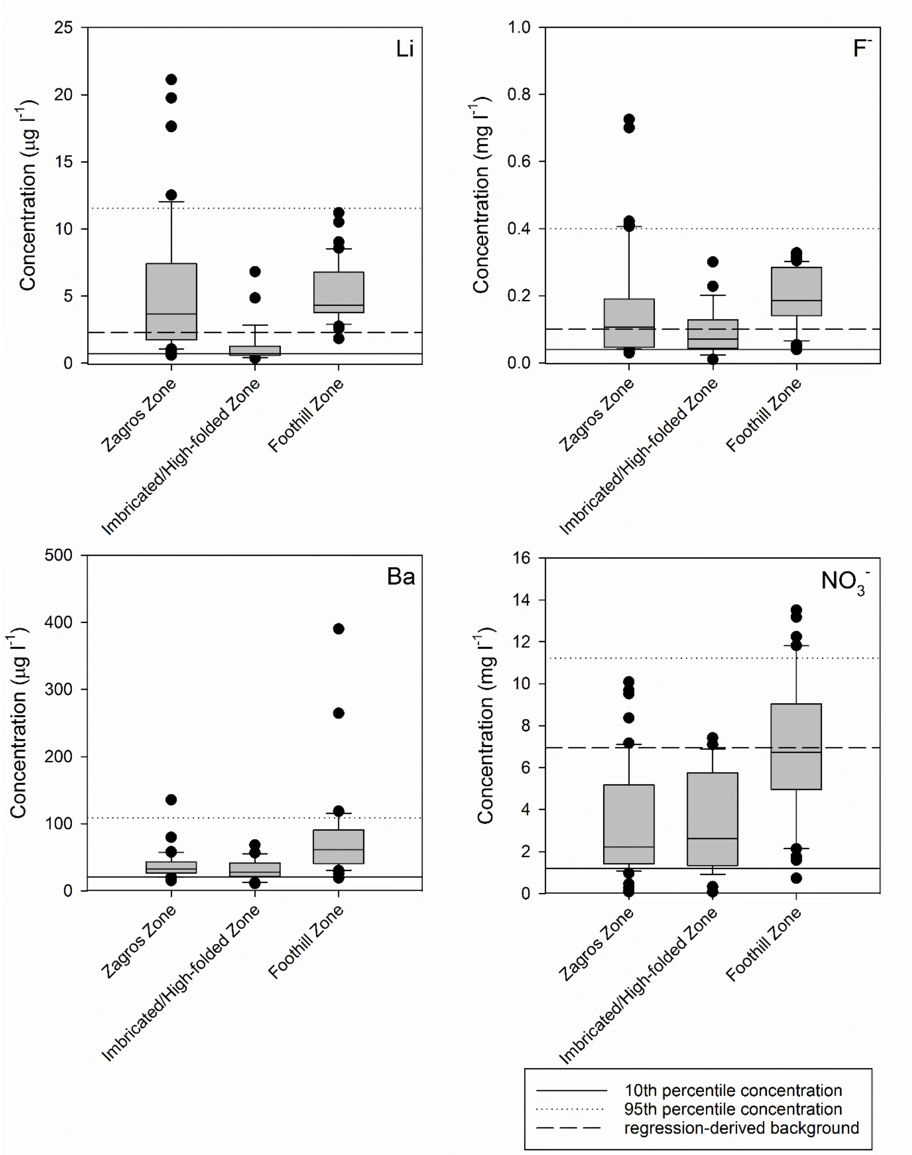


Figure 5.8 Minimum, median and maximum concentrations of Li, F-, Ba and NO3- determined in the river water from three geological zones within the Great Zab catchment.

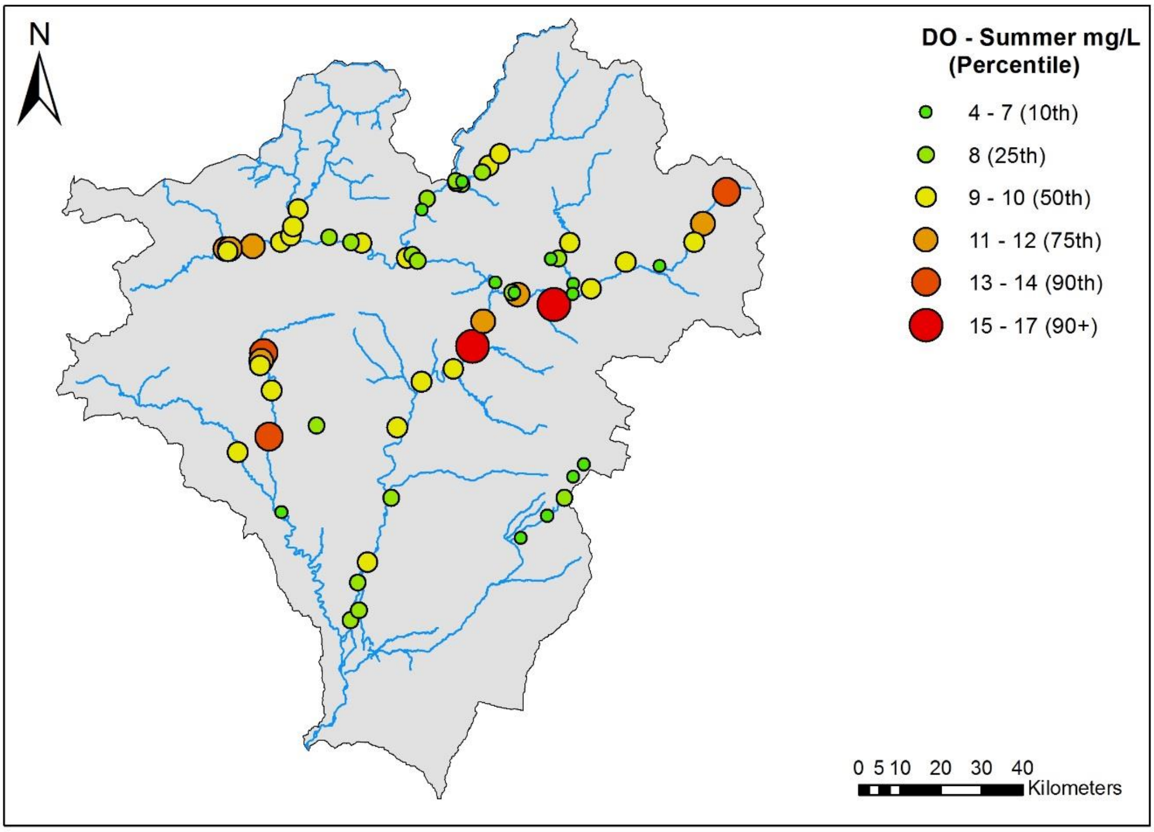
Table 5.4 Background conditions defined for the Great Zab catchment. WHO MAC and world median concentrations also given for comparison. Concentrations in µg l-1 unless stated.

Parameters	10th percentile	95th percentile	Regression analysis	WHO MAC	World median
Li	0.7	11.5	2.3	-	0.2[1]
Ca	26.1 mg l^{-1}	67 mg l^{-1}	22 mg l^{-1}	-	[1]12 mg l^{-1}
Cr	0.2	1.7	0.3	50	0.7[1]
Mn	1.4	14.6	3.6	400	4[1]
Fe	0.8	26.9	2.1	300	40[1]
Co	0.1	0.5	0.1	-	0.3[1]
Ni	0.9	7.2	1.7	70	0.3[1]
Cu	0.2	14.8	0.5	2000	3[1]
Zn	1.2	17.7	8.1	3000	15[1]
As	n/d	n/d	n/d	10	4[1]
Sr	161	1650	154	-	500[1]
Mo	0.2	3.3	0.4	70	0.5[1]
Cd	<0.01	0.01	<0.01	3	0.02[1]
Ba	21	108	21	700	20[1]
Hg	n/d	n/d	n/d	6	0.05[1]
Pb	0.1	1.8	0.2	10	3[1]
Cl^-	2.2 mg l^{-1}	31.5 mg l^{-1}	3.2 mg l^{-1}	[2]250 mg l^{-1}	[3]7.8 mg l^{-1}
$SO4^{2-}$	13.6 mg l^{-1}	105 mg l^{-1}	15.9 mg l^{-1}	[2]250 mg l^{-1}	[4]8.3 mg l^{-1}
F^-	0.04 mg l^{-1}	0.4 mg l^{-1}	0.1 mg l^{-1}	1.5 mg l^{-1}	[3]0.1 mg l^{-1}
NO_3^-	1.2 mg l^{-1}	11.2 mg l^{-1}	6.9 mg l^{-1}	50 mg l^{-1}	[3]1 mg l^{-1}
PO_4^{3-}	<0.01 mg l^{-1}	0.3 mg l^{-1}	mg l^{-1}	-	[3]0.03 mg l^{-1}

[1]Reimann and de Caritat (1998)
[2]Based upon acceptable taste. A health-based limit has not been established.
[3]Ivanov (1996)
[4]Berner and Berner (1996)

5.6 CONCLUSIONS

This study has conducted and presented data for the first regional survey of river water chemistry for the Great Zab River catchment, a major left-bank tributary of the River Tigris. Data analysis has shown that concentrations in river water of Ca, Li, Mo, Zn, F^{-}, Cl^{-}, $SO_4^{2-}$and PO_4^{3-} are significantly different during summer and winter sampling periods, however, there are variations in terms of when concentrations are highest for different elements. The Great Zab catchment can be divided into three major geological units, and the influence of bedrock geology upon surface water chemistry is evidenced by differences in elemental concentrations in waters sampled from the different units. In addition, whilst elemental concentrations in the Great Zab are below WHO MACs, a potential anthropogenic influence on water chemistry is identifiable through the location of highest elemental concentrations. The lower catchment, which is most highly populated contains highest elemental concentrations and represent areas of concern for water resources management. Background concentrations for the Great Zab catchment have been quantified using the 10^{th} and 95^{th} percentile concentrations and a regression analysis. Concentrations of rang of parameters in the Great Zab catchment plotted as proportional circles in Fig 5.9. These concentrations could be used as the basis for establishing water quality norms for the catchment and potentially the broader Kurdistan region. Comparison to WHO MACs, which provide human-health oriented guidelines for water quality, indicates that the use of a background concentration as a guide for water quality management, would produce much more conservative and stricter quality limits. This suggests that there is a potentially significant difference between background concentrations, which may be used to identify instances of contamination within a catchment and guidelines that establish potential threats to human health. The use of a guideline such as a WHO MAC as a measure of water quality in water quality assessments may actually mask instances of poor water quality that are identified via the establishment of a catchment-wide background concentrations.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(Percentile)
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8 (25th)
9 - 10 (50th)
11 - 12 (75th)
13 - 14 (90th)
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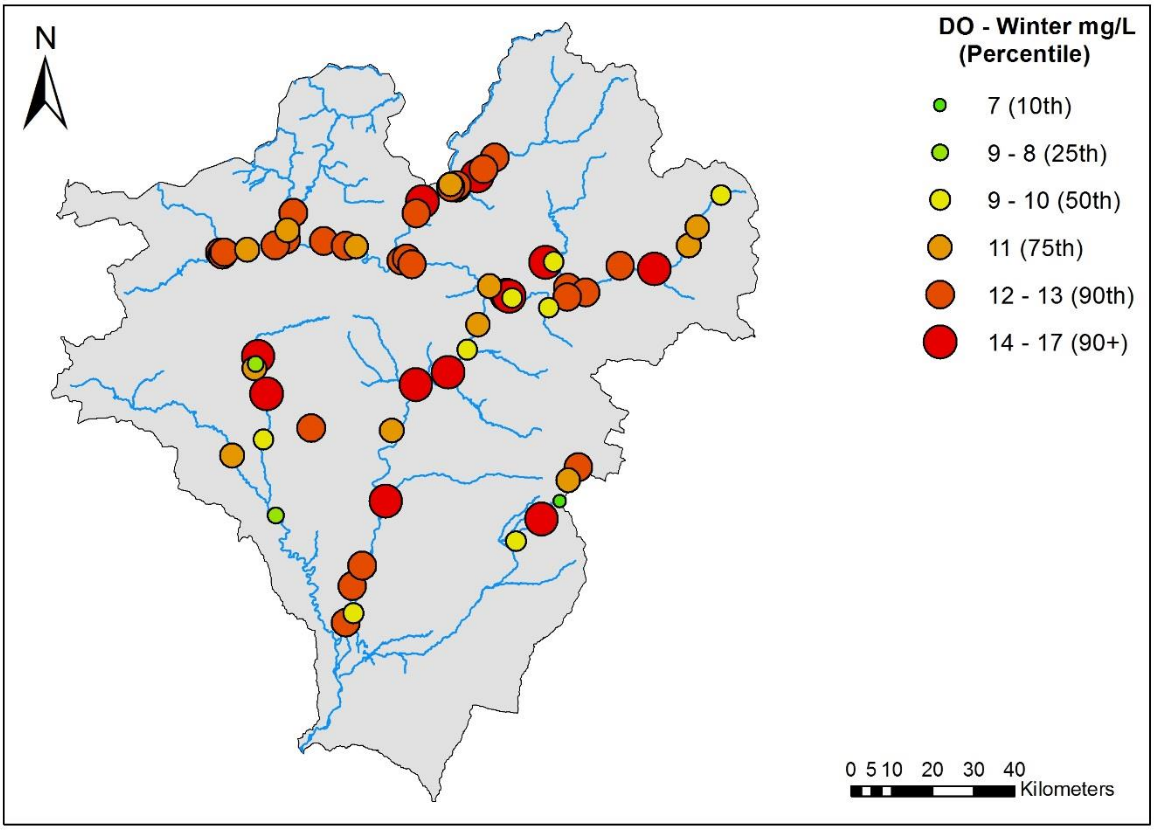
Kilometers


N
DO - Winter mg/L
(Percentile)
7 (10th)
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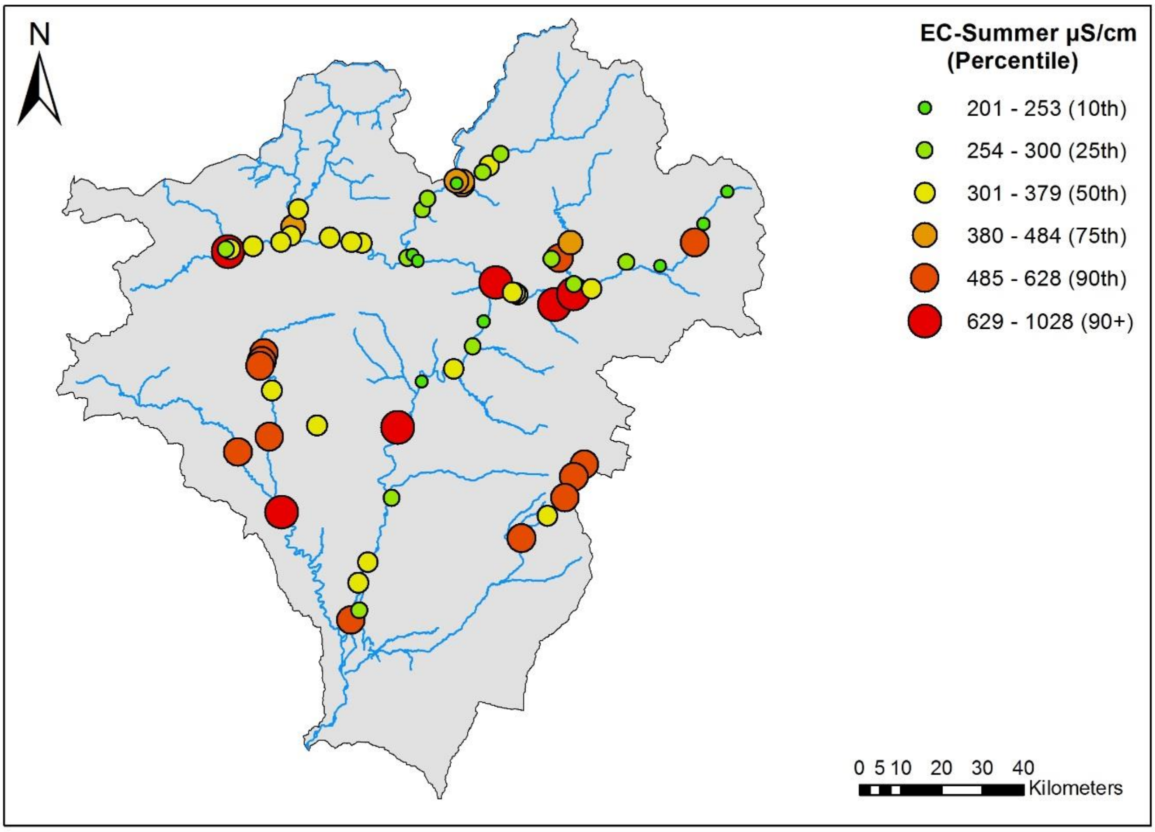
9 - 10 (50th)
11 (75th)
12 - 13 (90th)
14 - 17 (90+)
0 5 10 20 30 40
Kilometers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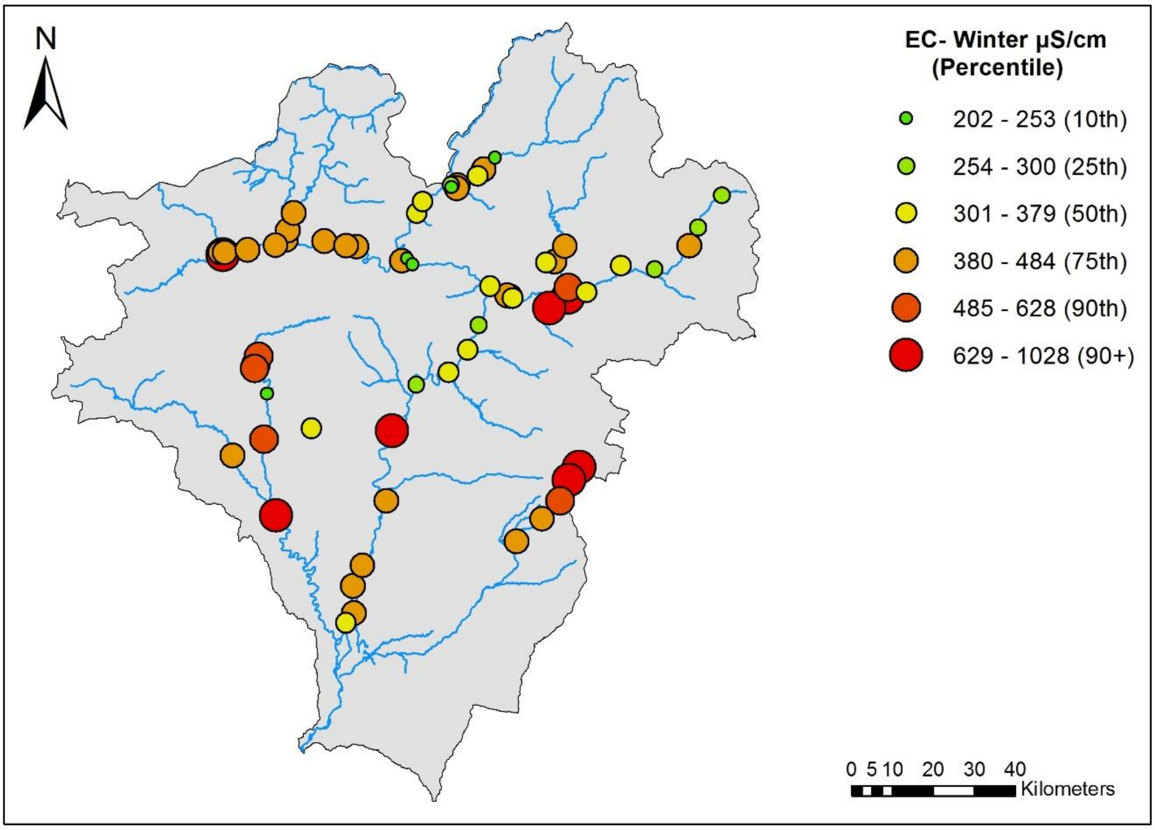
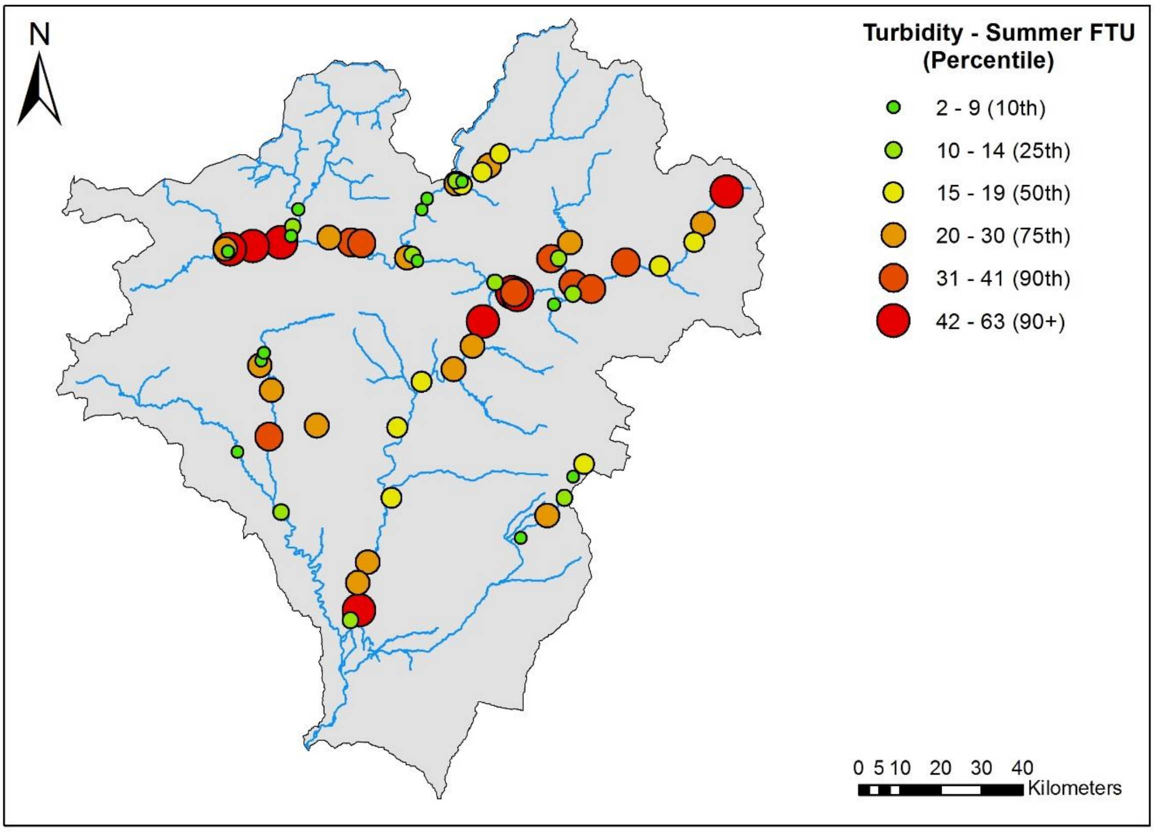
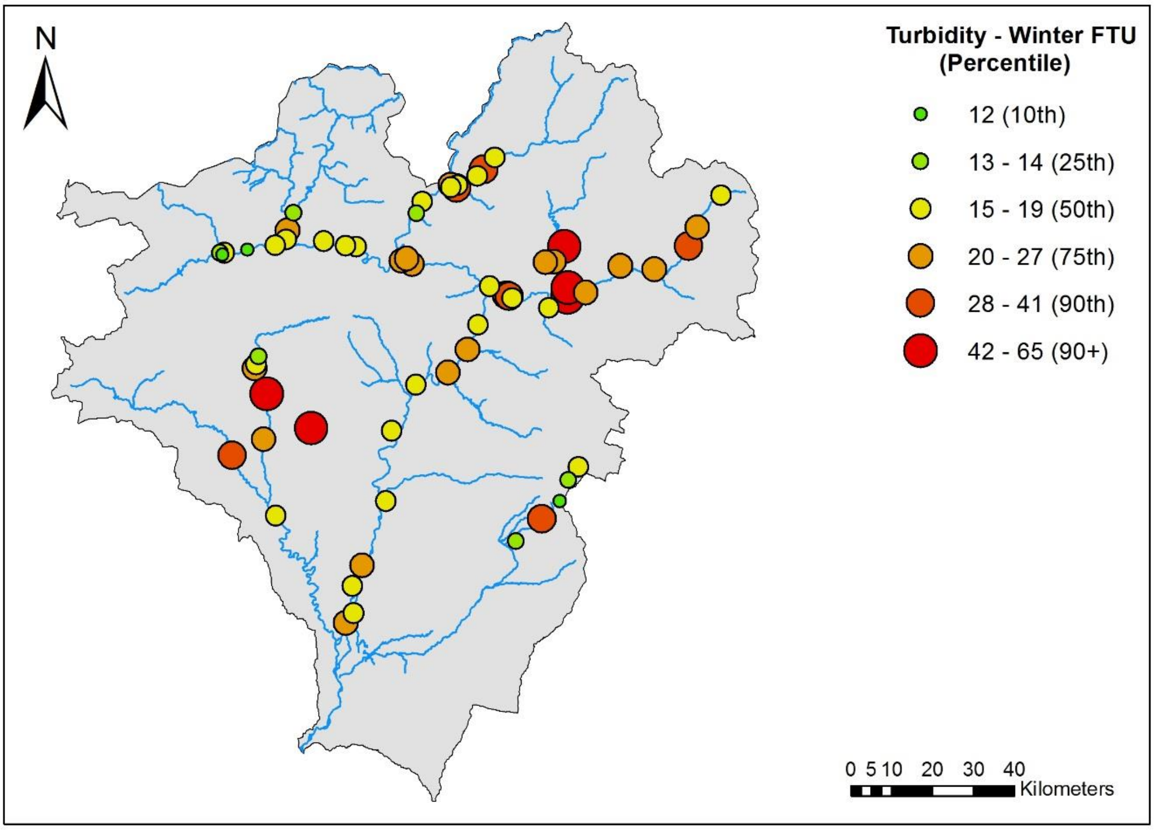
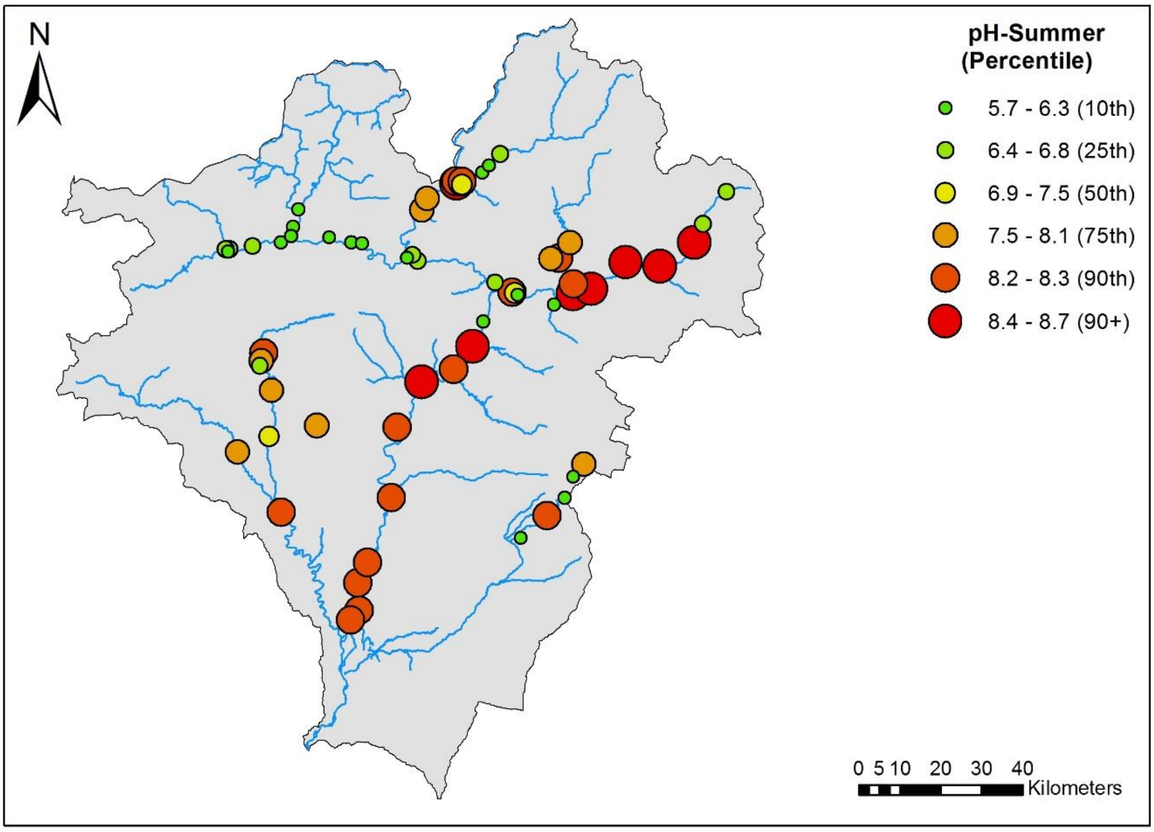
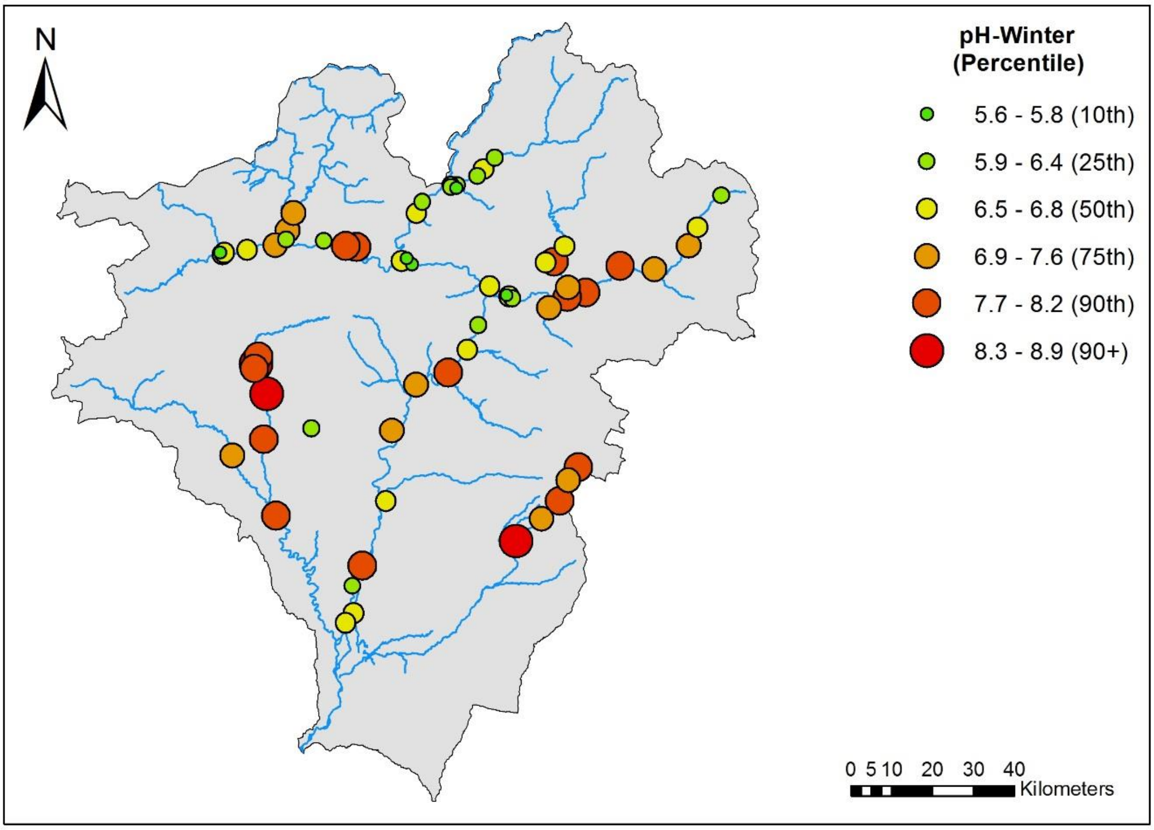
254 - 300 (25th)
301 - 379 (50th)
380 - 484 (75th)
485 - 628 (90th)
629 - 1028 (90+)
0 5 10 20 30 40
Kilometers

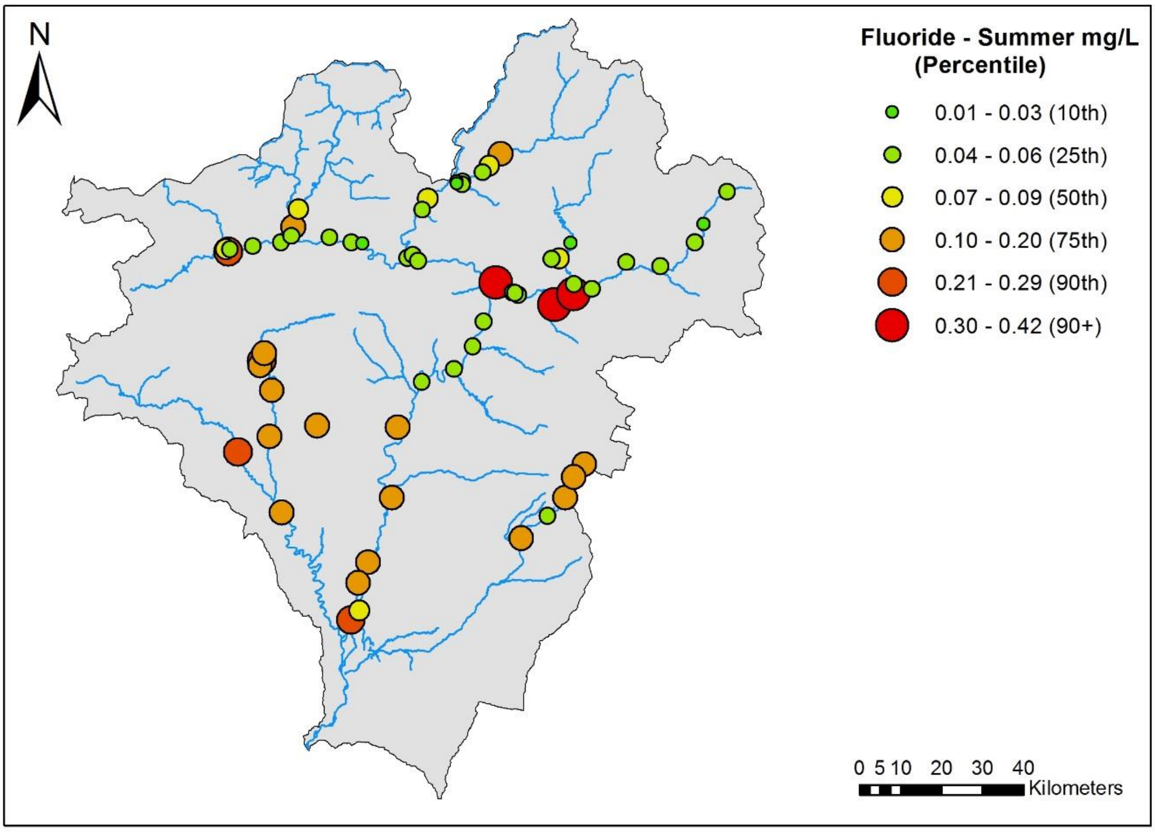

N
EC- Winter µS/cm
(Percentile)
202 - 253 (10th)
254 - 300 (25th)
301 - 379 (50th)
380 - 484 (75th)
485 - 628 (90th)
629 - 1028 (90+)
0 5 10 20 30 40
Kilometers

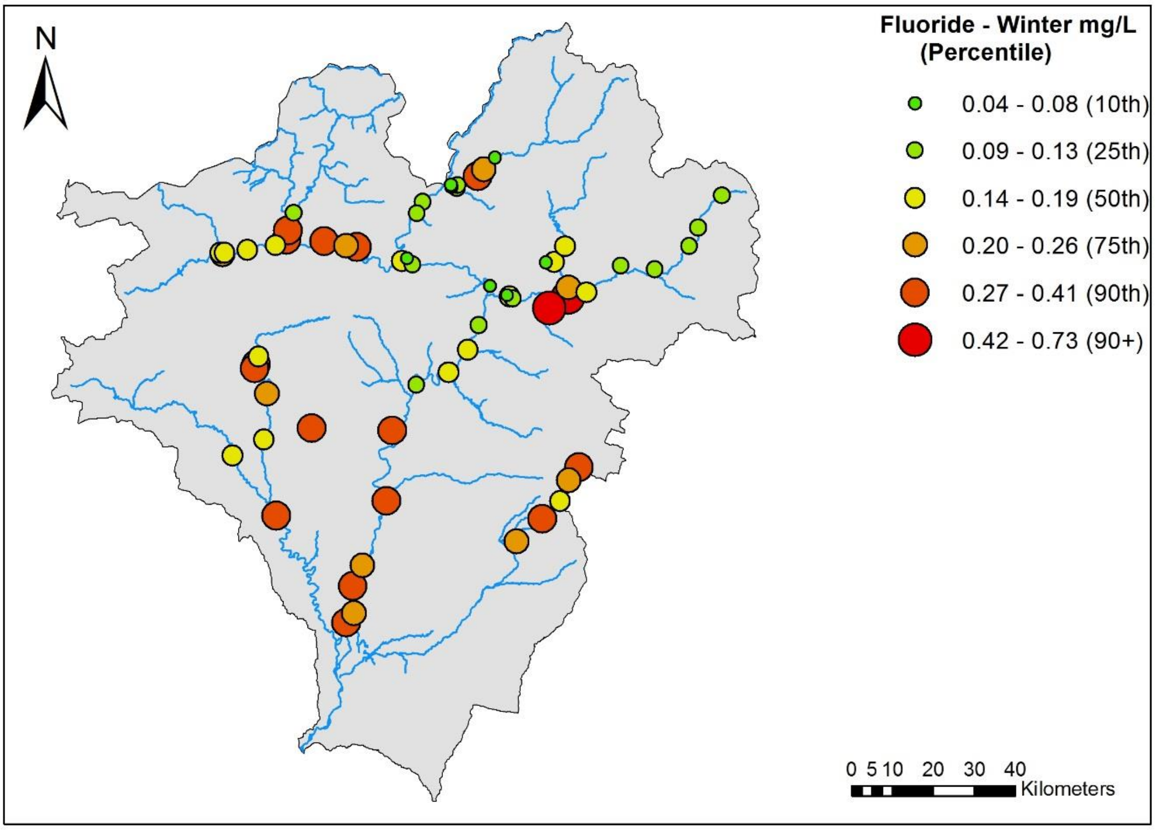

N
Turbidity - Summer FTU
(Percentile)
2 - 9 (10th)
10 - 14 (25th)
15 - 19 (50th)
20 - 30 (75th)
31 - 41 (90th)
42 - 63 (90+)
0 5 10 20 30 40
Kilometers

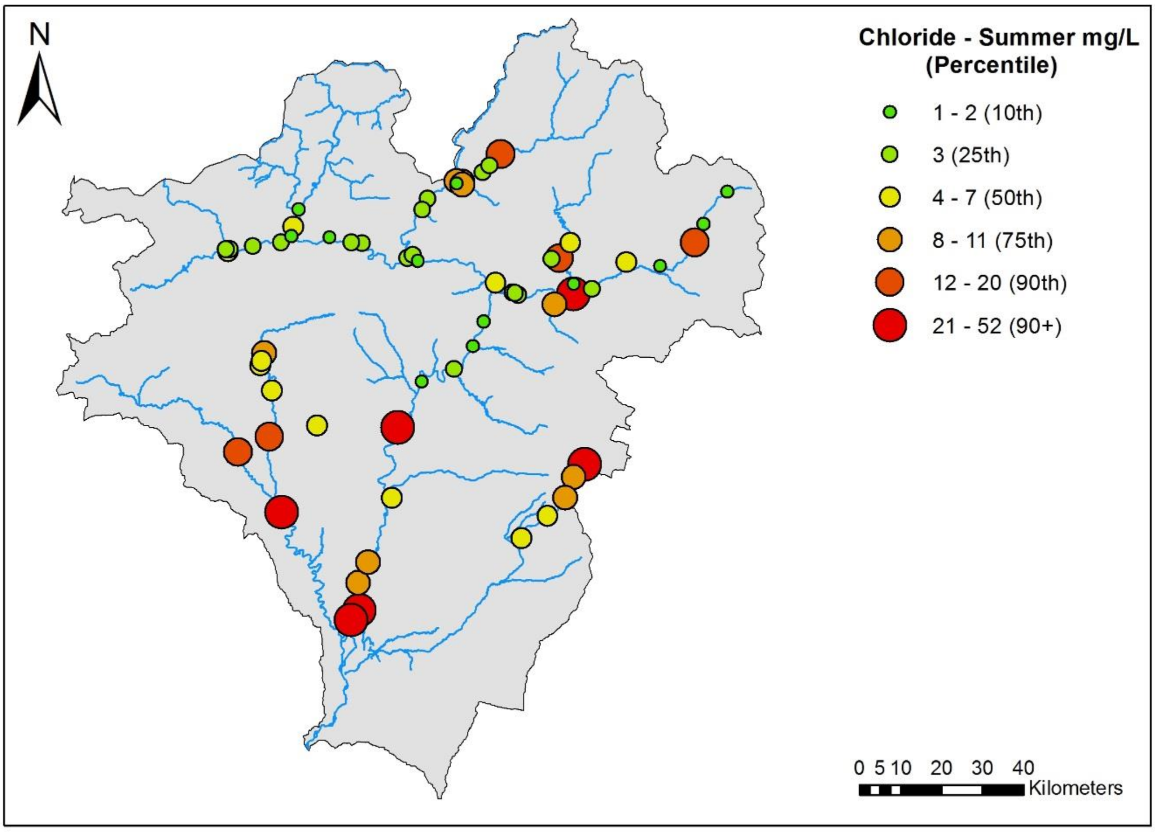

N
Turbidity - Winter FTU
(Percentile)
12 (10th)
13 - 14 (25th)
15 - 19 (50th)
20 - 27 (75th)
28 - 41 (90th)
42 - 65 (90+)
0 5 10 20 30 40
Kilometers

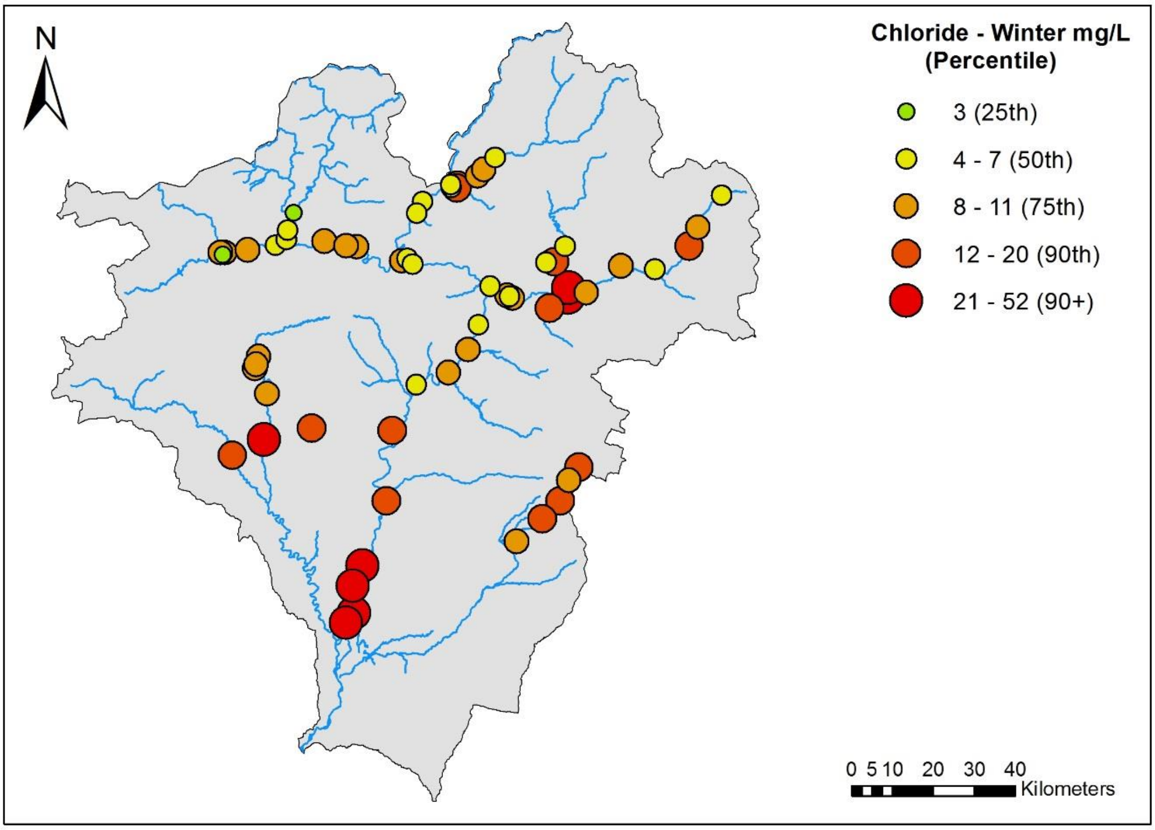

N
pH-Summer
(Percentile)
5.7 - 6.3 (10th)
6.4 - 6.8 (25th)
6.9 - 7.5 (50th)
7.5 - 8.1 (75th)
8.2 - 8.3 (90th)
8.4 - 8.7 (90+)
0 5 10 20 30 40
Kilometers

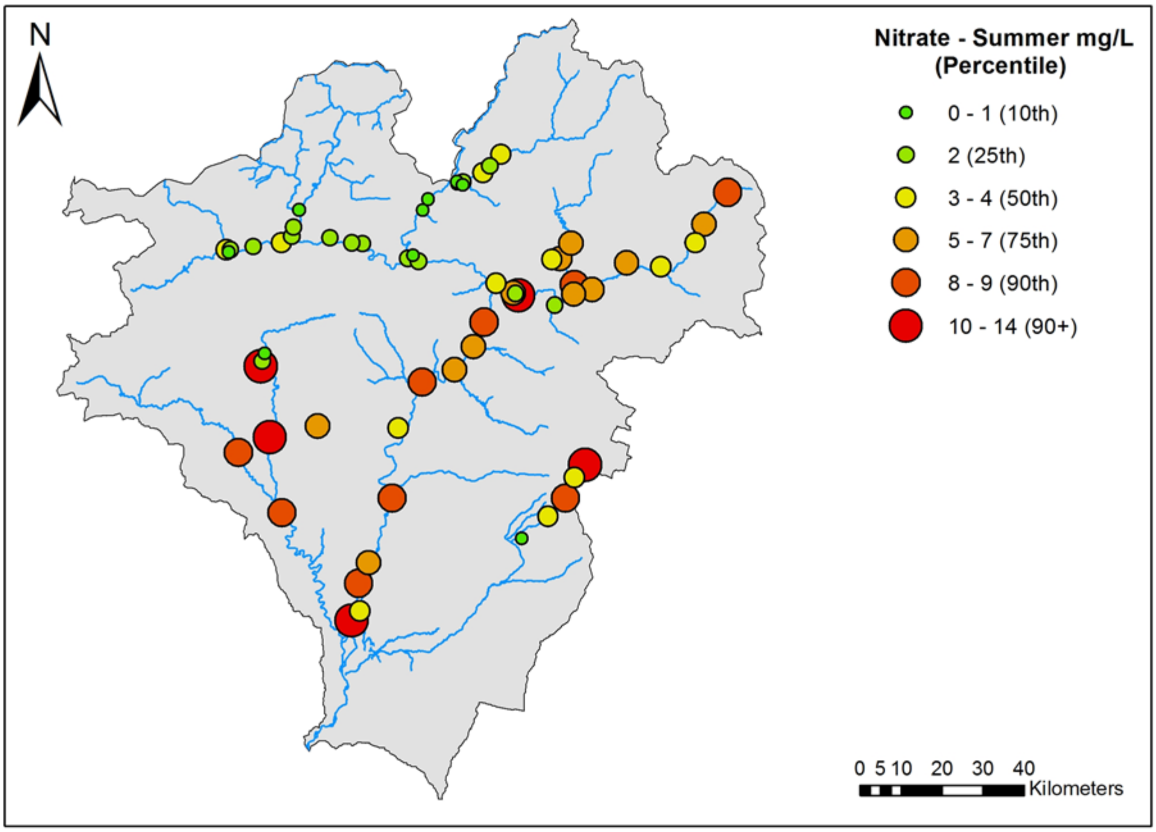

N
pH-Winter
(Percentile)
5.6 - 5.8 (10th)
5.9 - 6.4 (25th)
6.5 - 6.8 (50th)
6.9 - 7.6 (75th)
7.7 - 8.2 (90th)
8.3 - 8.9 (90+)
0 5 10 20 30 40
Kilometers

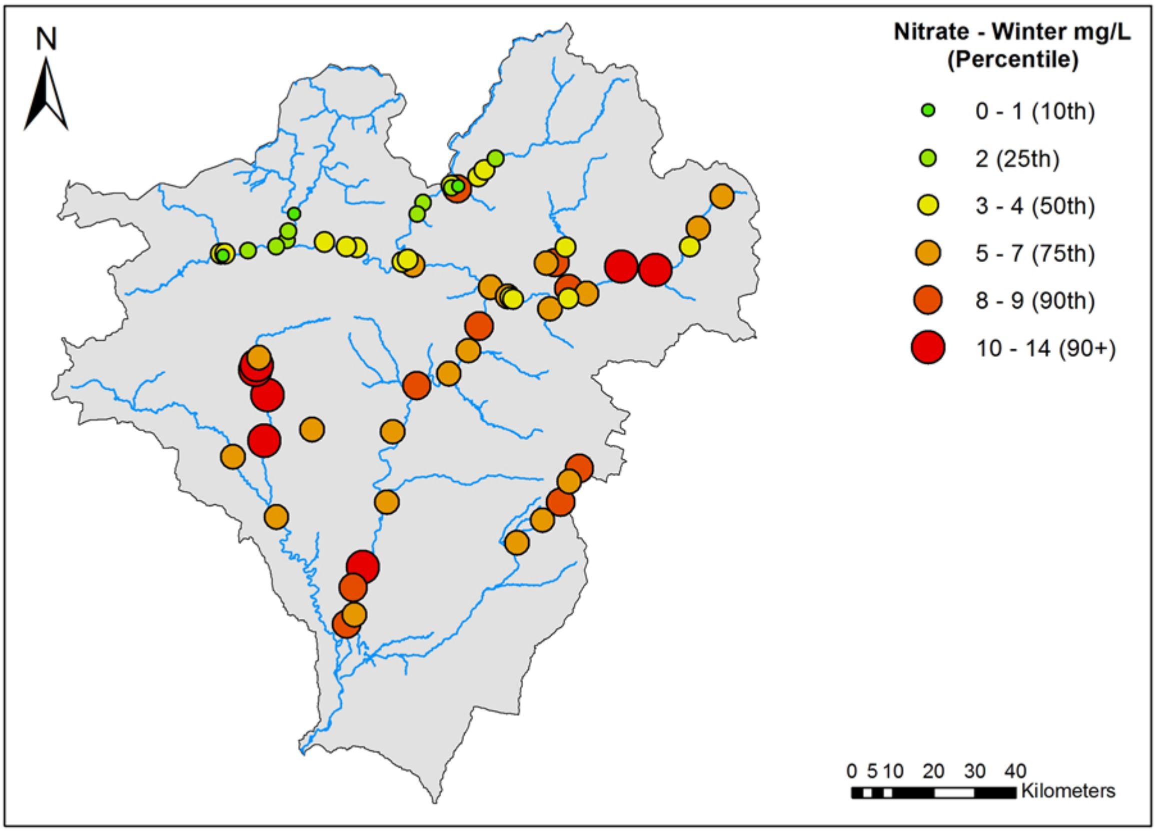

N
Fluoride - Summer mg/L
(Percentile)
0.01 - 0.03 (10th)
0.04 - 0.06 (25th)
0.07 - 0.09 (50th)
0.10 - 0.20 (75th)
0.21 - 0.29 (90th)
0.30 - 0.42 (90+)
0 5 10 20 30 40
Kilometers

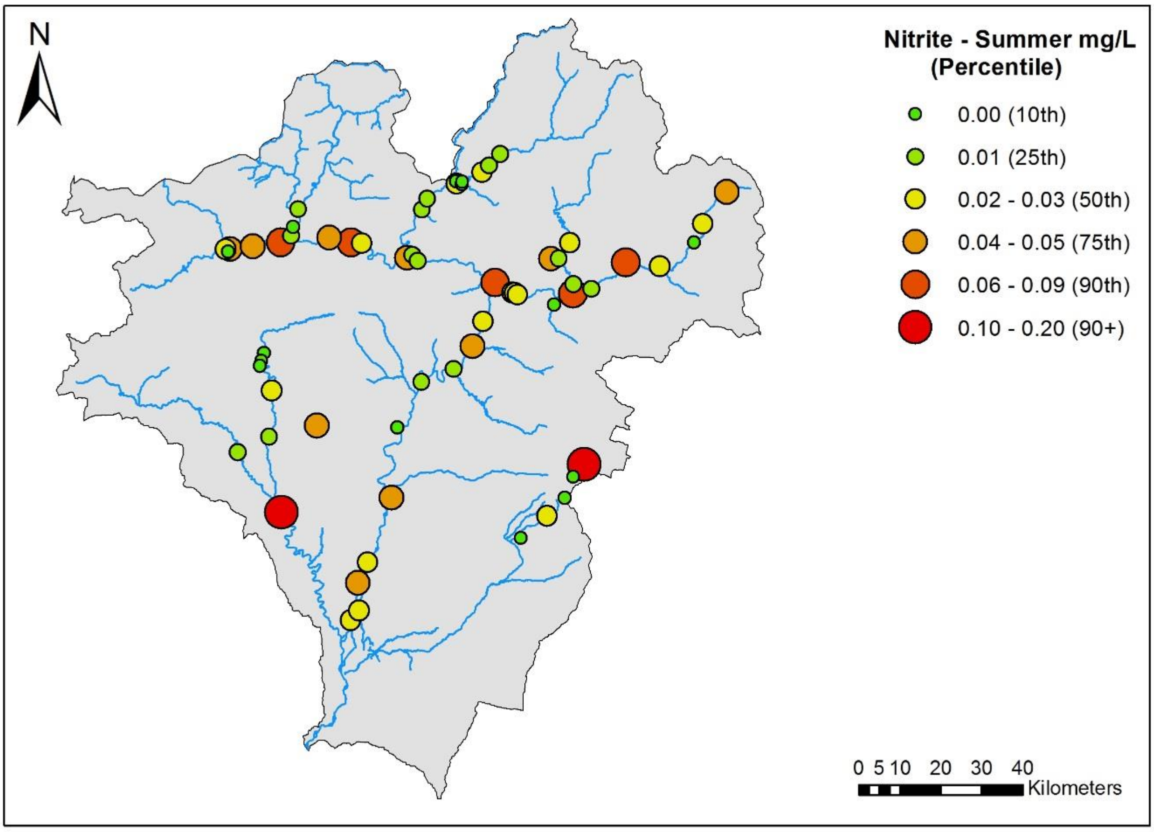

N
Fluoride - Winter mg/L
(Percentile)
0.04 - 0.08 (10th)
0.09 - 0.13 (25th)
0.14 - 0.19 (50th)
0.20 - 0.26 (75th)
0.27 - 0.41 (90th)
0.42 - 0.73 (90+)
0 5 10 20 30 40
Kilometers

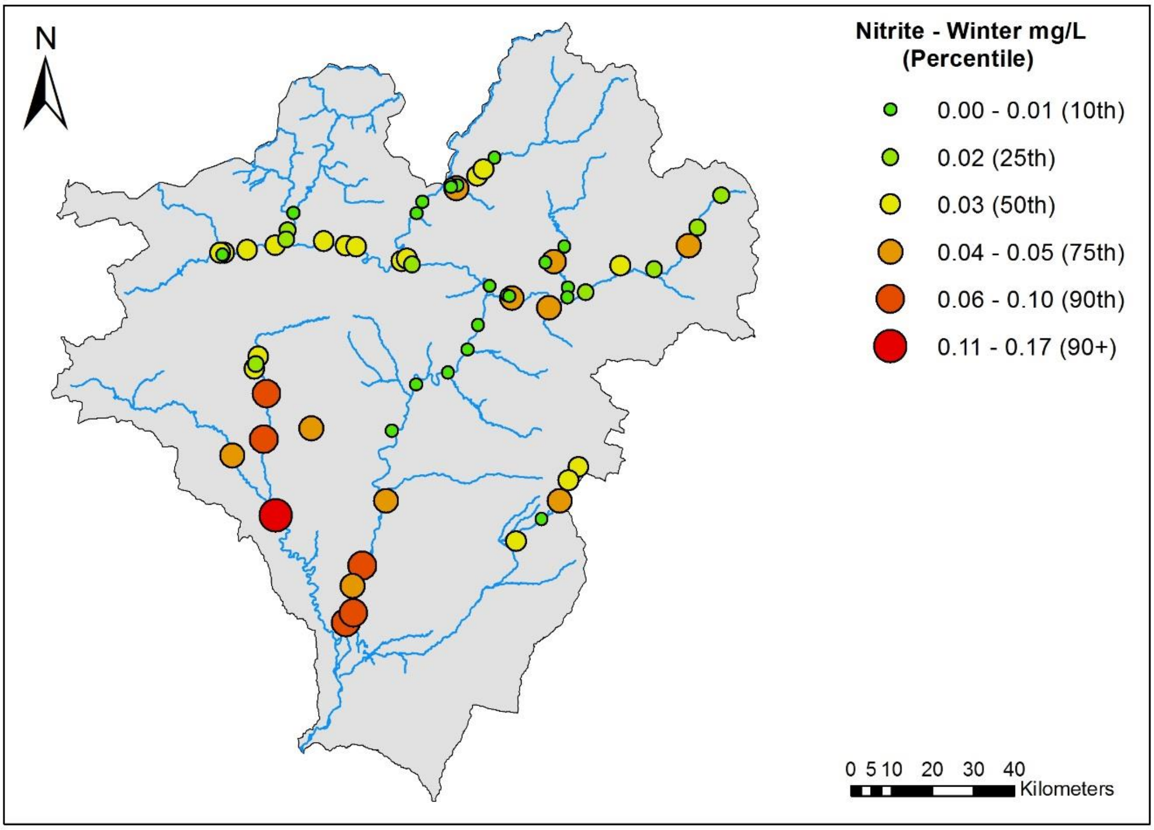

N
Chloride - Summer mg/L
(Percentile)
1 - 2 (10th)
3 (25th)
4 - 7 (50th)
8 - 11 (75th)
12 - 20 (90th)
21 - 52 (90+)
0 5 10 20 30 40
Kilometers

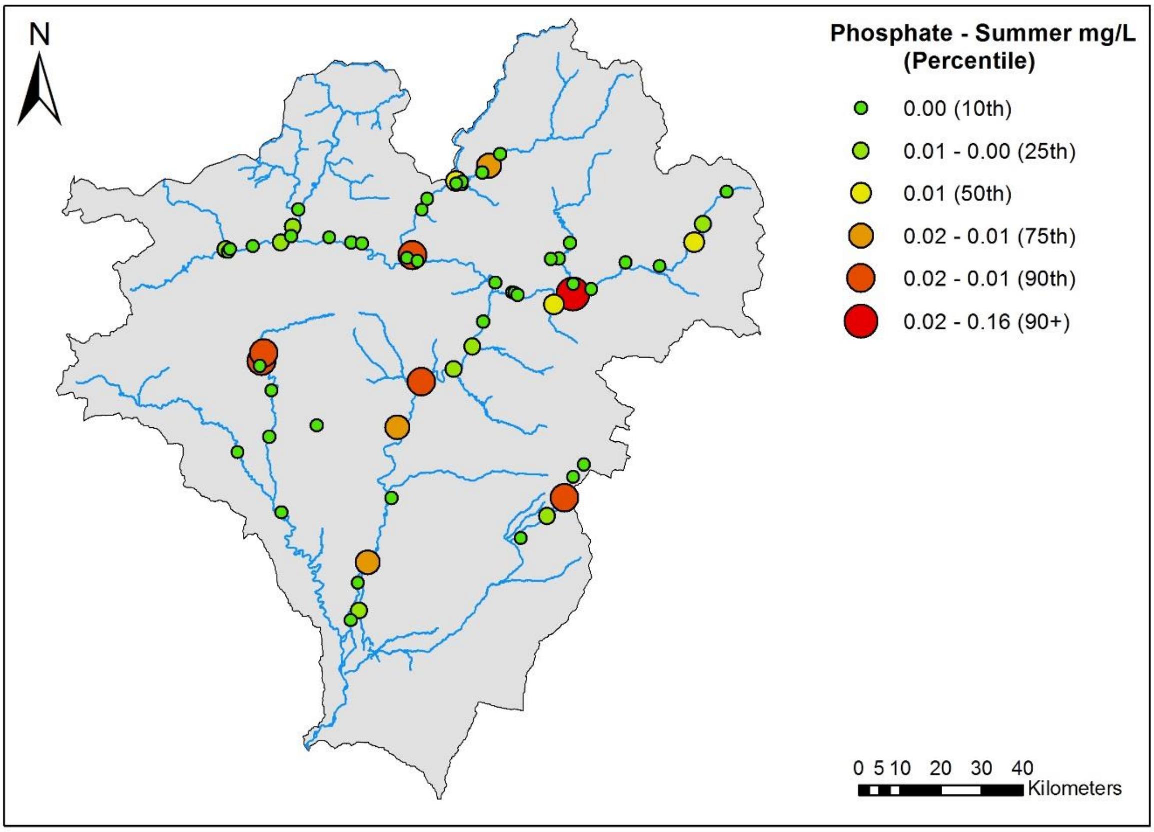

N
Chloride - Winter mg/L
(Percentile)
3 (25th)
4 - 7 (50th)
8 - 11 (75th)
12 - 20 (90th)
21 - 52 (90+)
0 5 10 20 30 40
Kilometers

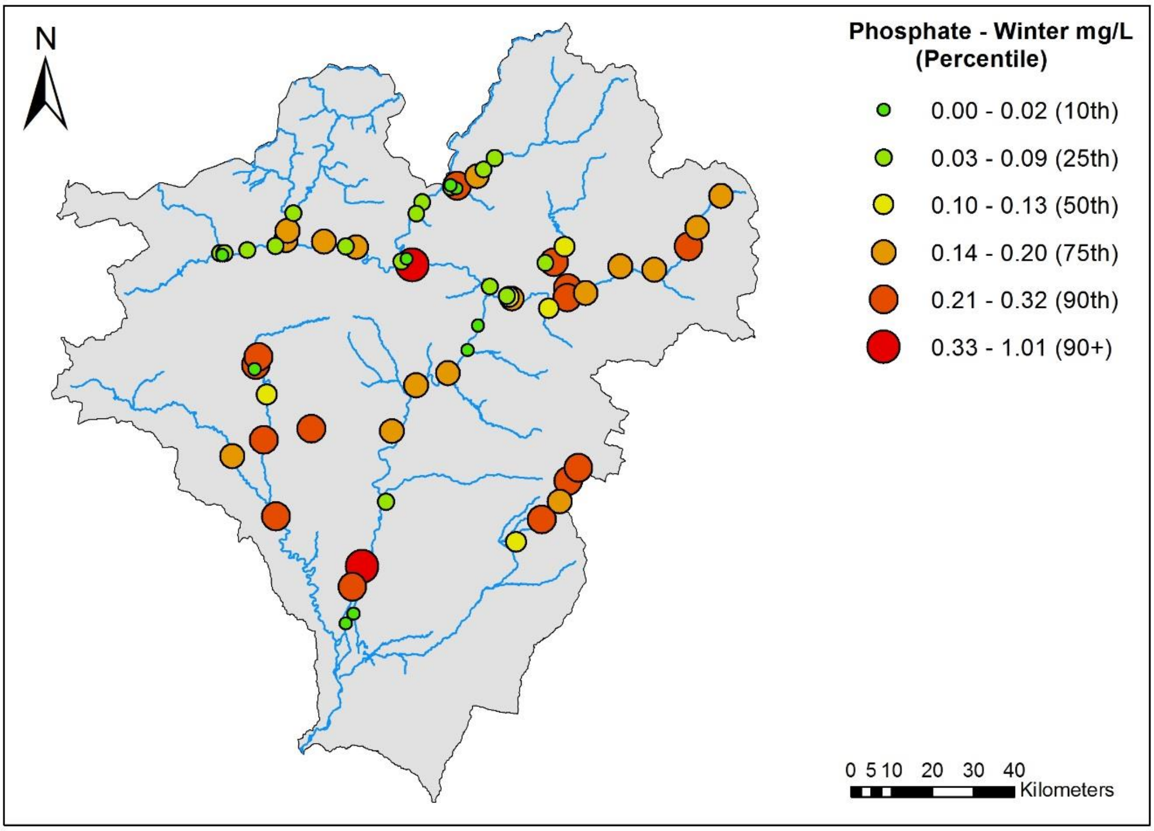

N
Nitrate - Summer mg/L
(Percentile)
0 - 1 (10th)
2 (25th)
3 - 4 (50th)
5 - 7 (75th)
8 - 9 (90th)
10 - 14 (90+)
0 5 10 20 30 40
Kilometers

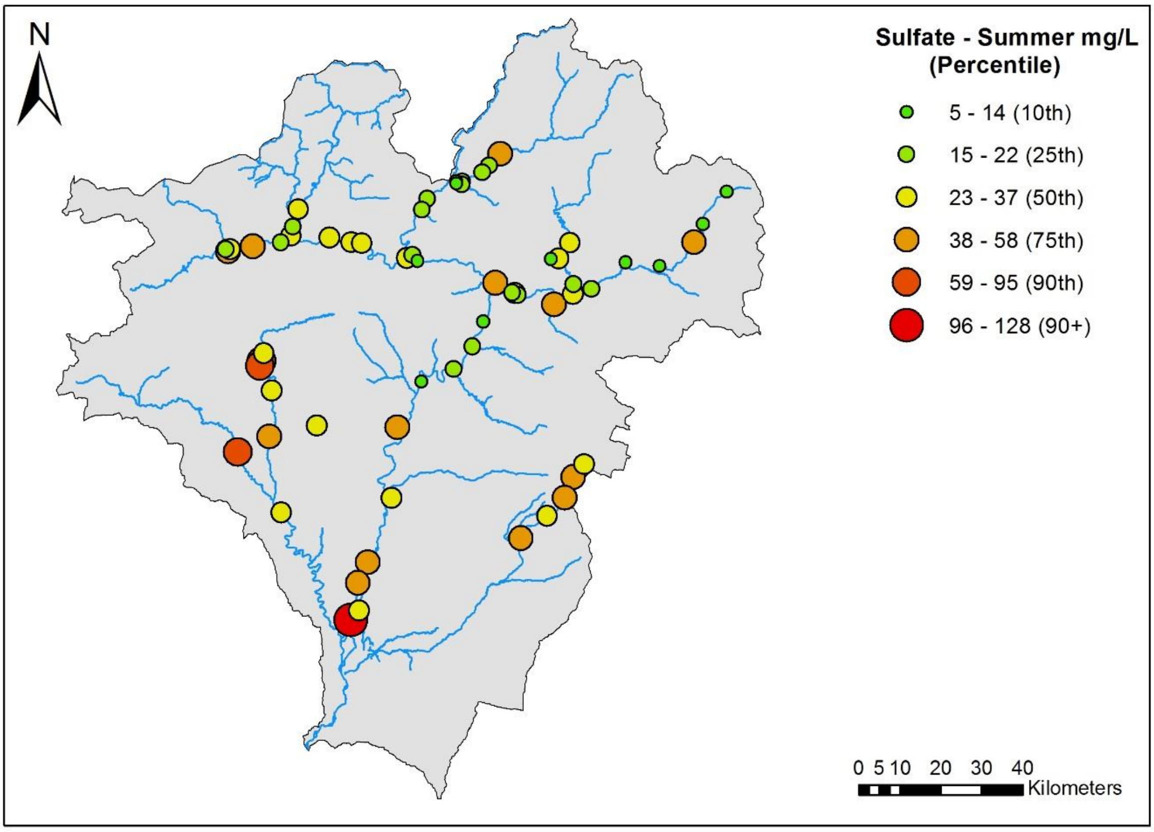

N
Nitrate - Winter mg/L
(Percentile)
0 - 1 (10th)
2 (25th)
3 - 4 (50th)
5 - 7 (75th)
8 - 9 (90th)
10 - 14 (90+)
0 5 10 20 30 40
Kilometers

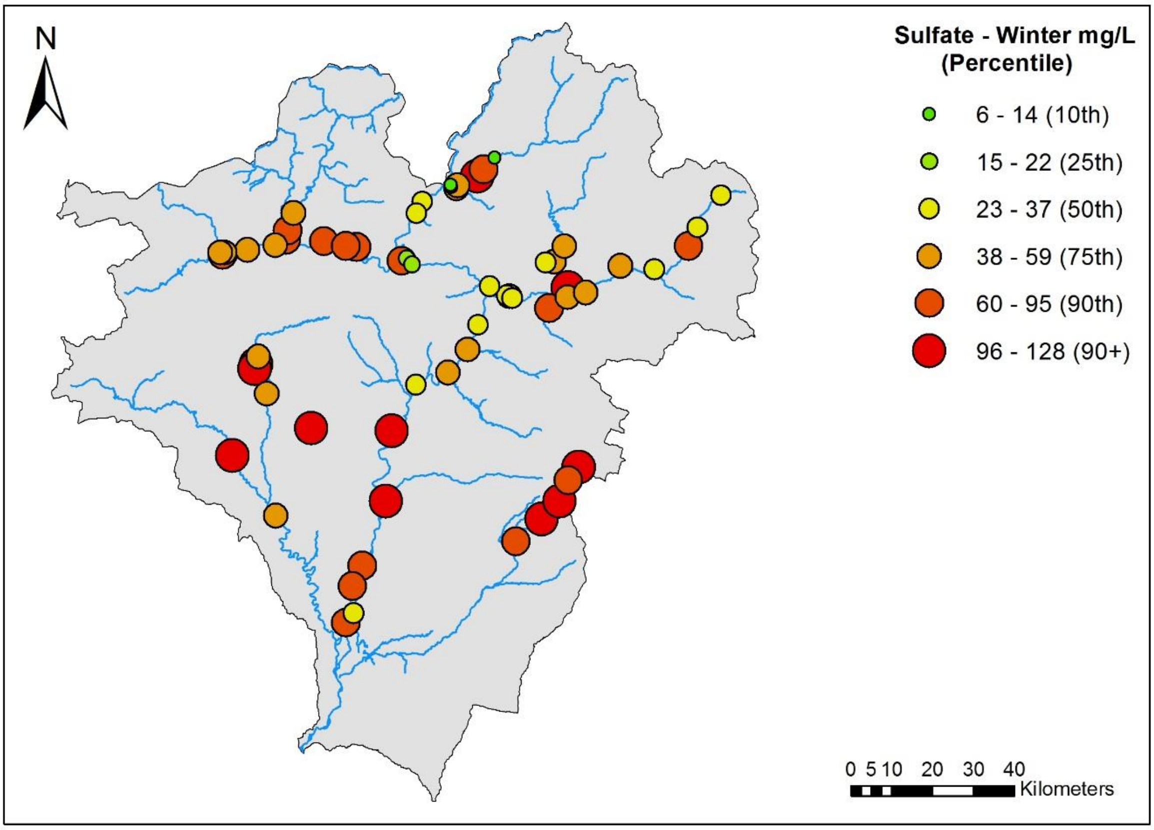

N
Nitrite - Summer mg/L
(Percentile)
0.00 (10th)
0.01 (25th)
0.02 - 0.03 (50th)
0.04 - 0.05 (75th)
0.06 - 0.09 (90th)
0.10 - 0.20 (90+)
0 5 10 20 30 40
Kilometers

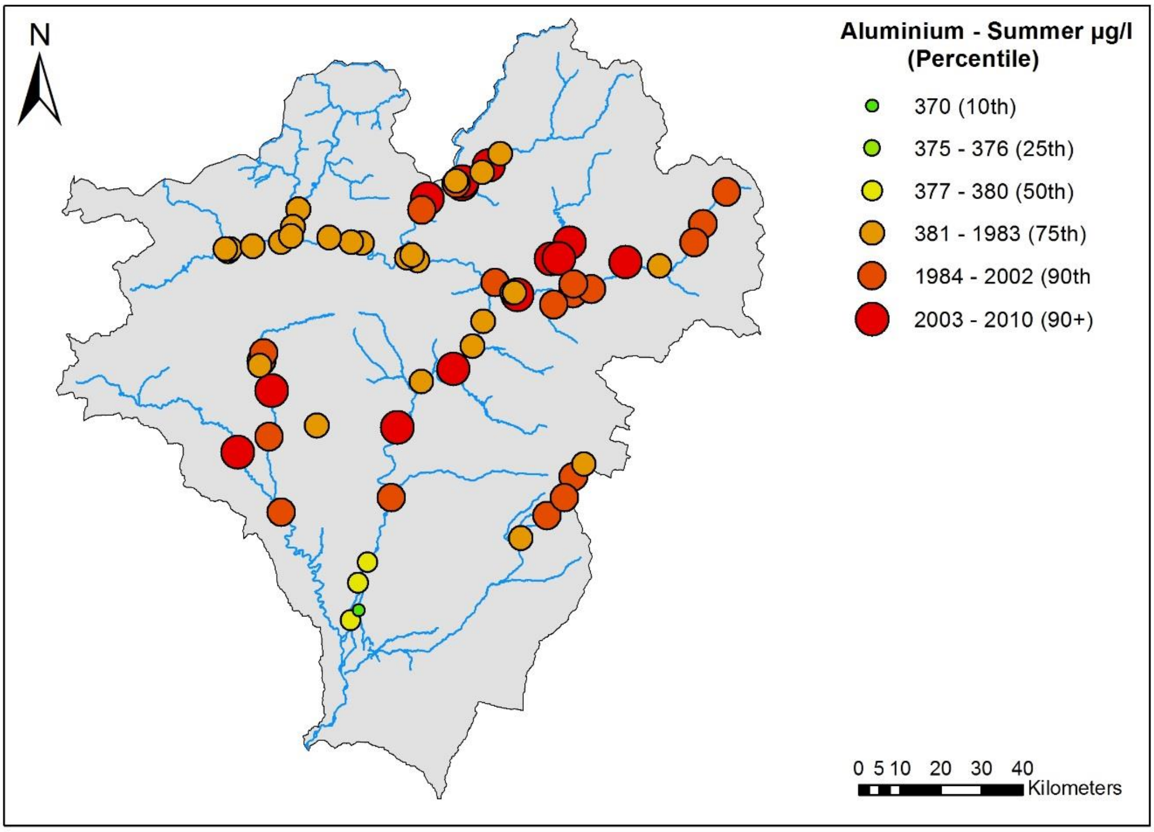

N
Nitrite - Winter mg/L
(Percentile)
0.00 - 0.01 (10th)
0.02 (25th)
0.03 (50th)
0.04 - 0.05 (75th)
0.06 - 0.10 (90th)
0.11 - 0.17 (90+)
0 5 10 20 30 40
Kilometers


N
Phosphate - Summer mg/L
(Percentile)
0.00 (10th)
0.01 - 0.00 (25th)
0.01 (50th)
0.02 - 0.01 (75th)
0.02 - 0.01 (90th)
0.02 - 0.16 (90+)
0 5 10 20 30 40
Kilometers

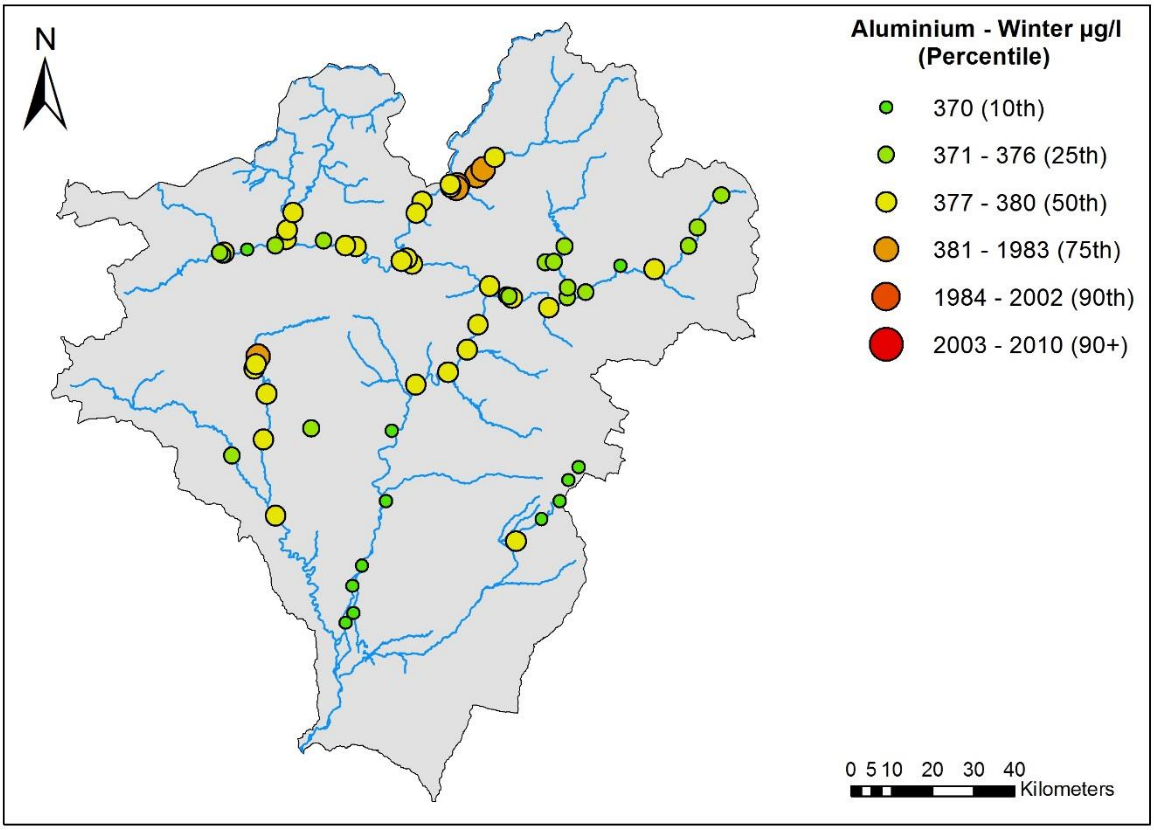

N
Phosphate - Winter mg/L
(Percentile)
0.00 - 0.02 (10th)
0.03 - 0.09 (25th)
0.10 - 0.13 (50th)
0.14 - 0.20 (75th)
0.21 - 0.32 (90th)
0.33 - 1.01 (90+)
0 5 10 20 30 40
Kilometers


N
Sulfate - Summer mg/L
(Percentile)
5 - 14 (10th)
15 - 22 (25th)
23 - 37 (50th)
38 - 58 (75th)
59 - 95 (90th)
96 - 128 (90+)
0 5 10 20 30 40
Kilometers

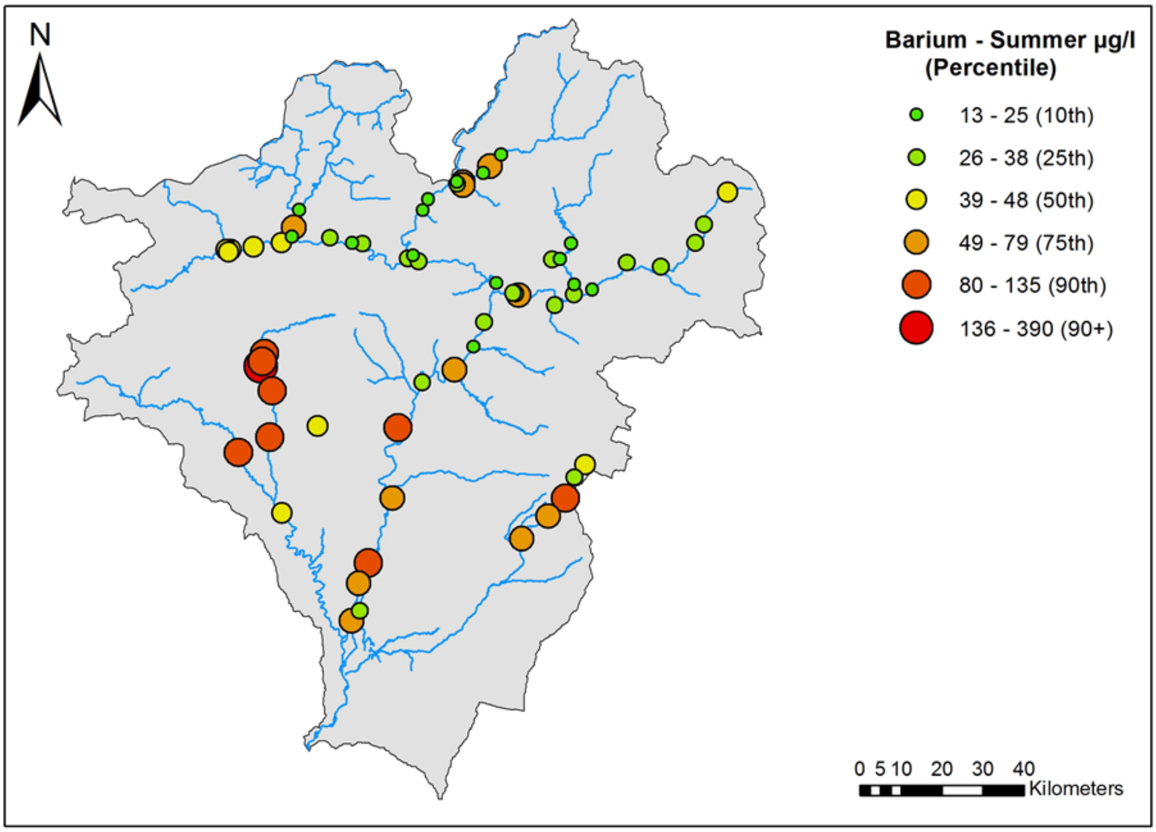

N
Sulfate - Winter mg/L
(Percentile)
6 - 14 (10th)
15 - 22 (25th)
23 - 37 (50th)
38 - 59 (75th)
60 - 95 (90th)
96 - 128 (90+)
0 5 10 20 30 40
Kilometers

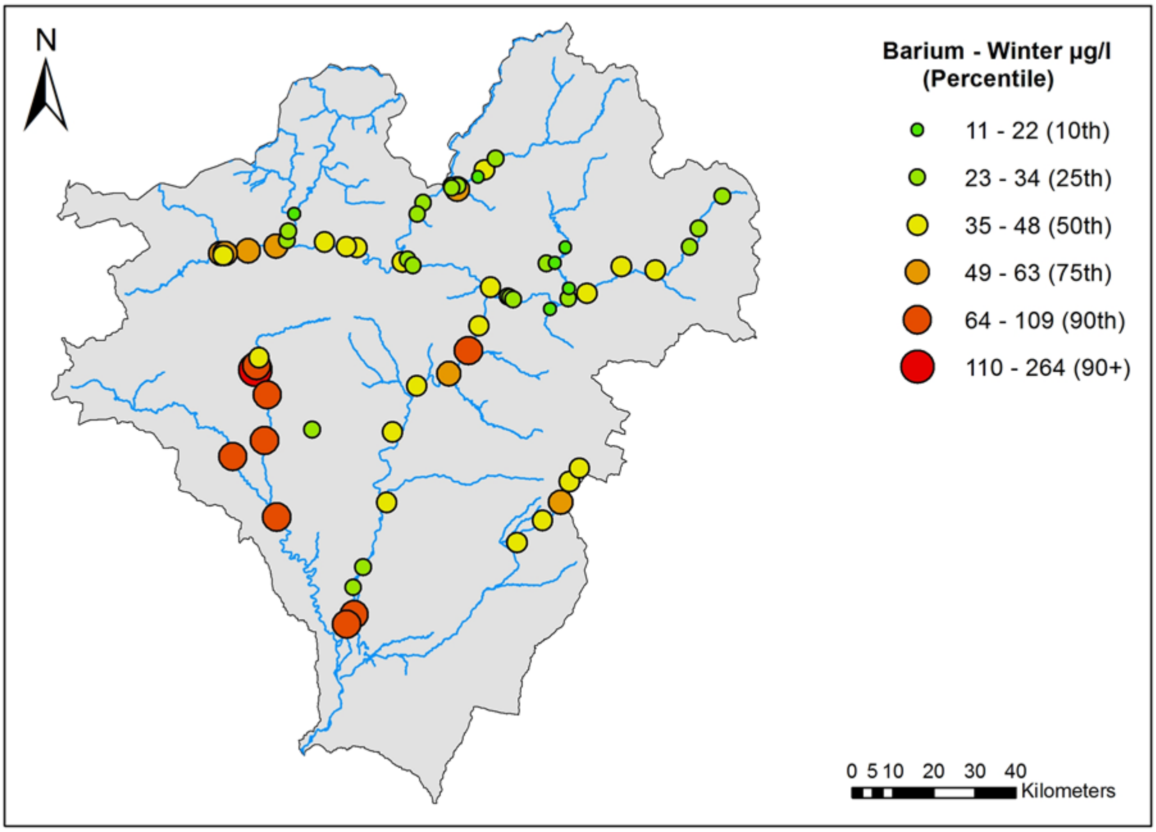


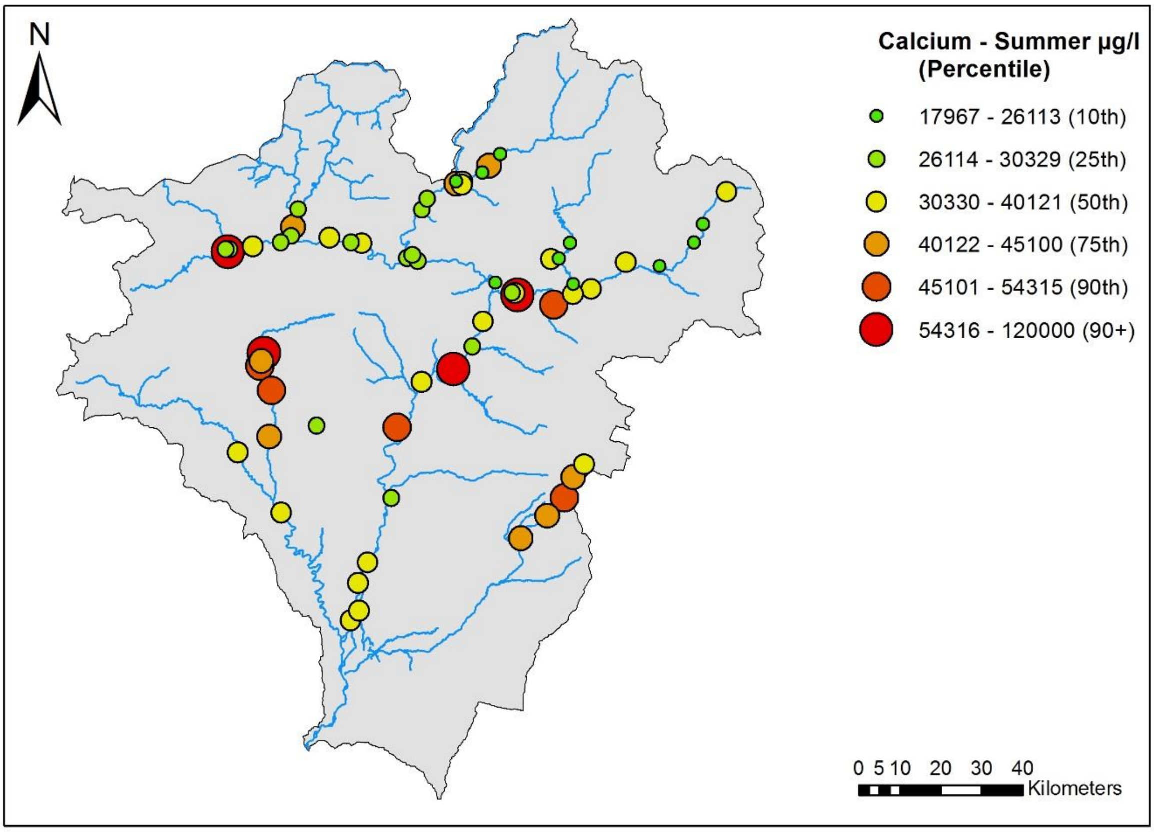
N
Aluminium - Summer µg/l
(Percentile)
370 (10th)
375 - 376 (25th)
377 - 380 (50th)
381 - 1983 (75th)
1984 - 2002 (90th
2003 - 2010 (90+)
0 5 10 20 30 40
Kilometers

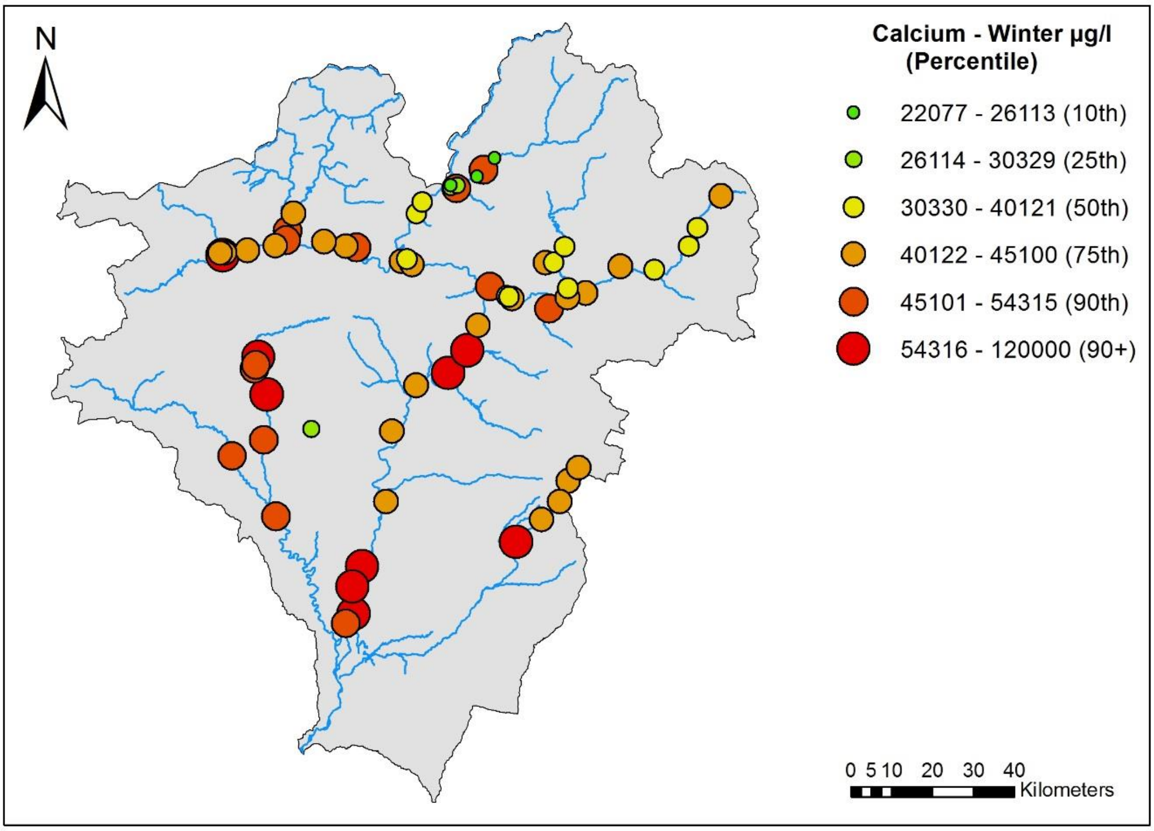


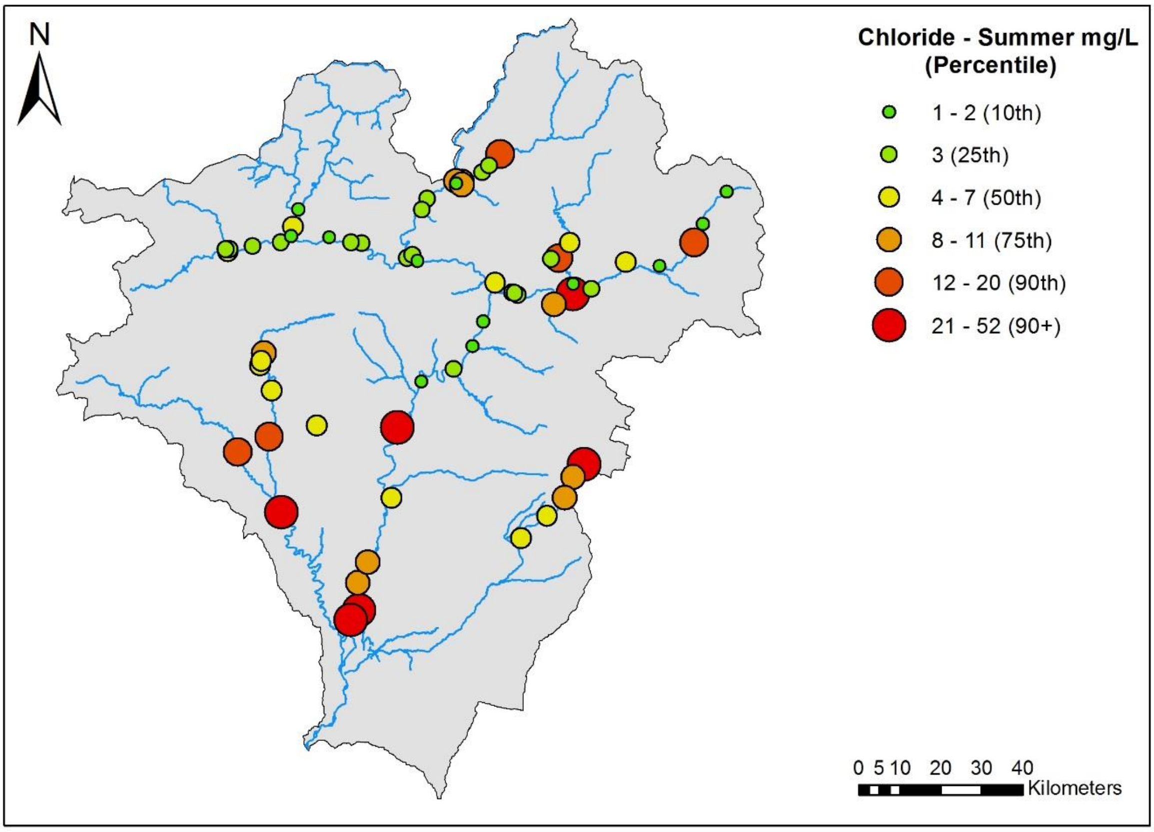
N
Aluminium - Winter µg/l
(Percentile)
370 (10th)
371 - 376 (25th)
377 - 380 (50th)
381 - 1983 (75th)
1984 - 2002 (90th)
2003 - 2010 (90+)
0 5 10 20 30 40
Kilometers

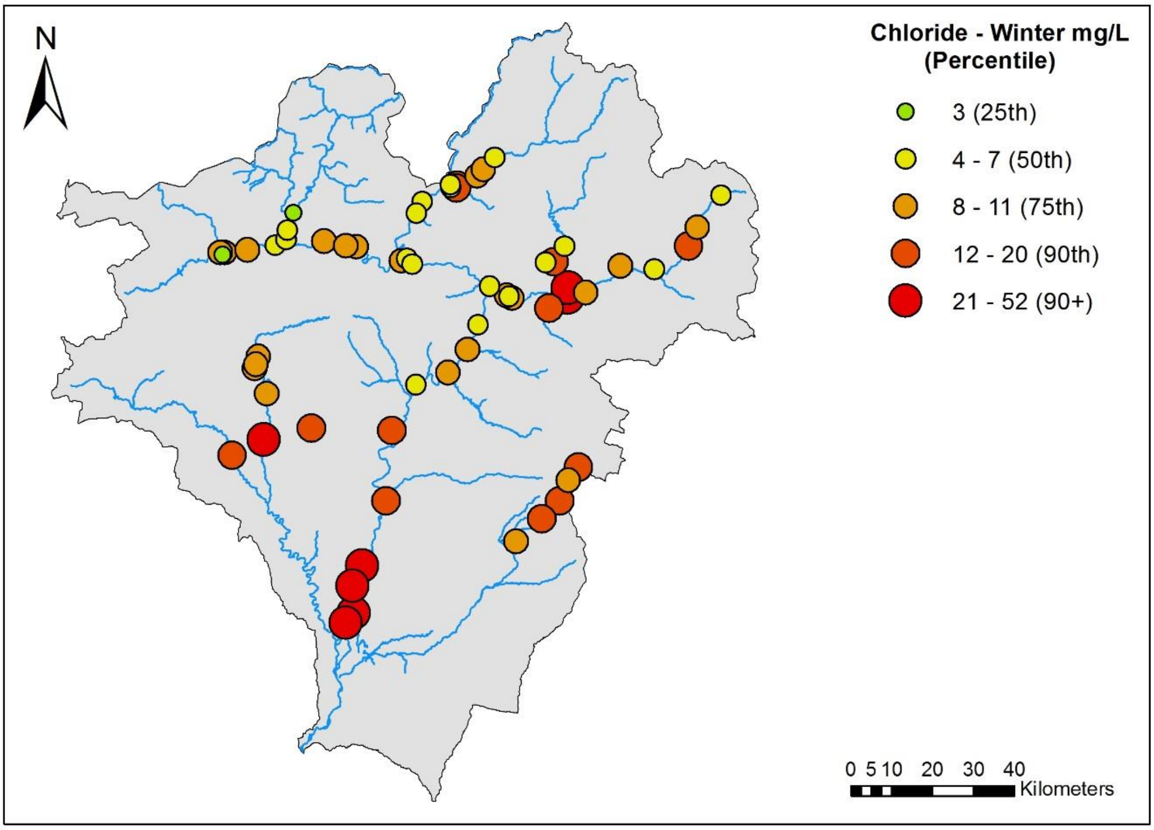

N
Barium - Summer µg/l
(Percentile)
13 - 25 (10th)
26 - 38 (25th)
39 - 48 (50th)
49 - 79 (75th)
80 - 135 (90th)
136 - 390 (90+)
0 5 10 20 30 40
Kilometers

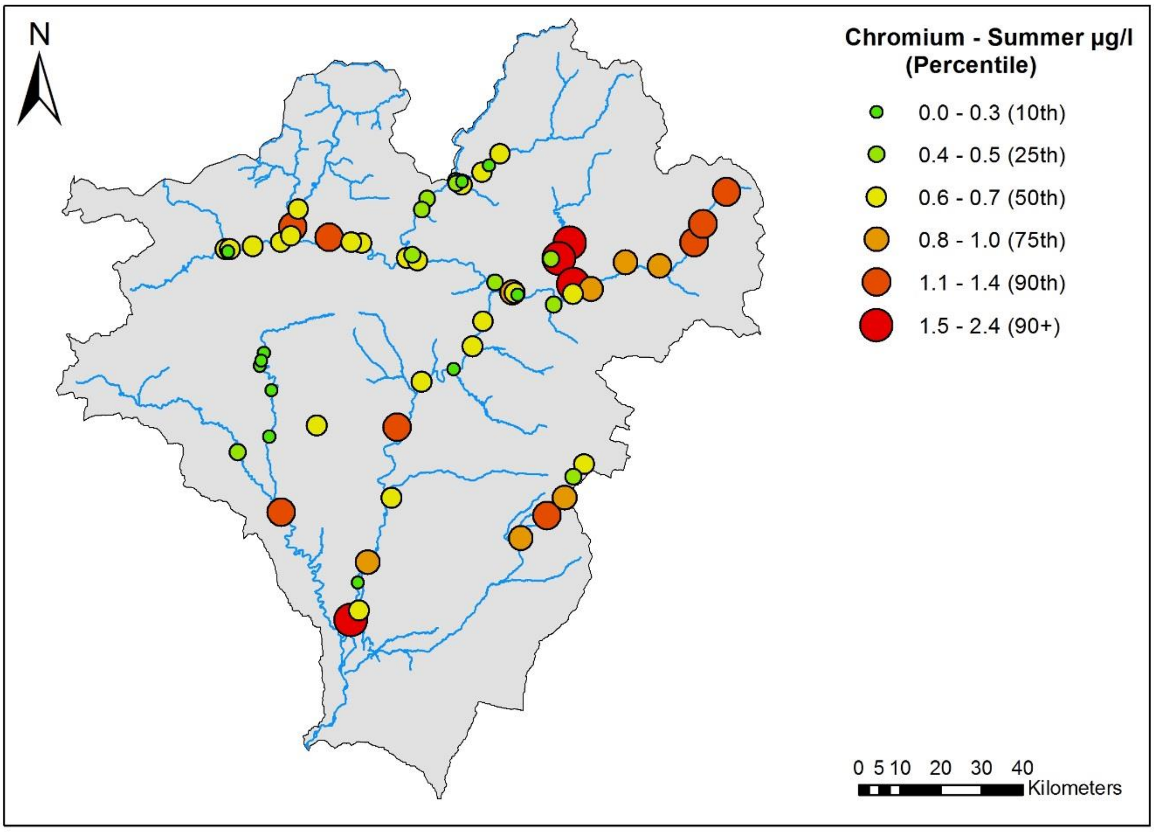

N
Barium - Winter µg/l
(Percentile)
11 - 22 (10th)
23 - 34 (25th)
35 - 48 (50th)
49 - 63 (75th)
64 - 109 (90th)
110 - 264 (90+)
0 5 10 20 30 40
Kilometers

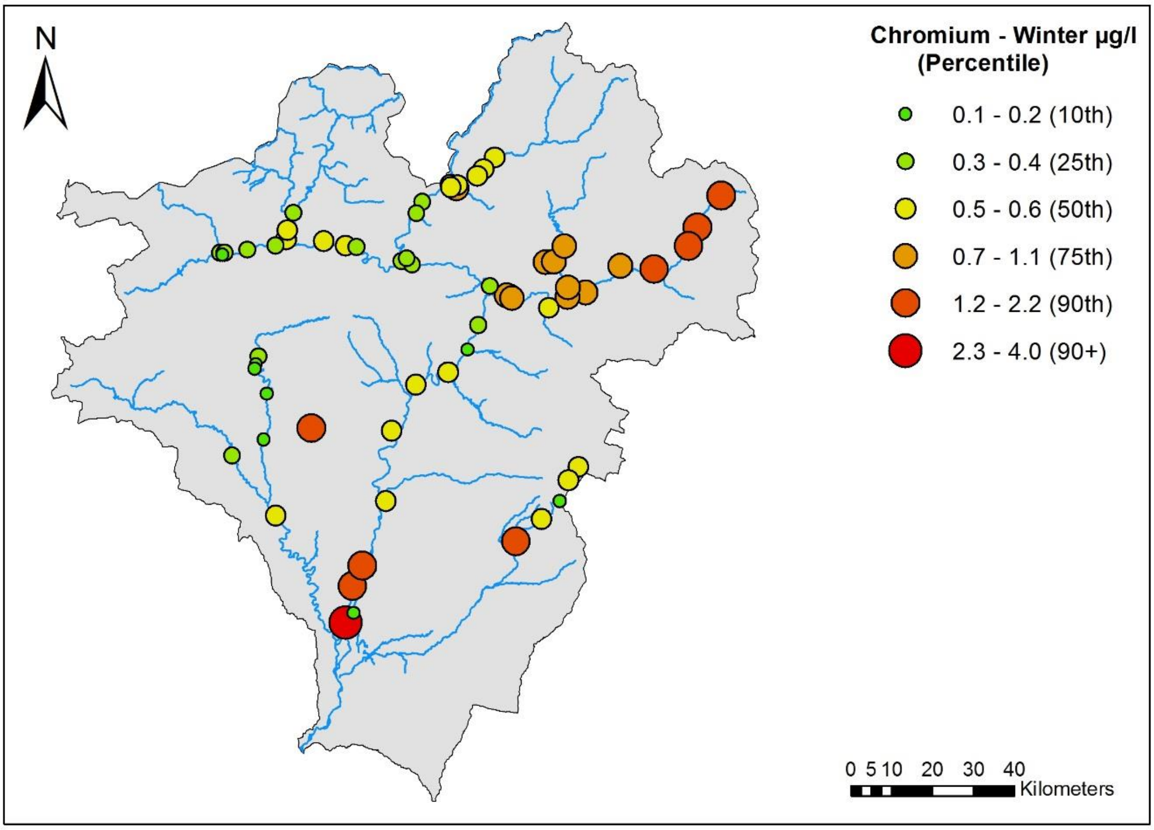

N
Calcium - Summer µg/l
(Percentile)
17967 - 26113 (10th)
26114 - 30329 (25th)
30330 - 40121 (50th)
40122 - 45100 (75th)
45101 - 54315 (90th)
54316 - 120000 (90+)
0 5 10 20 30 40
Kilometers

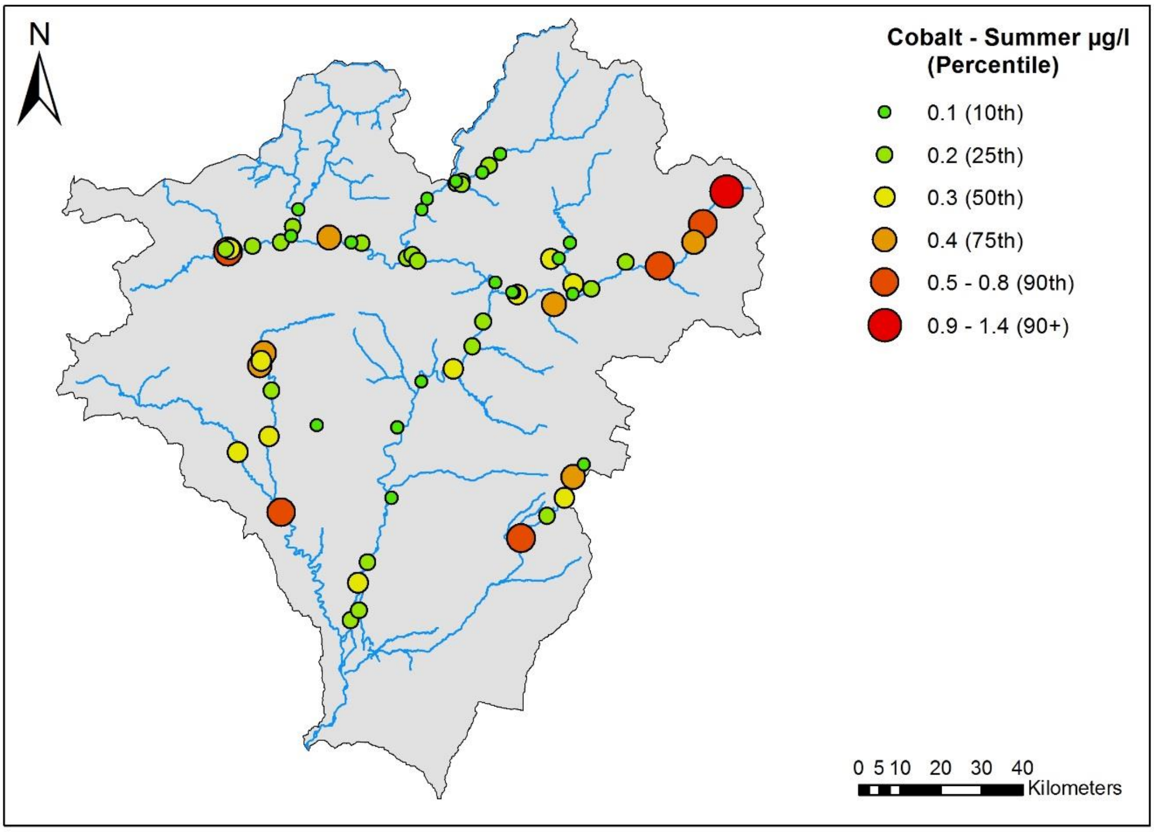

N
Calcium - Winter µg/l
(Percentile)
22077 - 26113 (10th)
26114 - 30329 (25th)
30330 - 40121 (50th)
40122 - 45100 (75th)
45101 - 54315 (90th)
54316 - 120000 (90+)
0 5 10 20 30 40
Kilometers

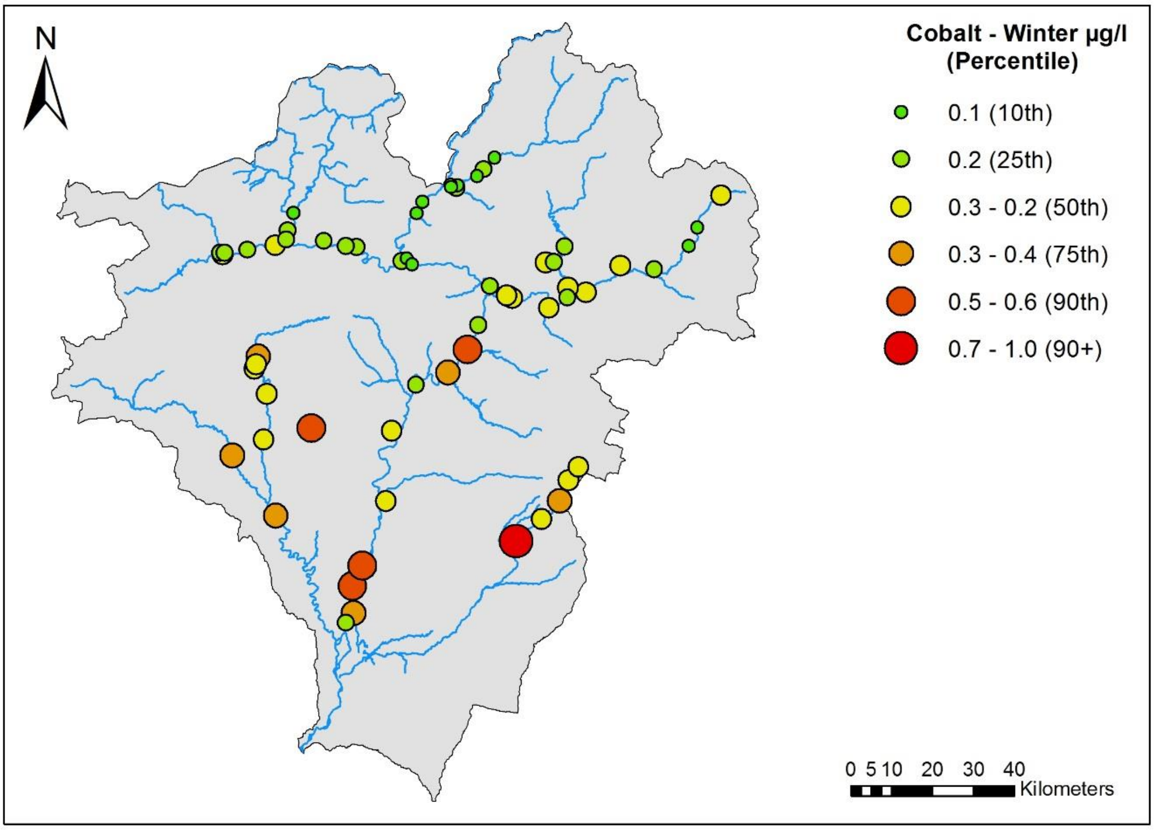

N
Chloride - Summer mg/L
(Percentile)
1 - 2 (10th)
3 (25th)
4 - 7 (50th)
8 - 11 (75th)
12 - 20 (90th)
21 - 52 (90+)
0 5 10 20 30 40
Kilometers

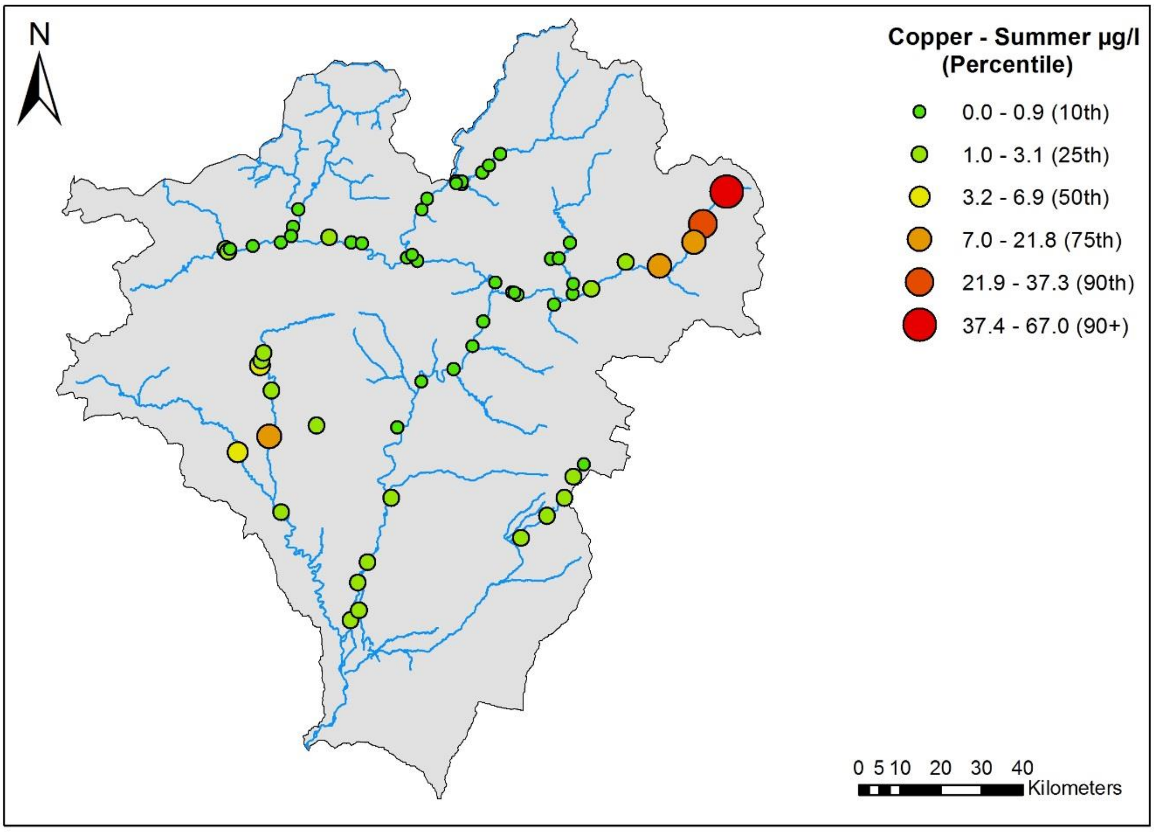

N
Chloride - Winter mg/L
(Percentile)
3 (25th)
4 - 7 (50th)
8 - 11 (75th)
12 - 20 (90th)
21 - 52 (90+)
0 5 10 20 30 40
Kilometers

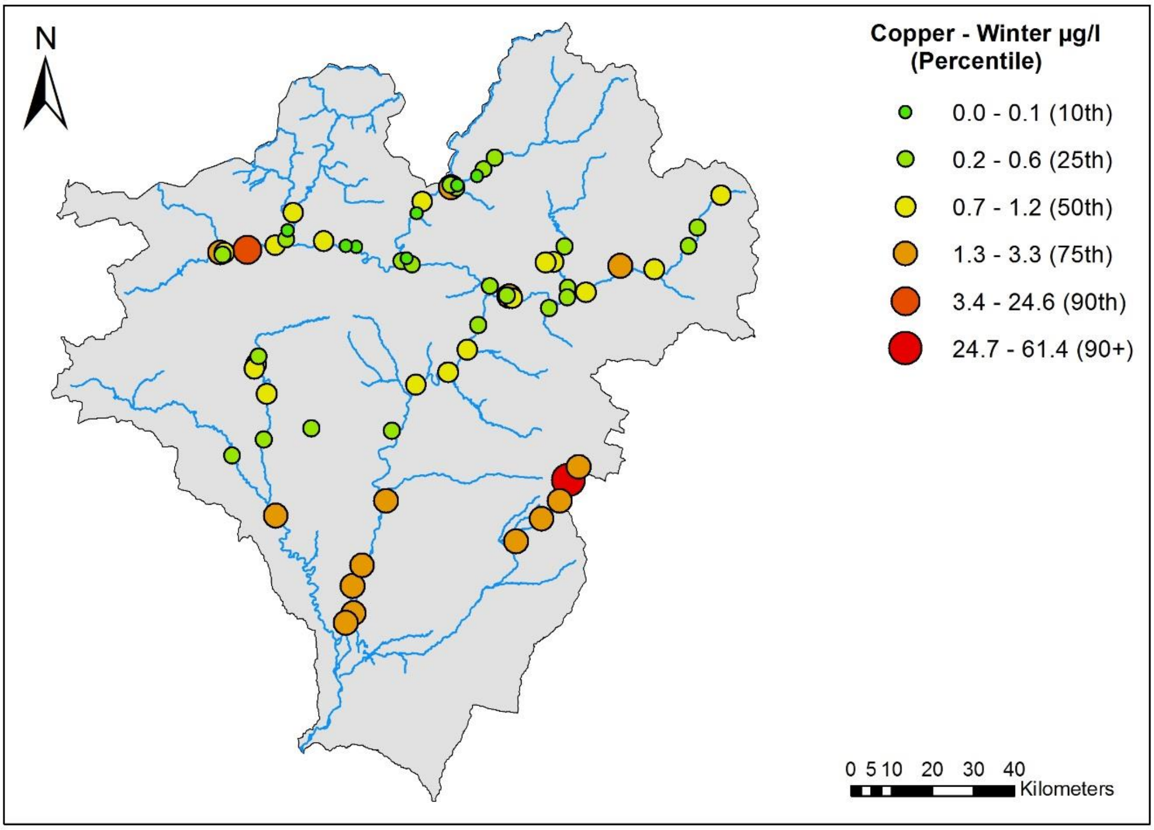

N
Chromium - Summer µg/l
(Percentile)
0.0 - 0.3 (10th)
0.4 - 0.5 (25th)
0.6 - 0.7 (50th)
0.8 - 1.0 (75th)
1.1 - 1.4 (90th)
1.5 - 2.4 (90+)
0 5 10 20 30 40
Kilometers

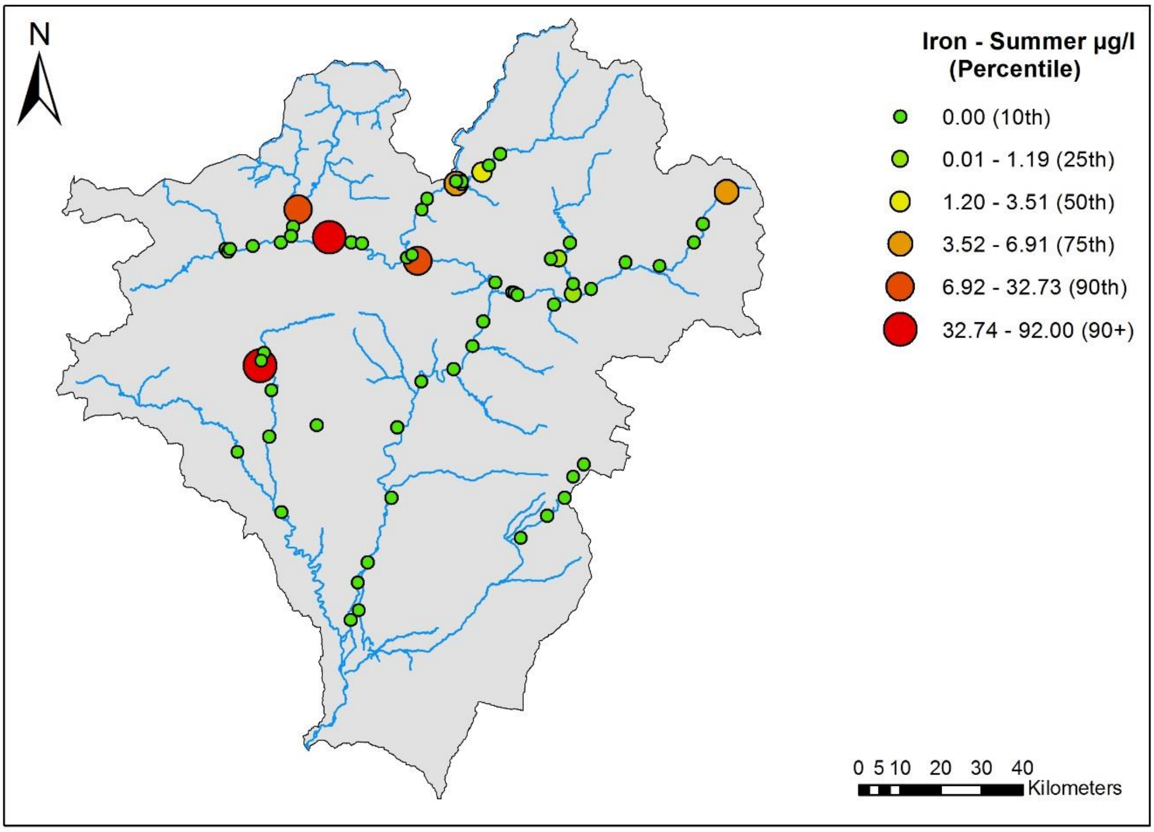

N
Chromium - Winter µg/l
(Percentile)
0.1 - 0.2 (10th)
0.3 - 0.4 (25th)
0.5 - 0.6 (50th)
0.7 - 1.1 (75th)
1.2 - 2.2 (90th)
2.3 - 4.0 (90+)
0 5 10 20 30 40
Kilometers

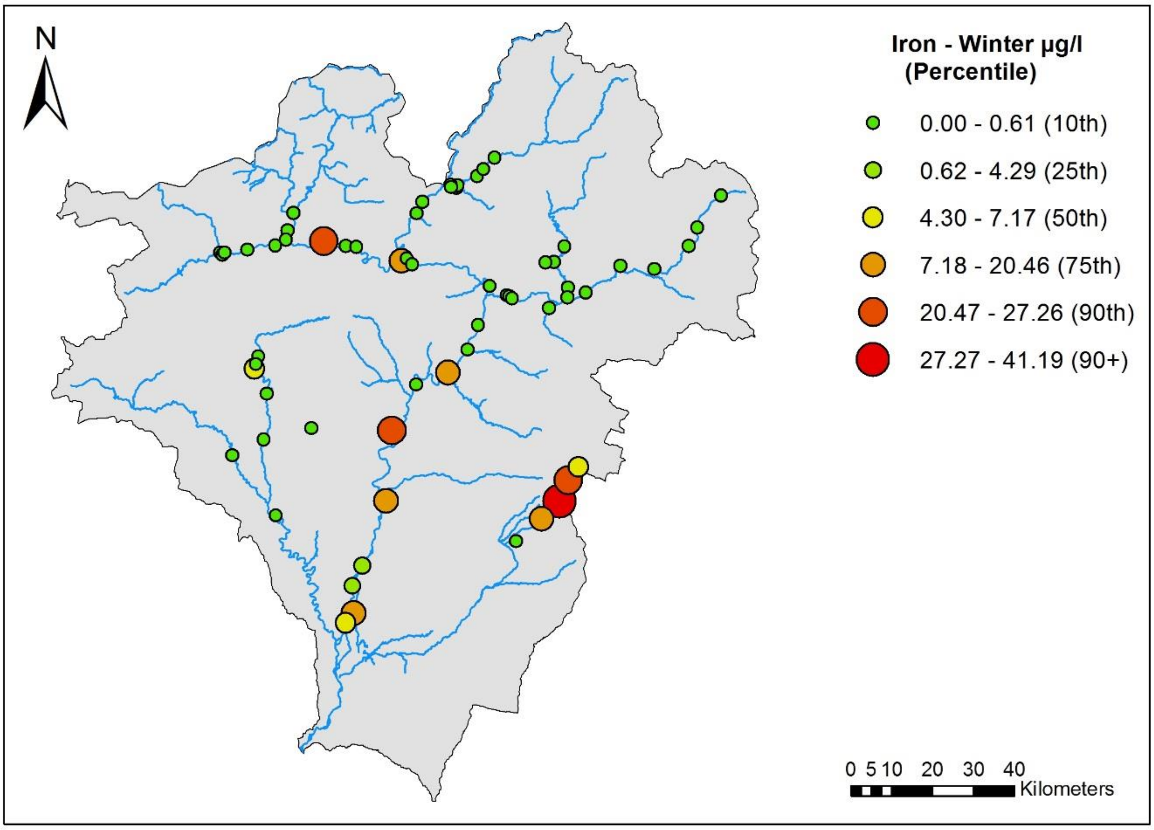

N
Cobalt - Summer µg/l
(Percentile)
0.1 (10th)
0.2 (25th)
0.3 (50th)
0.4 (75th)
0.5 - 0.8 (90th)
0.9 - 1.4 (90+)
0 5 10 20 30 40
Kilometers

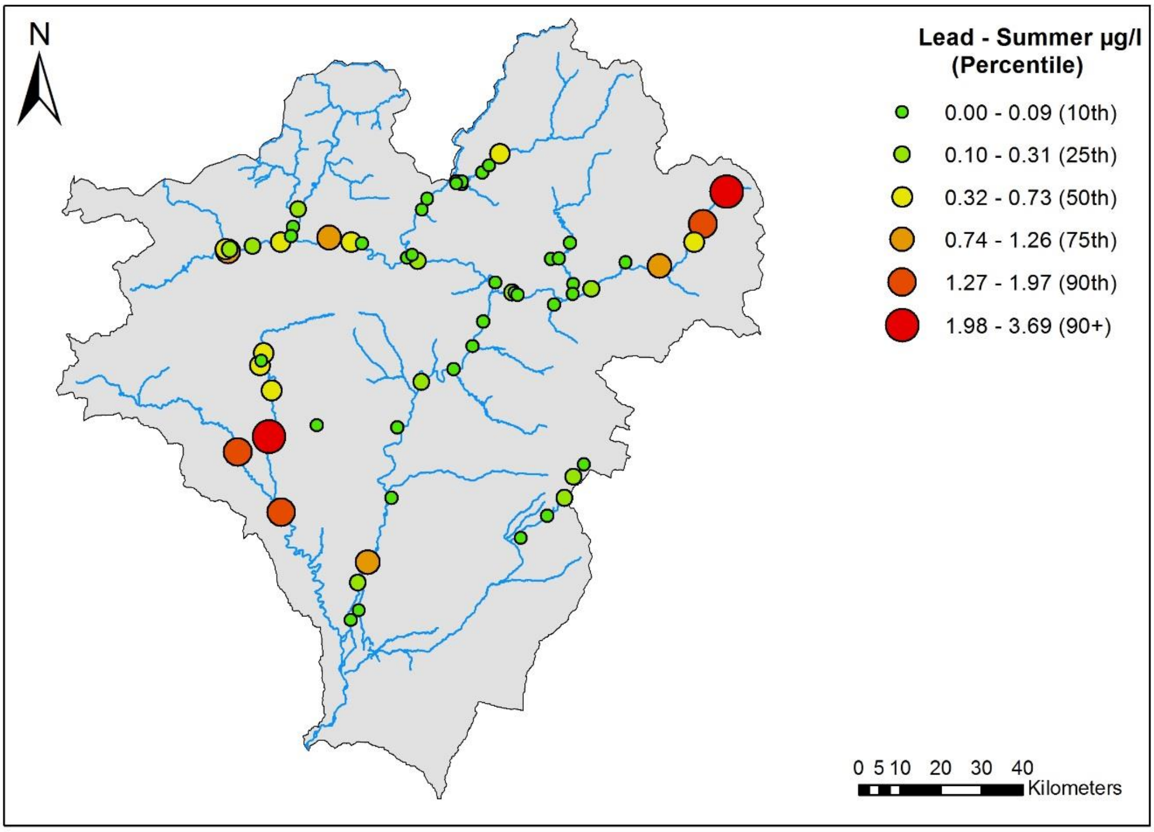

N
Cobalt - Winter µg/l
(Percentile)
0.1 (10th)
0.2 (25th)
0.3 - 0.2 (50th)
0.3 - 0.4 (75th)
0.5 - 0.6 (90th)
0.7 - 1.0 (90+)
0 5 10 20 30 40
Kilometers

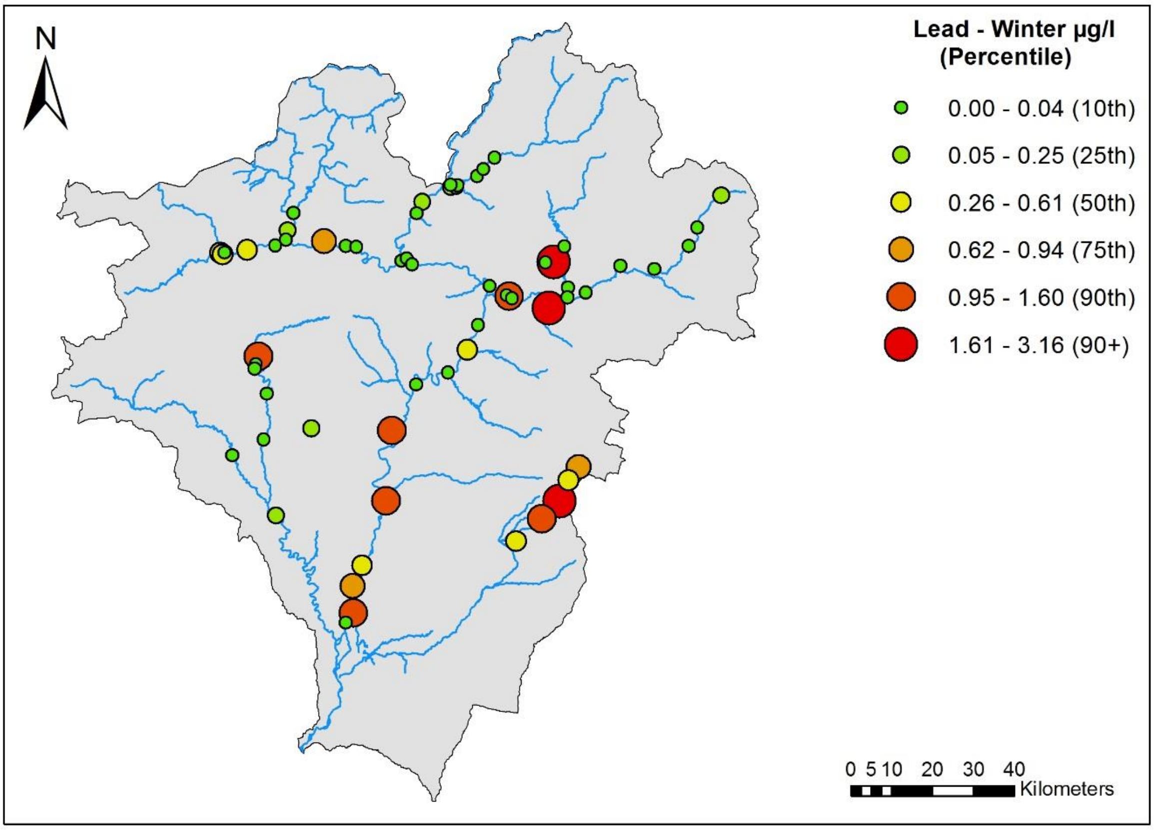

N
Copper - Summer µg/l
(Percentile)
0.0 - 0.9 (10th)
1.0 - 3.1 (25th)
3.2 - 6.9 (50th)
7.0 - 21.8 (75th)
21.9 - 37.3 (90th)
37.4 - 67.0 (90+)
0 5 10 20 30 40
Kilometers

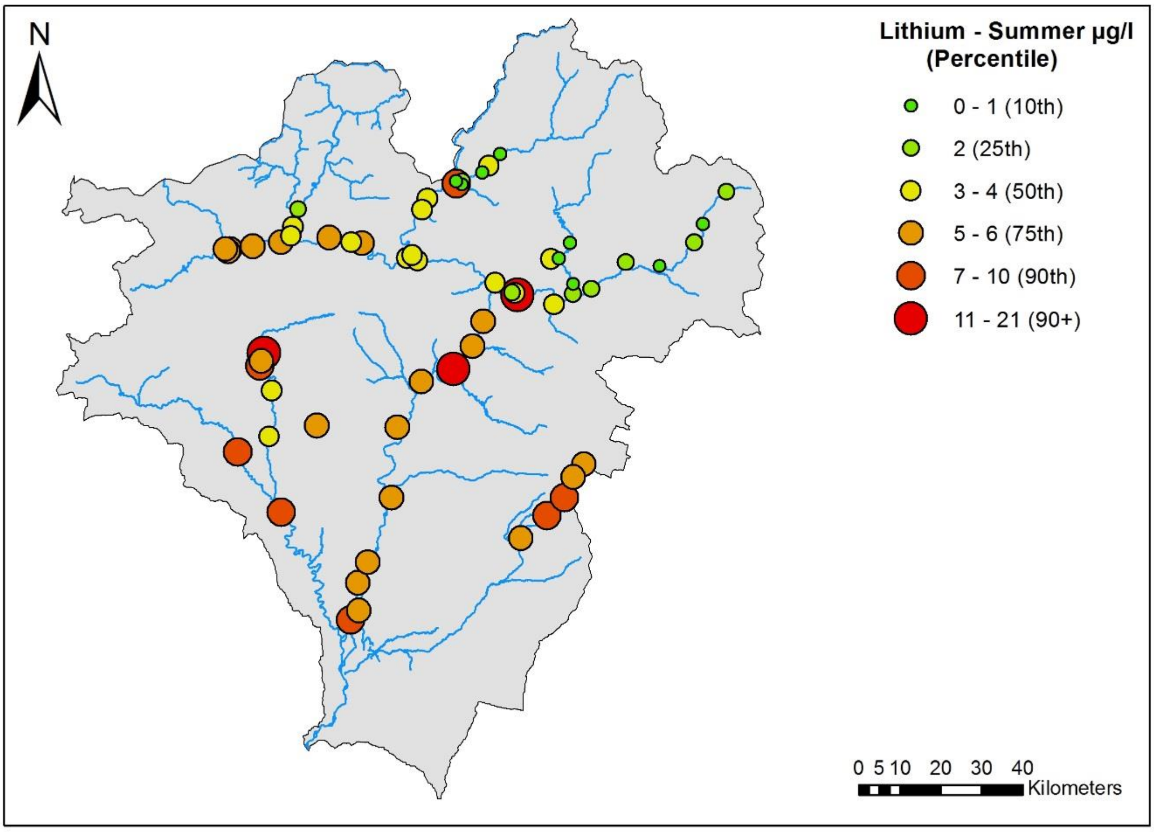

N
Copper - Winter µg/l
(Percentile)
0.0 - 0.1 (10th)
0.2 - 0.6 (25th)
0.7 - 1.2 (50th)
1.3 - 3.3 (75th)
3.4 - 24.6 (90th)
24.7 - 61.4 (90+)
0 5 10 20 30 40
Kilometers

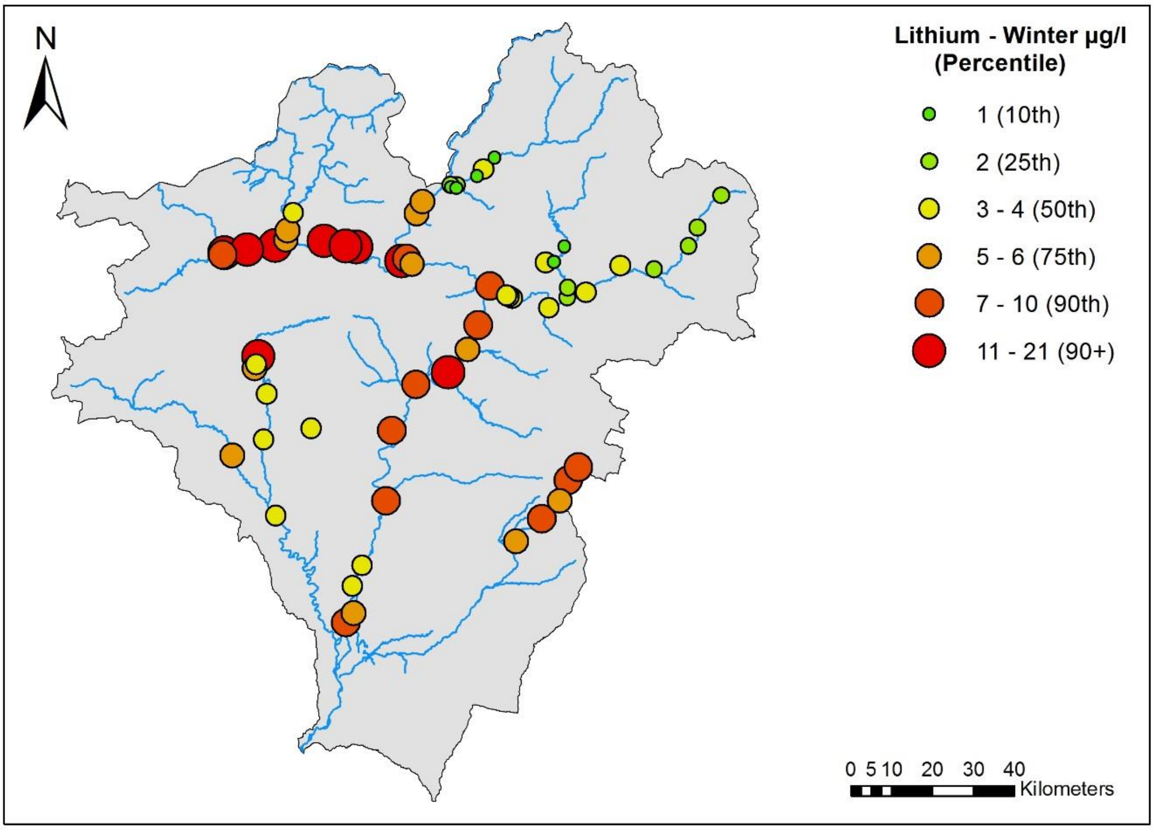

N
Iron - Summer µg/l
(Percentile)
0.00 (10th)
0.01 - 1.19 (25th)
1.20 - 3.51 (50th)
3.52 - 6.91 (75th)
6.92 - 32.73 (90th)
32.74 - 92.00 (90+)
0 5 10 20 30 40
Kilometers

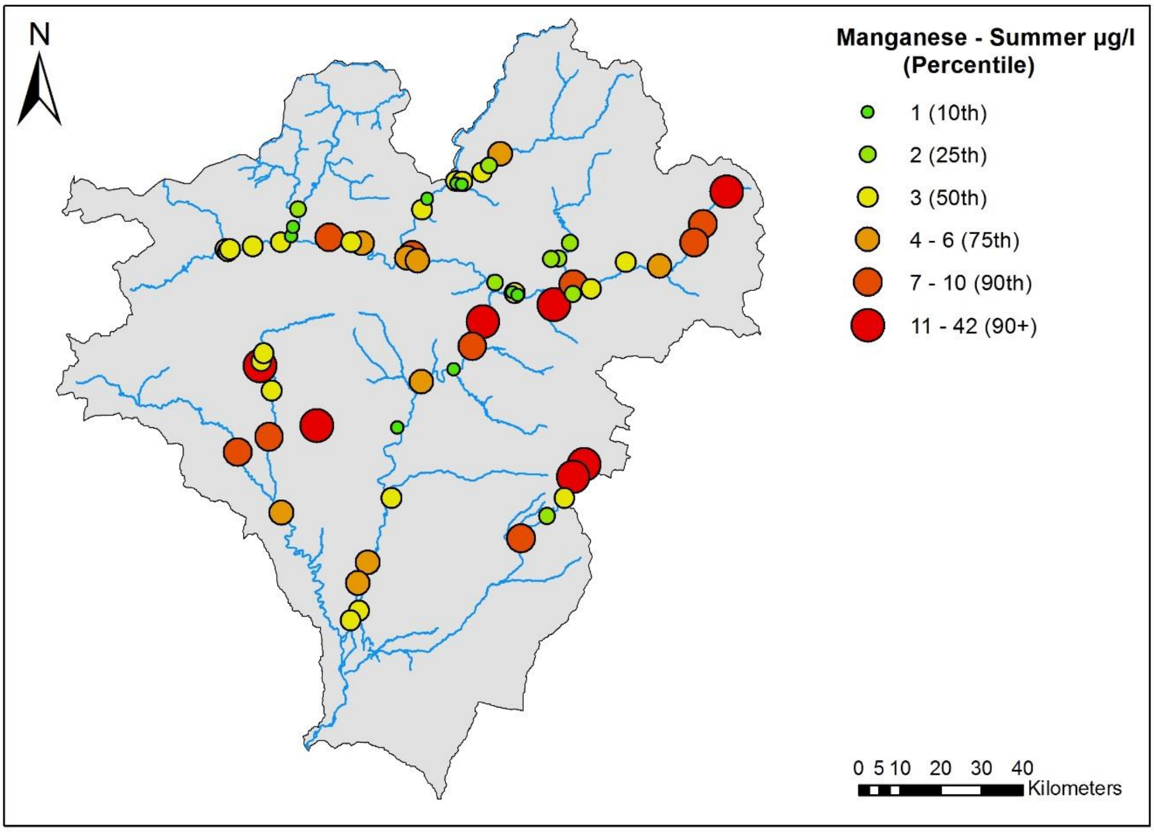

N
Iron - Winter µg/l
(Percentile)
0.00 - 0.61 (10th)
0.62 - 4.29 (25th)
4.30 - 7.17 (50th)
7.18 - 20.46 (75th)
20.47 - 27.26 (90th)
27.27 - 41.19 (90+)
0 5 10 20 30 40
Kilometers

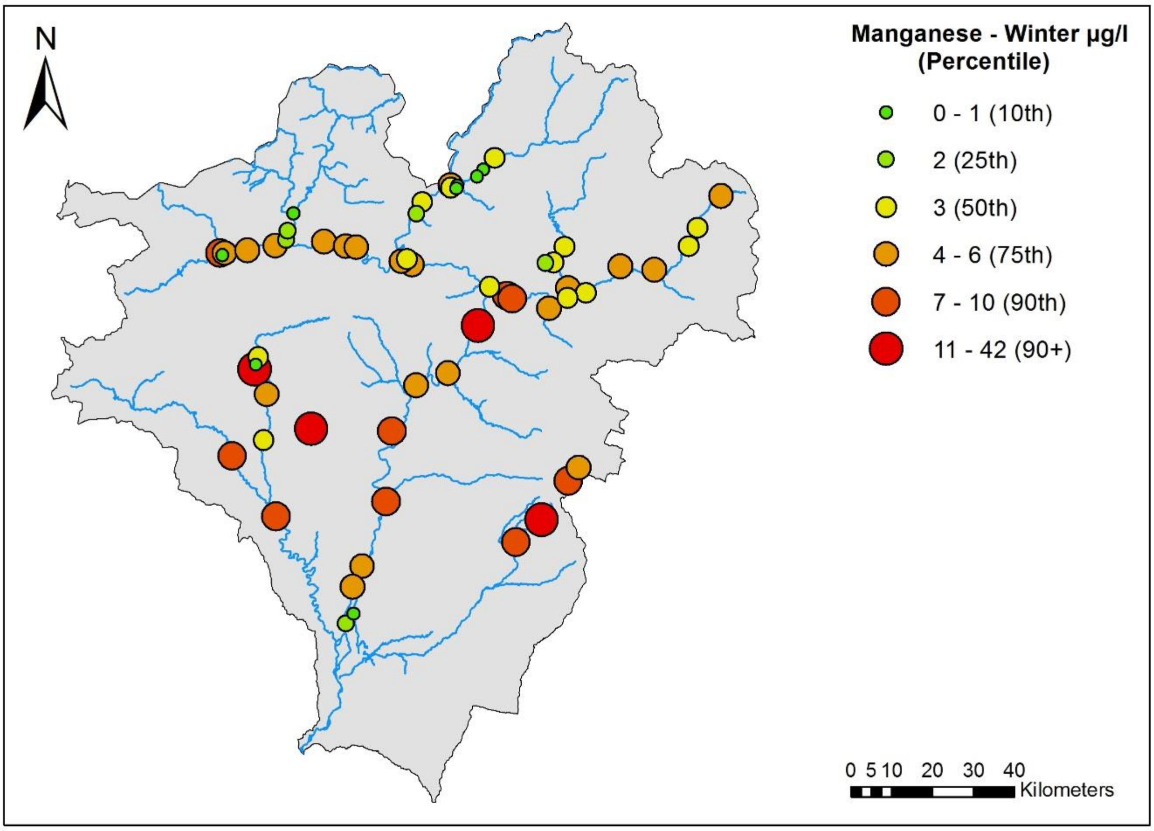

N
Lead - Summer µg/l
(Percentile)
0.00 - 0.09 (10th)
0.10 - 0.31 (25th)
0.32 - 0.73 (50th)
0.74 - 1.26 (75th)
1.27 - 1.97 (90th)
1.98 - 3.69 (90+)
0 5 10 20 30 40
Kilometers

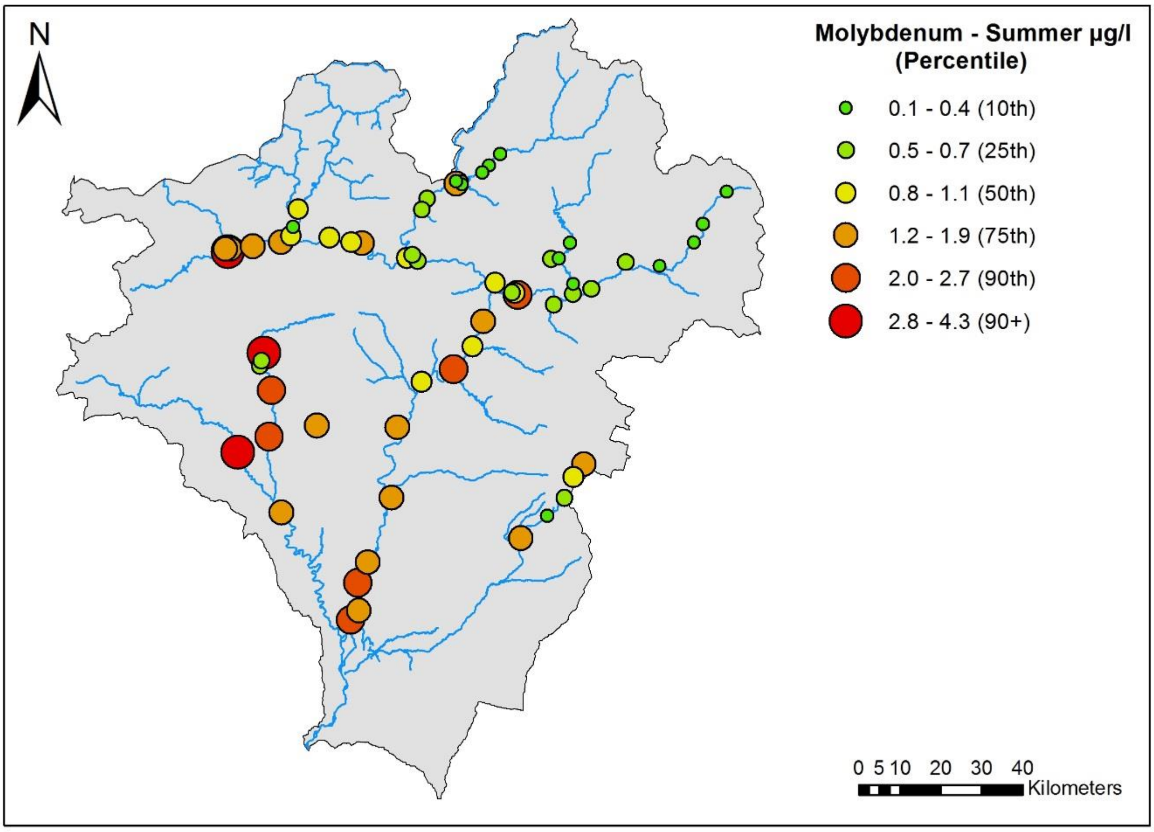

N
Lead - Winter µg/l
(Percentile)
0.00 - 0.04 (10th)
0.05 - 0.25 (25th)
0.26 - 0.61 (50th)
0.62 - 0.94 (75th)
0.95 - 1.60 (90th)
1.61 - 3.16 (90+)
0 5 10 20 30 40
Kilometers

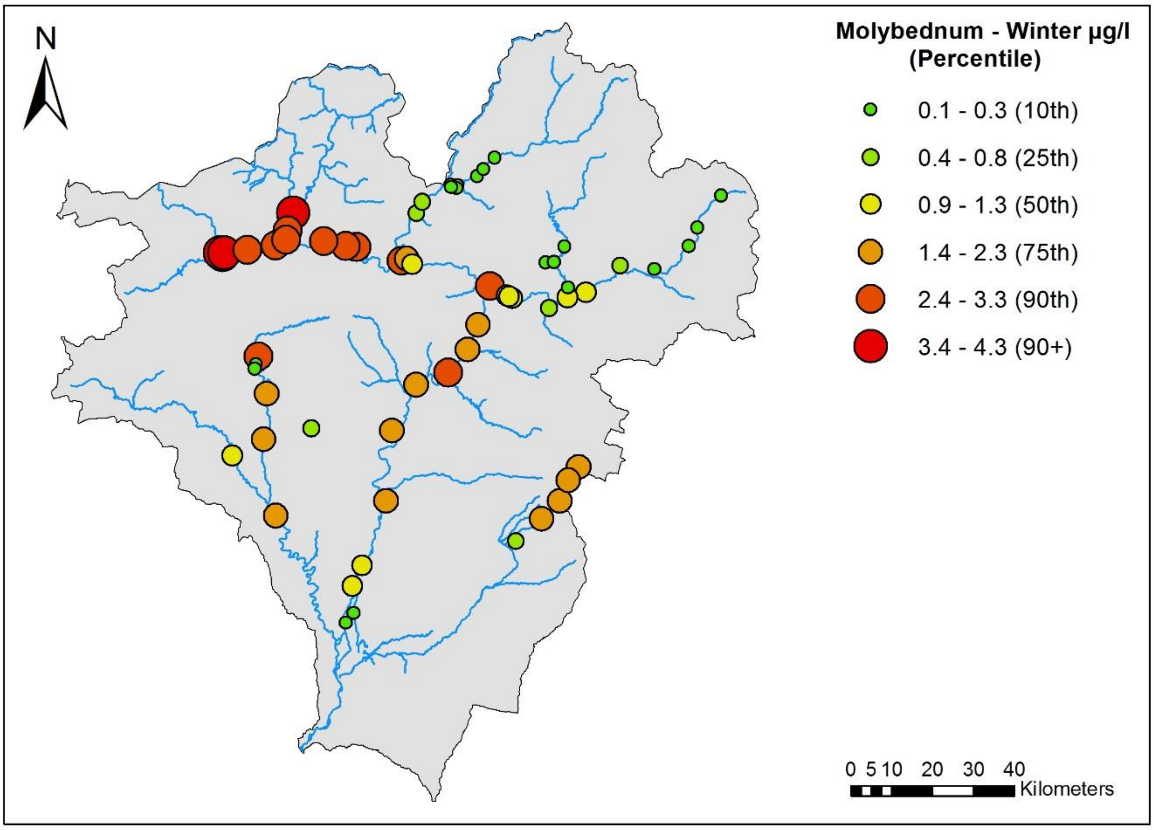

N
Lithium - Summer µg/l
(Percentile)
0 - 1 (10th)
2 (25th)
3 - 4 (50th)
5 - 6 (75th)
7 - 10 (90th)
11 - 21 (90+)
0 5 10 20 30 40
Kilometers

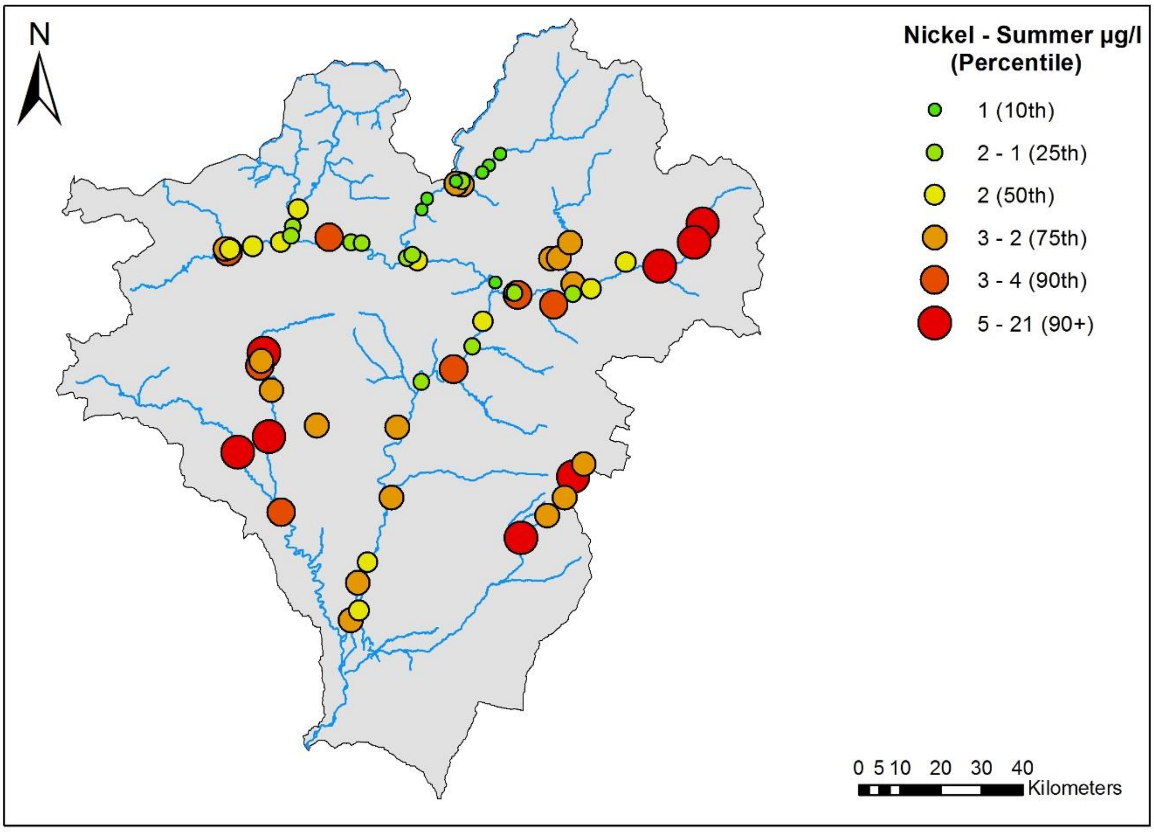

N
Lithium - Winter µg/l
(Percentile)
1 (10th)
2 (25th)
3 - 4 (50th)
5 - 6 (75th)
7 - 10 (90th)
11 - 21 (90+)
0 5 10 20 30 40
Kilometers

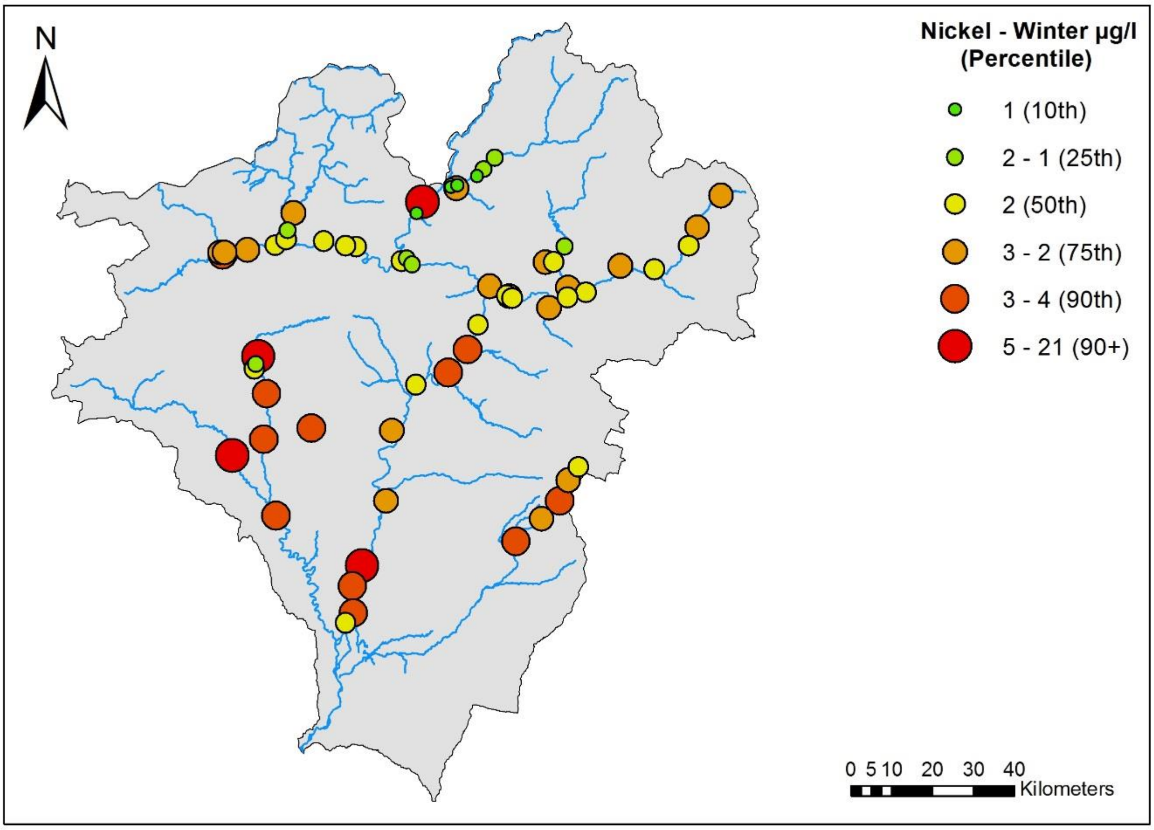

N
Manganese - Summer µg/l
(Percentile)
1 (10th)
2 (25th)
3 (50th)
4 - 6 (75th)
7 - 10 (90th)
11 - 42 (90+)
0 5 10 20 30 40
Kilometers

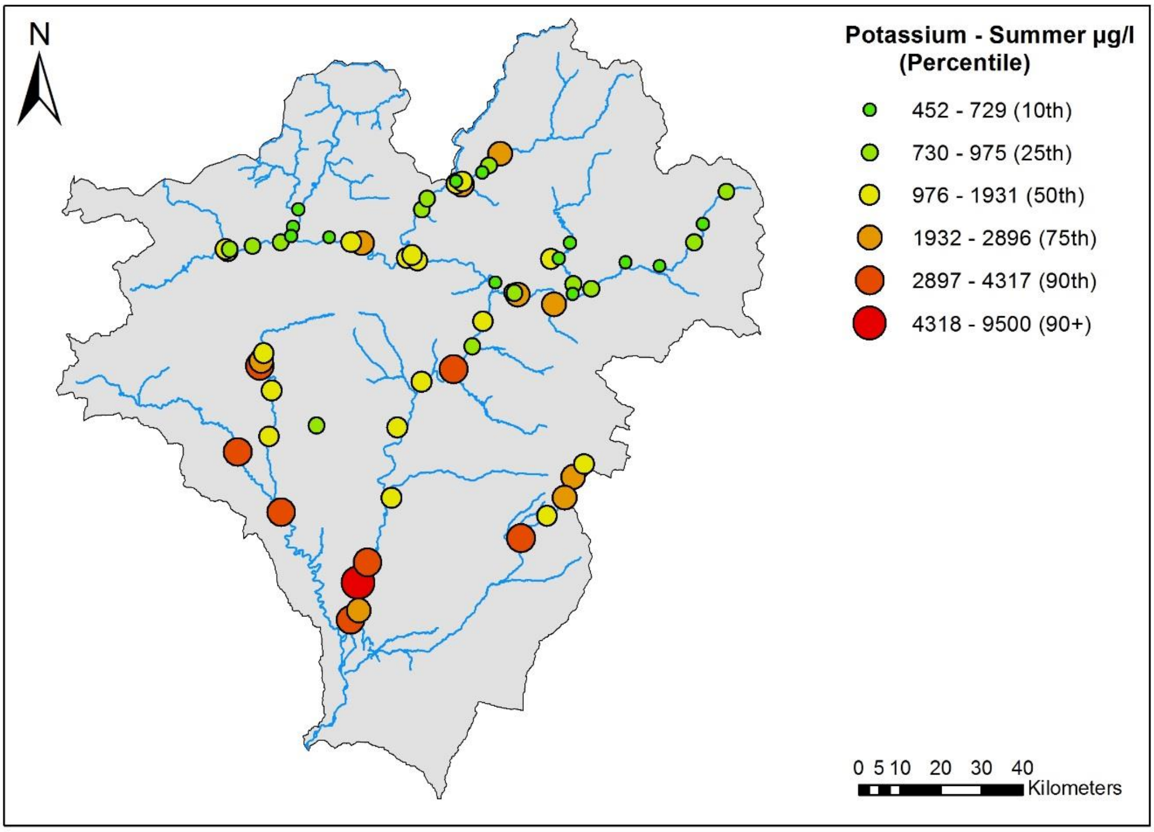

N
Manganese - Winter µg/l
(Percentile)
0 - 1 (10th)
2 (25th)
3 (50th)
4 - 6 (75th)
7 - 10 (90th)
11 - 42 (90+)
0 5 10 20 30 40
Kilometers

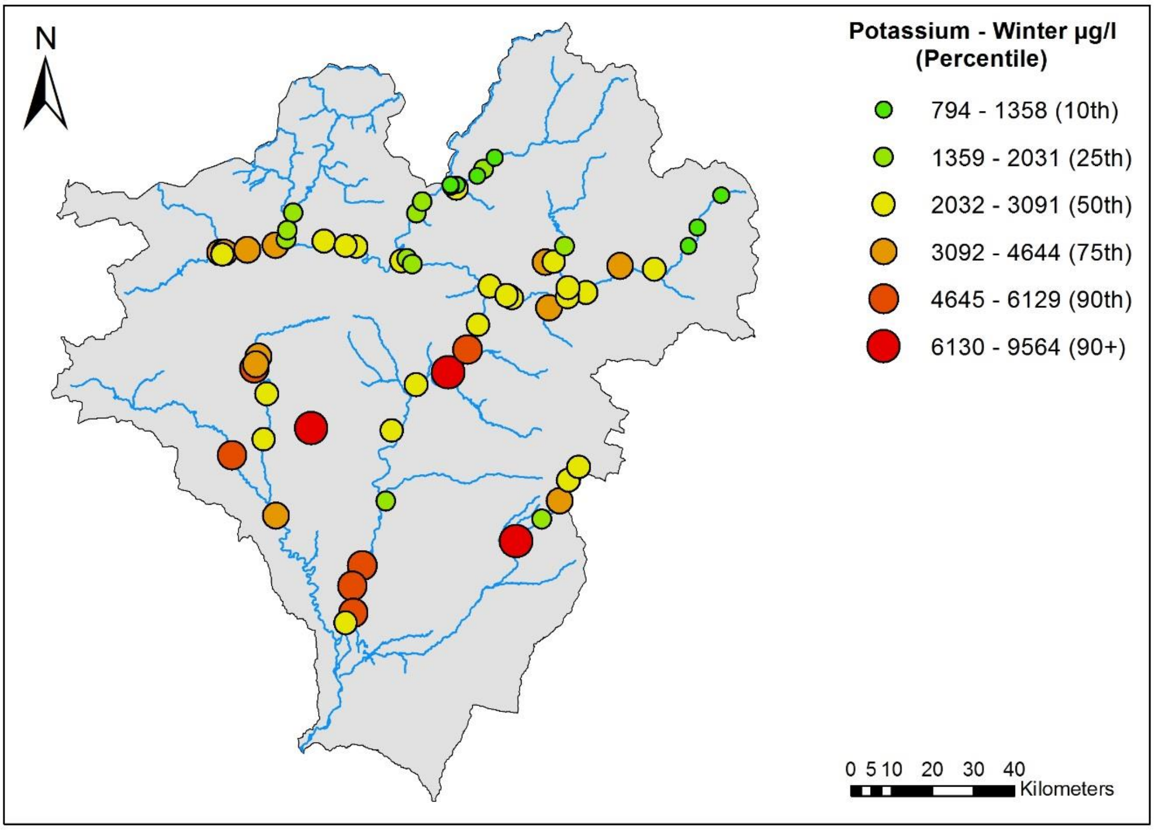

N
Molybdenum - Summer µg/l
(Percentile)
0.1 - 0.4 (10th)
0.5 - 0.7 (25th)
0.8 - 1.1 (50th)
1.2 - 1.9 (75th)
2.0 - 2.7 (90th)
2.8 - 4.3 (90+)
0 5 10 20 30 40
Kilometers

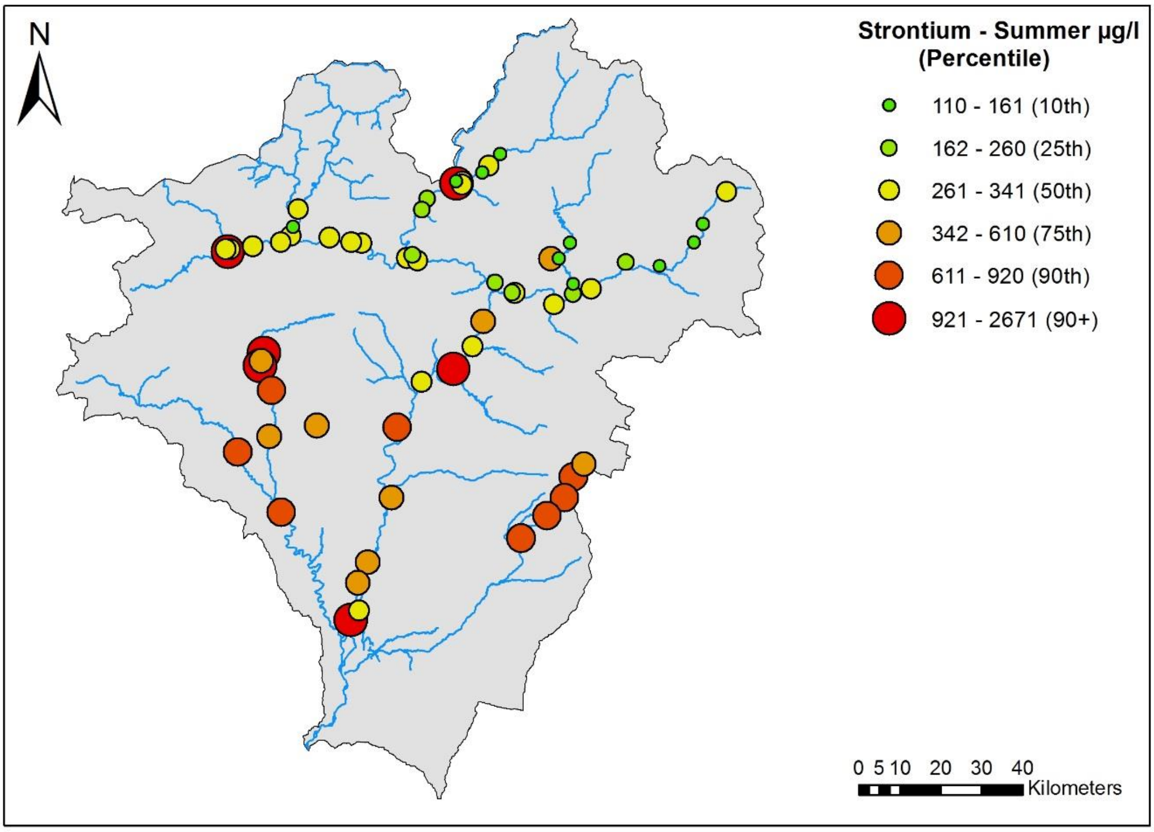

N
Molybednum - Winter µg/l
(Percentile)
0.1 - 0.3 (10th)
0.4 - 0.8 (25th)
0.9 - 1.3 (50th)
1.4 - 2.3 (75th)
2.4 - 3.3 (90th)
3.4 - 4.3 (90+)
0 5 10 20 30 40
Kilometers

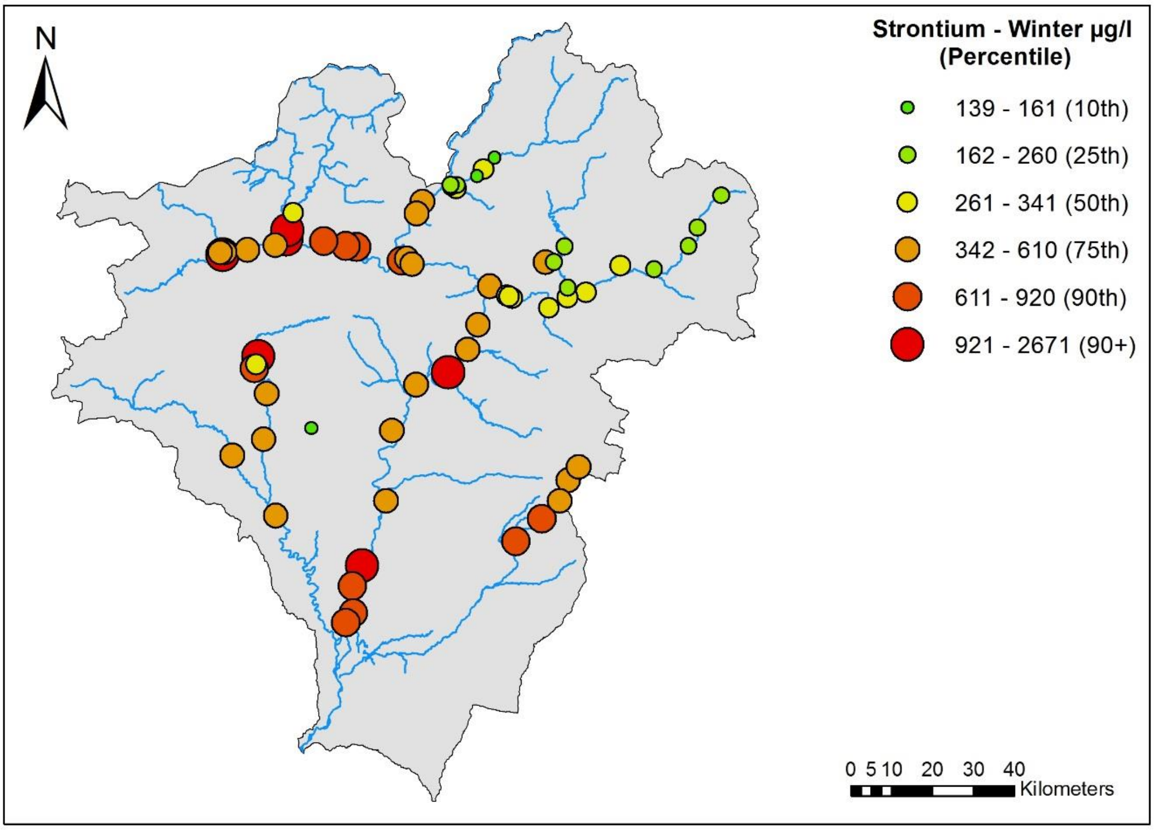

N
Nickel - Summer µg/l
(Percentile)
1 (10th)
2 - 1 (25th)
2 (50th)
3 - 2 (75th)
3 - 4 (90th)
5 - 21 (90+)
0 5 10 20 30 40
Kilometers

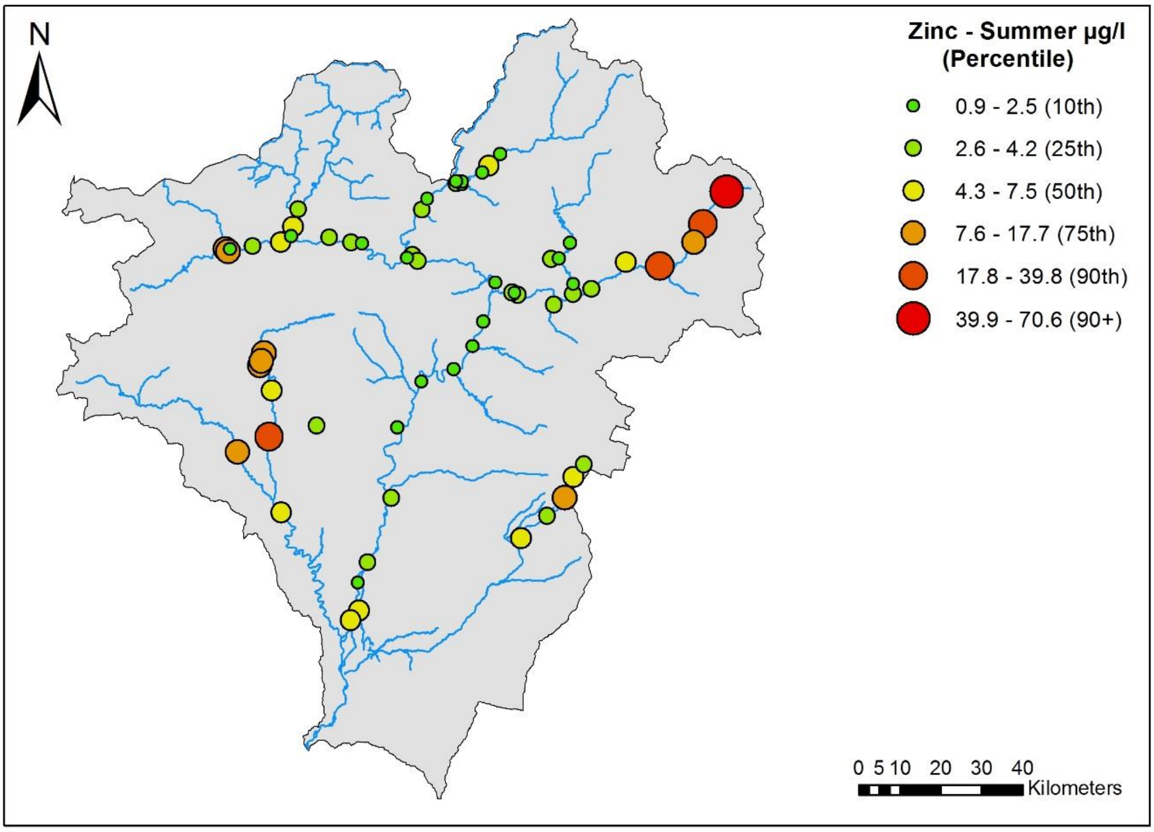

N
Nickel - Winter µg/l
(Percentile)
1 (10th)
2 - 1 (25th)
2 (50th)
3 - 2 (75th)
3 - 4 (90th)
5 - 21 (90+)
0 5 10 20 30 40
Kilometers


N
Potassium - Summer µg/l
(Percentile)
452 - 729 (10th)
730 - 975 (25th)
976 - 1931 (50th)
1932 - 2896 (75th)
2897 - 4317 (90th)
4318 - 9500 (90+)
0 5 10 20 30 40
Kilometers


N
Potassium - Winter µg/l
(Percentile)
794 - 1358 (10th)
1359 - 2031 (25th)
2032 - 3091 (50th)
3092 - 4644 (75th)
4645 - 6129 (90th)
6130 - 9564 (90+)
0 5 10 20 30 40
Kilometers


N
Strontium - Summer µg/l
(Percentile)
110 - 161 (10th)
162 - 260 (25th)
261 - 341 (50th)
342 - 610 (75th)
611 - 920 (90th)
921 - 2671 (90+)
0 5 10 20 30 40
Kilometers


N
Strontium - Winter µg/l
(Percentile)
139 - 161 (10th)
162 - 260 (25th)
261 - 341 (50th)
342 - 610 (75th)
611 - 920 (90th)
921 - 2671 (90+)
0 5 10 20 30 40
Kilometers



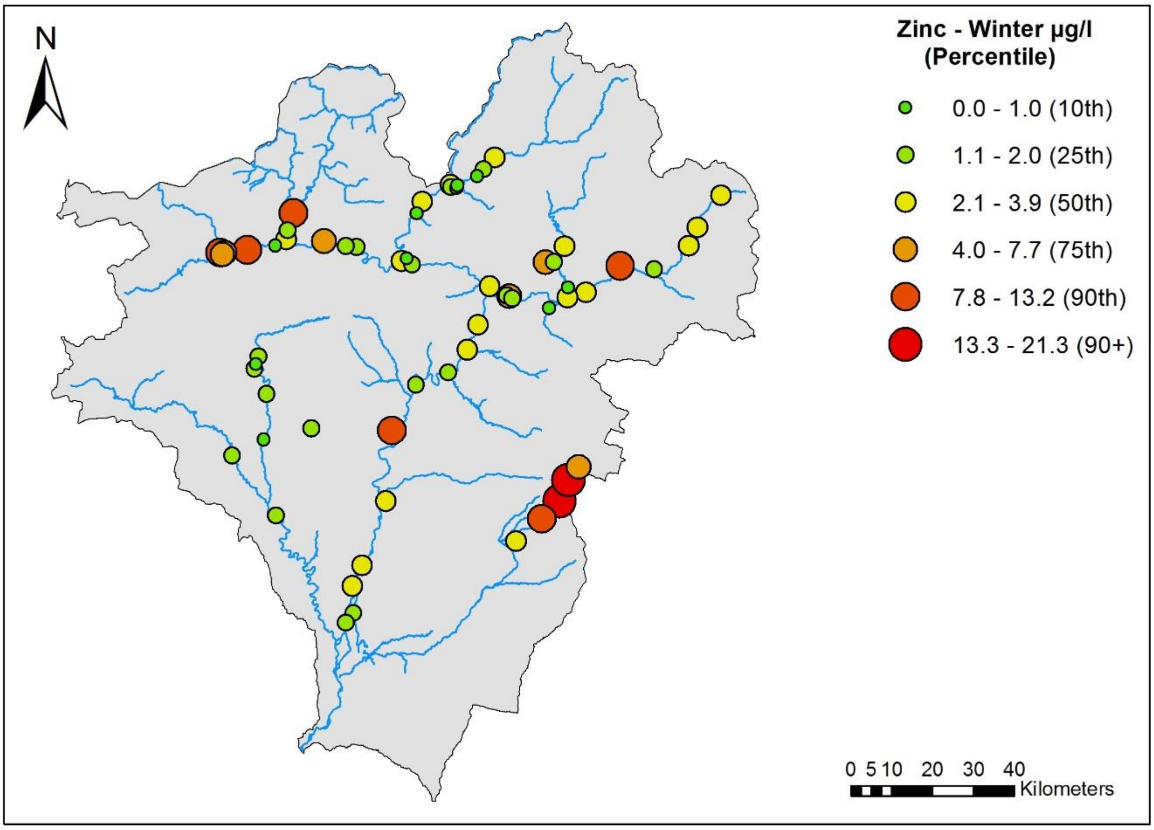


Figure 5.9 concentrations of rang of parameters in the Great Zab catchment plotted as proportional circles

Correlation matrix for range of parameters in Great Zab catchment

pH	-.094	.215*	.116	.125	.086	.101	.006	-.037	.098	-.143
Turb	.125	-.143	.105	.026	-.109	-.098	.002	-.055	-.137	.038
DO	-.032	-.066	.011	.115	-.094	.002	-.105	-.007	.070	-.008
EC	-.007	.224*	-.004	-.050	.064	.008	-.008	-.004	.125	.119
SO_4^{2-}	-.025	.035	.082	-.034	.031	.077	-.015	.103	.092	-.005
PO_4^{3-}	-.119	-.166	.046	-.072	.007	.086	.043	.104	-.029	-.124
NO_2^-	.180*	.018	.075	.065	.090	.040	.293**	.049	.028	.226*
Cl^-	-.066	-.045	.182*	-.074	.069	.046	.132	.050	-.002	-.051
F^-	-.094	.058	.061	-.061	.043	-.004	-.035	-.014	.034	-.030
Pb	.016	.143	-.017	.085	.520**	.577**	.491**	.623**	.076	.072
Ba	.245**	.349**	-.192*	.182*	.120	.108	.029	.130	.340**	.085
Cd	.134	.146	-.063	.031	-.007	.060	-.027	.031	.145	.160
Mo	.742**	.518**	-.346**	.089	.009	.029	-.011	.033	.564**	
Sr	.538**	.822**	-.211*	.015	.177*	.197*	-.050	-.009		.564**
Zn	.017	-.017	.062	.035	.650**	.816**	.739**		-.009	.033
Cu	.030	-.049	.095	.010	.557**	.659**		.739**	-.050	-.011
Ni	.002	.228*	.111	.103	.801**		.659**	.816**	.197*	.029
Co	.000	.258**	.155	.266**		.801**	.557**	.650**	.177*	.009
Mn	.015	.109	-.112		.266**	.103	.010	.035	.015	.089
Cr	-.255**	-.240**		-.112	.155	.111	.095	.062	-.211*	-.346**
Ca	.426**		-.240**	.109	.258**	.228*	-.049	-.017	.822**	.518**
Li		.426**	-.255**	.015	.000	.002	.030	.017	.538**	.742**
	Li	**Ca**	**Cr**	**Mn**	**Co**	**Ni**	**Cu**	**Zn**	**Sr**	**Mo**

-.046	.192*	.108	.082	.250**	.342**	-.004	.137	.155	-.294**	-.057	
-.045	.026	-.139	-.105	-.042	.149	.049	-.037	-.249**	.237**		-.057
.125	.064	-.106	.190*	-.066	.104	.310**	.271**	-.079		.237**	-.294**
-.062	.148	.167	.682**	.490**	.059	.102	.471**		-.079	-.249**	.155
-.030	.441**	.084	.637**	.384**	.307**	.356**		.471**	.271**	-.037	.137
.016	.030	.064	.312**	.332**	.182*		.356**	.102	.310**	.049	-.004
-.009	.101	.135	.139	.546**	.302**	.108	.083	.127	-.203*	.087	.194*
-.047	.119	.241**	.439**		.311**	.332**	.384**	.490**	-.066	-.042	.250**
-.024	.191*	.020		.439**	.167	.312**	.637**	.682**	.190*	-.105	.082
-.025	.074		.020	.241**	.093	.064	.084	.167	-.106	-.139	.108
.090		.074	.191*	.119	.408**	.030	.441**	.148	.064	.026	.192*
	.090	-.025	-.024	-.047	.048	.016	-.030	-.062	.125	-.045	-.046
.160	.085	.072	-.030	-.051	-.083	-.124	-.005	.119	-.008	.038	-.143
.145	.340**	.076	.034	-.002	.015	-.029	.092	.125	.070	-.137	.098
.031	.130	.623**	-.014	.050	.125	.104	.103	-.004	-.007	-.055	-.037
-.027	.029	.491**	-.035	.132	.197*	.043	-.015	-.008	-.105	.002	.006
.060	.108	.577**	-.004	.046	.165	.086	.077	.008	.002	-.098	.101
-.007	.120	.520**	.043	.069	.129	.007	.031	.064	-.094	-.109	.086
.031	.182*	.085	-.061	-.074	.115	-.072	-.034	-.050	.115	.026	.125
-.063	-.192*	-.017	.061	.182*	.177*	.046	.082	-.004	.011	.105	.116
.146	.349**	.143	.058	-.045	.034	-.166	.035	.224*	-.066	-.143	.215*
.134	.245**	.016	-.094	-.066	-.112	-.119	-.025	-.007	-.032	.125	-.094
Cd	**Ba**	**Pb**	**F^-**	**Cl^-**	**NO_3^-**	**PO_4^{3-}**	**SO_4^{2-}**	**EC**	**DO**	**Turb.**	**pH**

CHAPTER 6: SPATIOTEMPORAL TRENDS OF MAJOR HYDROCLIMATIC VARIABLES IN THE GREAT ZAB RIVER BASIN

6.1 ABSTRACT

Precipitation, runoff and temperature trends of nine stations in the Great Zab catchment from 1960–2012 were analysed and interpolated. The non-parametric Mann-Kendall trend and Sen’s slop estimator tests were applied to examine the precipitation, runoff and temperature data on basis of annually, seasonally and monthly scales. Significant positive and negative trends at the 90, 95 and 99% significance levels were detected. In the present study, the increasing trends were indicated in annual, seasonal and monthly air temperatures' series at all weather station across the catchment. While decreasing precipitation and runoff in annual, seasonal and monthly scales detected in some stations. In general, the results of using the Mann-Kendall and Sen's methods demonstrated the good agreement of performance in detection of the trend for meteorological variables.

6.2 INTRODUCTION

Water availability at global and regional scales is currently of paramount importance both environmentally; for maintaining optimal functionality of ecosystems and geophysical processes, and socio-economically; the analysis of their variability is an area of research interest. In recent decades, against the background of global climate change, especially since the 1970s, there have been changes in streamflow variability reported in many parts of the globe (Mitof and Pravalie, 2014). Although the most important form of climate change corresponds to a global warming trend, which has also been highlighted by means of statistical analysis (Westra et al., 2012), streamflow rate changes have been mostly influenced by changes in rainfall quantities (Mitof and Pravalie, 2014). Time series analysis of hydroclimatic data provides direct information about hydrological changes and plays important role in understanding and managing water resources (Antico et al., 2014).

Detecting trends in hydrologic, as well as climatic, and other natural time series, has been an active subject of research for more than three decades (Hamed, 2008). With recent extensive work in the field of water resources and their variability, the subject of trend detection has received even greater attention (Chen et al., 2007). According to the Report of the Intergovernmental Panel on Climate Change (IPCC, 2014), annual average river runoff is projected to increase by 10–40% at high latitudes and in some wet tropical areas, and decrease by 10–30% over some dry regions at mid-latitudes and in the dry tropics by mid-century. While temperature is expected to increase practically everywhere over land, precipitation is expected to increase globally (IPCC, 2007). In many river basins, precipitation is expected to increase, but in many others a decrease is expected (IPCC, 2007). In addition, precipitation intensities are expected to increase in some seasons or areas, but decrease in others (IPCC, 2014). All these changes in the climate may threaten the global freshwater system and increase uncertainty associated with hydrological processes (IPCC, 2007; Koutsouris et al., 2010). The IPCC (2014) documented with strong confidence that the impacts of climate change on freshwater systems and their management are mostly caused by increases in temperature, sea level and precipitation variability that have been observed.

The management and planning of water resources increasingly need to incorporate the effects of global climate change in order to accurately predict future supplies (Fu et al., 2007a), particularly in arid and semi-arid regions, where water availability is more sensitive to precipitation and air temperature (Chen et al., 2006). Most of the runoff in the Great Zab catchment is generated in mountainous regions of the basin, which are covered by snow. Increased air temperature in these regions could induce more runoff from the melting of snow and glaciers. However, more actual evaporation can be expected, due to the increase of air temperature (Abbas et al., 2016). This conclusion can be obtained based on the general relationship between streamflow precipitation-temperature and climate elasticity of streamflow (Fu et al., 2007b). Numerous studies have been carried out in various regions of the world to detect trends in hydro-meteorological variables including annual precipitation, air temperature and runoff time series. Beyene et al. (2010) simulated the impacts of climate change on the hydrology of the Nile River basin and found that the basin is likely to have higher streamflow up to 2039 as a result of increased precipitation; however, from 2040 to 2099, streamflow is expected to decrease. Douglas et al. (2000) and Lins and Slack (1999) studied trends in stream flows in the United States. Chen et al. (2007) investigated temporal trends in annual and seasonal precipitation, temperature, and runoff in the Hanjiang basin in China. Zhang et al. (2005) analysed monthly temperature and precipitation data for 51 climate stations and three hydrometric stations in the Yangtze basin, China. In Canada, Burn and Hag Elnur (2002) applied the Mann-Kendall test to identify trends in hydrological variables. Whitfield (2001) examined temperature, precipitation and streamflow data for sites in British Columbia and the Yukon. Abdul Aziz and Burn (2006) analysed trends and variability in the hydrological regime for the Mackenzie Basin in northern Canada. Burn (1994) and Westmacott & Burn (1997) examined the impacts of climate change on the timings of spring runoff in West-Central Canada. Dixon et al. (2006) studied trends in stream flows in western Britain.

A number of studies have endorsed studying the trends for different hydroclimatic variables, to understand the relationship between hydrology and climate. In light of this, the main objective of this chapter is to analyse the trends that may exist in the time series of three hydroclimatic variables, namely temperature, precipitation and streamflow. These parameters serve as good indicators of how the climate has evolved because: (1) studies on climate change indicate an increase in temperature, and patterns of precipitation have experienced changes in different parts of the world (Burn and Hag Elnur, 2002); and (2) streamflow tends to reflect how a catchment area as a whole has been responding to the variability in climate (Gaucherel, 2002). Zhang et al. (2009) also indicated that in order to understand the effects of climate change on global and regional water resources, information about the impacts of climate change on the spatiotemporal characteristics of precipitation are required. One of the goals of trend detection is to determine the main causes affecting these trends (Yu et al., 1993). With growing demand for water and problems related to water resources, it is essential to understand the effects of climatic variability/change on hydrological processes, as they are indicators of how the climate has changed over time (Burn, 1994). The results of this research should be useful for current and future water resources planning efforts in Great Zab catchment, as it involves making reasonable predictions or assumptions about future hydro-climatic conditions.

6.3 METHOD AND METRIALS

The Mann-Kendall (MK) trend test (Mann, 1945; Kendall, 1975) is a rank-based test of randomness against monotonic trends (Zhang et al., 2001; Burn et al., 2010). Detection of trend is a complex subject because of characteristics of data, and the main idea of trend analysis is to detect whether values of data are increasing, decreasing or trendless over time (Kisi and Ay 2014). Numerous studies have employed the MK trend test in their data analysis in order to assess and identify trends in a time series (e.g. Chiew and McMahon, 1993; Burn, 1994; Gan, 1998; Lins and Slack, 1999; Douglas et al., 2000; Pilon and Yue, 2002; Yue et al., 2003; Fu et al., 2004; Xu et al., 2004, 2007; Hamed, 2008; Sharif and Burn, 2009, Burn et al., 2010; Jain and Kumar, 2012; Salami et al., 2014). The MK trend test is one of the most widely applied non-parametric tests for detecting a trend in the hydro-meteorological time series (Yue and Pilon, 2004; Hamed, 2008). The most attractive features of this test are that it is powerful even for skewed distributions (Önöz and Bayazit, 2003), simple to compute, and resilient to non-stationary data and missing values (Partal and Küçük, 2006). Since it is rank-based, it placed emphasis on the order of the rank, and not on the actual value of the records themselves. Thus, if some values are missing or if an outlier is present, the results would not be affected much because the ranks would not significantly change. Mann-Kendall and Sen's Slop estimator tests are nonparametric tests. Therefore, data outliers do not affect the result (Ahmed et al., 2015). The Mann-Kendall statistical test has been frequently used to quantify the significance of trends in hydro-meteorological time series (Douglas et al., 2000; Yue et al., 2002). The homogeneity of the data time series was assessed by applying two tests, standard normal homogeneity test (SNHT) (Alexandersson and Moberg, 1997) and Buishand's rang (BR) test (Ahmed et al., 2015), at 95% significance level for each station. The data time series is considered homogenous if the critical values of SNHT and BR statistics are less than 9.17 (Khaliq and Ouarda, 2007) and 1.27, 1.55 (Ahmed et al., 2015) respectively. As Table 6.1 and 6.2 shows, all the data series were found to be homogenous.

The Agro-meteorological Department, Ministry of Agriculture and Water Resources operated weather data from nine stations namely Akri, Amedi, Erbil, Khabat, Mergasur, Salahaddin, Shaqlawa, and Soran (Fig 6.1). The record from agro-meteorological stations includes monthly precipitation and temperature for the period from 1960 – 2012. Monthly stream flow time series of Great Zab River covering the period 1960-2012 have been collected from the Ministry of Agriculture and Water Resources, Directorate of Water Resources and United State Geological Survey (USGS, 2009). Because the availability of climatic measurements varies spatially and temporally, sets of climate data are usually incomplete. In order to overcome the problems of inconsistency, inaccuracy and measurement errors and to put together a solid database for analysis, a reconstruction process is required which involves a method of imputation and quality control of weather data (Feng and Qian, 2004; Vicente-Serrano et al. 2010). Missing data occurs in many spatial datasets. Data might be missing because a sensor is temporarily broken, a sampling site is inaccessible, or data values are intentionally suppressed to protect confidentiality. If any variable for an observation is missing, a common way to deal with this situation is to delete that observation from the dataset. However, rather than throwing out valuable data that can impact analyses or result in “holes” in the map, missing data values can be “filled in” using other information from the dataset. In the case of spatial data, the values of neighbouring features in space can be used to create an estimate for missing values. For spatiotemporal data, neighbours in time can be used to fill in the missing values.

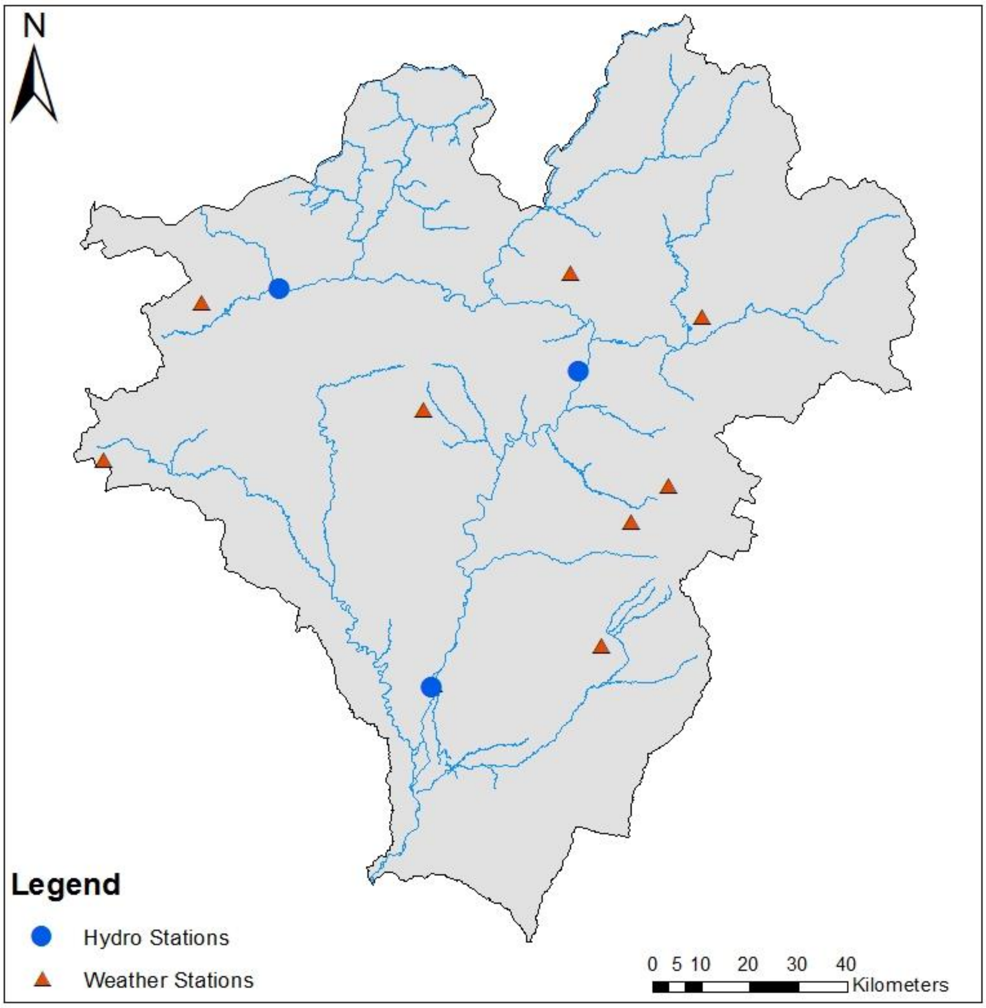


Figure 6.1 Location of weather and streamflow stations and study area

Table 6.1 Seasonal and annual trends in precipitation as estimated from Mann-Kendall and Sen’s slope statistics for various meteorological station.

Station	Data time series	SNHT	Buishand’s rang (BR) test	
		T_0	$Q/\sqrt{n}$	$R/\sqrt{n}$
Akre	Precipitation	7.82	1.23	1.49
	Temperature	7.80	1.24	1.48
Amedi	Precipitation	9.14	1.12	1.11
	Temperature	9.15	1.9	1.30
Erbil	Precipitation	8.92	1.07	1.25
	Temperature	8.96	1.08	1.34
Khabat	Precipitation	9.1	1.22	1.37
	Temperature	9.2	1.24	1.38
Mergasur	Precipitation	8.97	1.03	1.22
	Temperature	9.05	1.16	1.34
Salahaddin	Precipitation	7.85	0.89	1.17
	Temperature	8.25	1.08	1.29
Shaqlawa	Precipitation	6.94	0.98	1.42
	Temperature	5.73	1.09	1.39
Soran	Precipitation	7.44	1.17	1.52
	Temperature	8.32	1.12	1.41
Zawita	Precipitation	9.03	1.6	1.37
	Temperature	8.95	1.4	1.40

Table 6.2 Results of homogeneity tests for mean annual streamflow time series.

Station	Data time series	SNHT	Buishand’s rang (BR) test	
		T_0	$Q/\sqrt{n}$	$R/\sqrt{n}$
Bekhme	Streamflow	4.92	0.78	1.3
Deralok	Streamflow	8.72	1.06	1.15
Eski-Kelek	Streamflow	7.26	0.92	1.25

Prior to applying MK and Sen's Slope tests to identify hydroclimatic trends over the time series from selected stations, data were tested according to the test's requirements. The trend-free prewhitening (TFPW) approach was applied to eliminate serial correlations in the time series data. The magnitude of the slope in time series data was calculated using Sen's slope method. The statistical methods used are briefly discussed below. Removing serial dependence is one of the main problems in testing and interpreting time series data. Applying nonparametric tests to detect trends can significantly affect the result. Therefore, all of the time series data was first tested for the presence of autocorrelation coefficient (r_1) at a 95% significance level, using a two-tailed test:

$$r_1 = \frac{\sum_{i=1}^{n-1} (X_i - \bar{X})(X_{i+1} - \bar{X})}{\sum_{i=1}^{n} (X_i - \bar{X})^2} \tag{6.1}$$

The autocorrelation coefficient value of r_1 was tested against the null hypothesis at a 95% confidence interval, using a two-tailed test:

$$r_1(95\%) = \frac{-1 \pm 1.96\sqrt{(n-2)}}{n-1} \tag{6.2}$$

If r_1 falls between the upper and lower limits of confidence interval (the data are considered serially correlated), the methods of prewhitening, variance correlation, and trend-free prewhitening (TFPW) approach have been proposed (Hamed and Rao, 1998). In this study, for the stations where serial correlations were detected in the data, the TFPW method was applied to remove the correlation for both tests (Mann-Kendall and Sen's Slope). Other studies (Shadmani, et al., 2012; Onoz and Bayazit, 2012; Yaseen et al., 2014) have also used this approach to eliminate serial correlation in time series data.

6.3.1 Mann-Kendall Test

Kendall statistics: The Mann-Kendall test is a nonparametric test used for identifying trends in a time series data. The test compares the relative magnitudes of sample data rather than the data values themselves Both Kendall tau coefficient (τ) and Mann-Kendall score (s) are nonparametric statistics used to find rank correlation. Kendall τ is a ratio between the actual rating score of correlation, to the maximum possible score. To obtain the rating score for a time series, the dataset is sorted in ascending order according to time and then the following formula is applied:

$$s = \sum_{i=1}^{j=n-1} \sum_{j=i+1}^{i=n} sig\left(X_j - X_i\right), \qquad (6.3)$$

Where:

s = The rating score (also called the Mann- Kendall sum)

x = The data value

i and j = Counters

n = Number of data values

Sign = A function having values of +1, 0, or -1 if (xi-xj) is positive zero, or negative, respectively According to this formula, the maximum value of s is:

Where X_j and X_i are the annual values in years j and I, j > I, respectively.

According to this formula, the maximum value of s is:

$$S_{max} = \frac{1}{2}\, n\, (n-1) \qquad (6.4)$$

Hence, the Kendall tau is calculated as:

$$t = \frac{S}{S_{max}} \qquad (6.5)$$

A positive value of s or τ is an indicator of an increasing trend and a negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with s or τ and the sample size, n, to statistically quantify the significance of the trend. Kendall and Gibbons

(1990) introduced a normal-approximation test that could be applied on datasets with more than ten values. After calculating s, the variance (σ^2) of s is calculated:

$$\sigma^2 = \frac{1}{18} [N (N-1)(2N+5)] \, CF_R \tag{6.7}$$

$$CF_R = \frac{1}{18} \sum_{k=1}^{g} m_k \, (m_k - 1)(2m_k + 5) \tag{6.8}$$

Where:

CFR = Repetition correction factor, to fix the effect of tied groups of data (when some of the data values appear more than one time in the dataset, this group of values are called a tied group)

g = Number of tied groups

k = A counter

m = Count of data values in each tied group

Next, the normal distribution parameter (called the Mann-Kendall statistic, Z) is calculated as follows:

$$z = \begin{cases} \frac{1}{\sigma} \, (s-1) & s > 0 \\ 0 \quad \rightarrow & s = 0 \\ \frac{1}{\sigma} \, (s+1) & s < 0 \end{cases} \tag{6.9}$$

The last step is to find the minimum level at which the parameter Z is significant as mentioned by Abramowitz and Stegun (1972):

$$\alpha_{min} = (b_0 \, e \, -0.5z^2) \sum_{q=1}^{q=5} b_{q \; (1+b_\sigma \, ABS(Z))^{-q}} \tag{6.10}$$

Where:
$^{\alpha}$min = Minimum level of significance

q = Counter
b_q = Constants: $b_0 = 0.3989$, $b_1 = 0.3194$,
$b_2 = -0.3566$, $b_3 = 1.7814$, $b_4 = -1.8213$,
$b_5 = 1.3303$, $b_6 = 0.2316$
ABS (Z) = The absolute value of Z

6.3.2 Sen's slope Estimator

Sen's nonparametric method was used to estimate the magnitude of trends in the time series data (Sen, 1968). To perform the complete Sen's test the following rules and conditions are applied:

• The time series should be equally spaced, i.e., the interval between data points should be equal. However, Sen's method considers missing data.

• Data should be sorted in ascending order according to time, then apply the following formula to calculate Sen's slope estimator (Q) as the median of Sen's matrix members:

$$Q = Median \left\{ \left[\left[\frac{X_i - X_j}{i - j} \right] \begin{matrix} j = n-1 \\ j = 1 \end{matrix} \right] \begin{matrix} i = n \\ i = j+1 \end{matrix} \right\} \tag{6.11}$$

Q is the main component of Sen's statistics. Its sign reflects data trend direction, while its value indicates the steepness of the trend.

• To determine whether the median slope is statistically different than zero, one should obtain the confidence interval of Q at specific probability level, e.g., 95%. Assuming that Q is normally distributed then the value of Z under two-tailed normal distribution curve is calculated at the level (1-α/2), where a = 1-confedence level, e.g., Z = 1.96. The variance of Q is calculated using Eq. 4.3 and a statistic Ca is now calculated as follows:

$$C_{a = Z_{1-a/2}\sqrt{\sigma^2}} \tag{6.12}$$

• The upper and lower boundary limits of the slope Q are calculated as follows:

$$M_u = int\ \left(0.5\left(n_q - c_a\right)\right) \tag{6.13}$$

$$M_1 = int\ \left(0.5\left(n_q - c_a\right)\right) + 1 \tag{6.14}$$

Where, M_u and M_l = the upper and lower boundary .positions, respectively n_q = The number of members of Sen’s matrix that was produced by Eq. 4.4; nq = n (n-1).

The slope Q is statistically different from zero if the two limits have similar sign. Sen's slope estimator has been widely used in hydro-meteorological time series (Lettenmaier et al., 1994; Yue and Hashino, 2003; Yunling and Yiping, 2005; Partal and Kahya, 2006; ElNesr et al., 2010; Tabari and Marofi, 2011; Tabari et al., 2011a).

6.4 RESULT

6.4.1 Precipitation

As discussed earlier in this study, the portion of Great Zab basin covered by assessment generally is semi-arid, with most precipitation occurring in the late autumn, winter and spring (see Tables 6.3 and 6.4). The bulk of this precipitation occurs in the form of rain. Monthly and annual values have been calculated for each year for all the stations. Average, max, min, standard deviation, and coefficient of variation have been calculated on annual and seasonal bases for all stations using the data for a period of 53 years for 1960-2012. These values have been taken as climatic normal and have been analysed.

Table 6.3 Mean, max, min, standard deviation, and coefficient of variation for precipitation 2003-2012.

Station	Season	Mean	Max	Min	Stdev	CV
Akre	Spring	68.2	144.7	21.3	25.7	2.6
	Summer	1.4	10.7	0.0	2.4	0.6
	Autumn	33.7	96.7	3.7	19.2	1.8
	Winter	109	182.7	48.7	29.7	3.7
	Annual	636	1108	331	148.8	4.3
Amedi	Spring	83.5	166.0	35.7	29.1	2.9
	Summer	1.9	12.8	0.0	3.2	0.6
	Autumn	44.5	131.7	2.0	28.3	1.6
	Winter	116.4	256.3	58.3	40.3	2.9
	Annual	734.9	1130	419	169.8	4.3
Erbil	Spring	44.3	105.3	10.3	20.6	2.2
	Summer	0.4	4.3	0.0	0.9	0.4
	Autumn	20.5	66.0	1.8	16.6	1.2
	Winter	70.1	143.3	26.0	22.1	3.2
	Annual	405.7	729	229	111.7	3.6
Khabat	Spring	36.9	83.0	10.7	15.9	2.3
	Summer	0.0	0.8	0.0	0.1	0.3
	Autumn	17.3	52	0.0	12.3	1.4
	Winter	60.6	118.7	24.0	18.0	3.4
	Annual	344.4	586	208	87.3	3.9
Mergasur	Spring	101.6	192.3	37.7	35.3	2.9
	Summer	2.8	15.9	0.0	4.6	0.6
	Autumn	52.7	135	6.7	28.7	1.8
	Winter	164.3	329	74.8	49.8	3.3
	Annual	963.9	1638	536	250.6	3.8
Salahaddin	Spring	61.6	120.2	19.7	21.4	2.9
	Summer	1.4	8.7	0.0	2.1	0.7
	Autumn	32.2	93	3.1	19.4	1.7
	Winter	93.5	160.3	48	23.7	3.9
	Annual	566.1	927	384	115.4	4.9
Shaqlawa	Spring	72.3	125.9	29	21.6	3.3
	Summer	2.0	17.1	0.0	3.5	0.6
	Autumn	36.2	96	2.0	19.1	1.9
	Winter	119.9	205	56	32.6	3.7
	Annual	691.2	1060	413	135.0	5.1
Soran	Spring	67.7	113	29.6	19.7	3.4
	Summer	1.8	12.3	0.0	3.1	0.6
	Autumn	36	104.7	4.3	19.6	1.8
	Winter	107	171.7	68.7	24.7	4.3
	Annual	637.7	976.6	402	111.6	5.7
Zawita	Spring	74.1	136	18.0	24.2	3.1
	Summer	1.6	9.9	0.0	2.7	0.6
	Autumn	41.2	134.7	1.3	26.6	1.5
	Winter	132.7	292	60.3	48.5	2.7
	Annual	748.9	1271	363	199.6	3.8

The mean monthly precipitation over the period to the study area calculated using the monthly long-term precipitation of (9) stations amounts to (53.1mm). Average monthly precipitation ranged from (115.1mm) in January to (0.1mm) in July (Fig 6.2). The average annual precipitation was (637.1mm) during the period of (1960-2012).

Table 6.4 Average monthly and annual precipitation 2000-2012.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average (mm)	115.1	110.4	96.2	76.7	30.5	3.7	0.1	0.6	4.0	32.6	68.2	99.0

The wet period in a year lies between October and May and the dry period between June and September. More than eighty percent of the mean annual precipitation falls in the period from October through March.

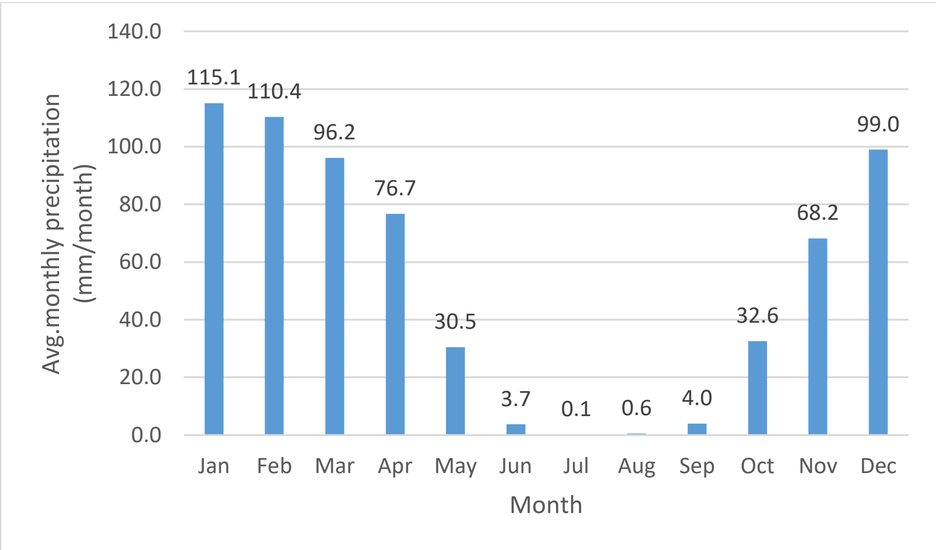


Figure 6.2 Distribution of mean monthly precipitation across all station 2000-2012

Annual variability of precipitation on the catchment is apparent as indicated on (Fig 6.3, 6.4), that annual precipitation ranges from 914.4 mm on the wettest year (1988) to 376.7 mm on the driest year (1999).

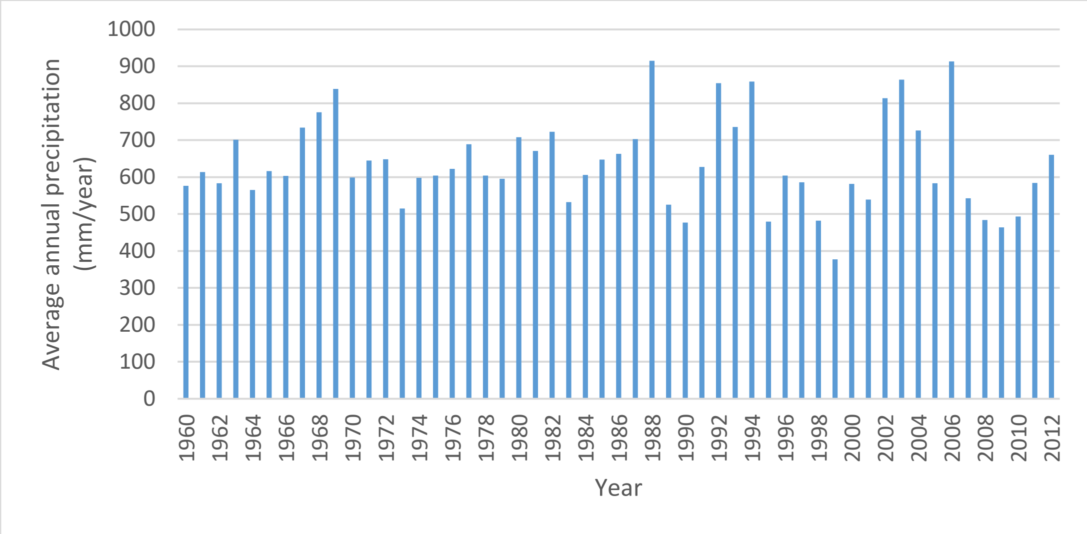


Figure 6.3 Distributions of mean Annual precipitation across all station.

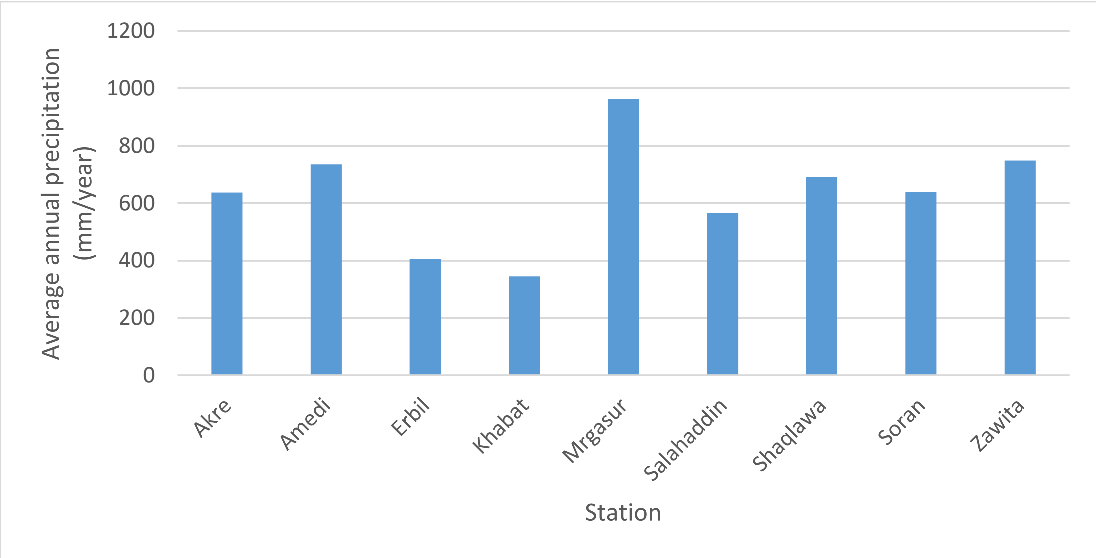


Figure 6.4 Annual precipitation distributions at different stations.

6.4.1.1 Seasonal distribution of precipitation

The figures below (6.5, 6.6 and 6.7) shows climate diagrams for three typical stations, Erbil (lower catchment), Soran (middle catchment) and Amedi (upper catchment):

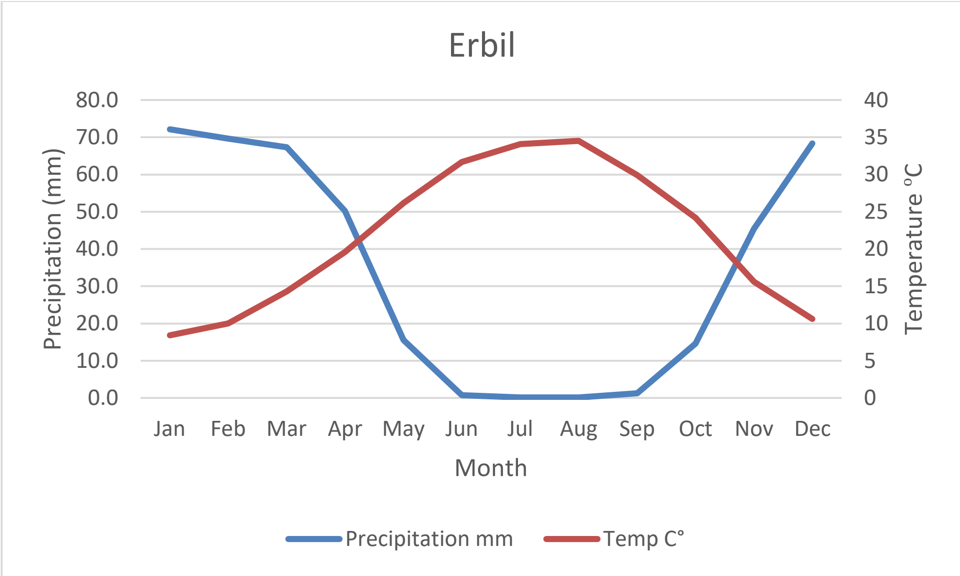


Figure 6.5 Erbil Station: elevation 420masl, annual average 405.7mm (1960-2012).

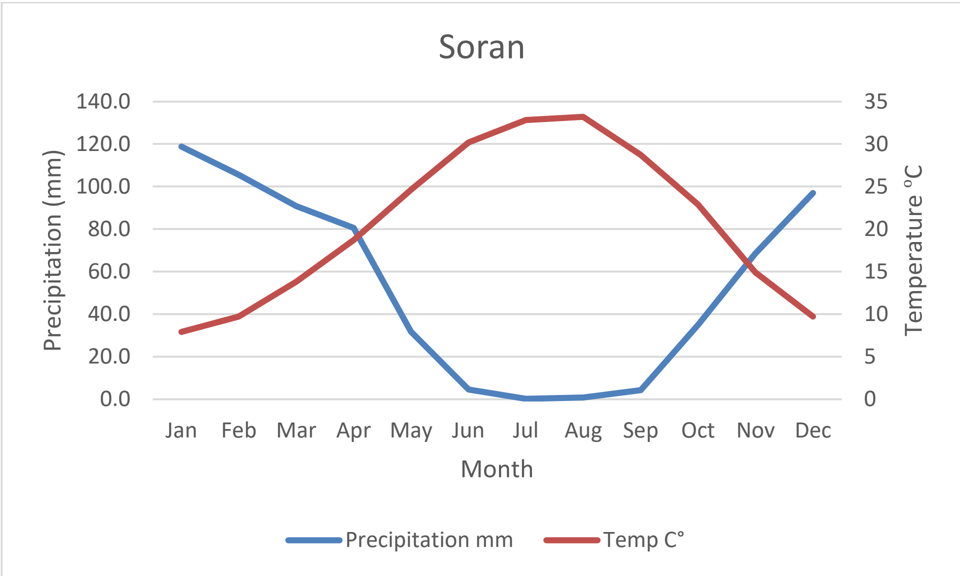


Figure 6.6 Soran Station: elevation 680masl, annual average 637.7mm (1960-2012).

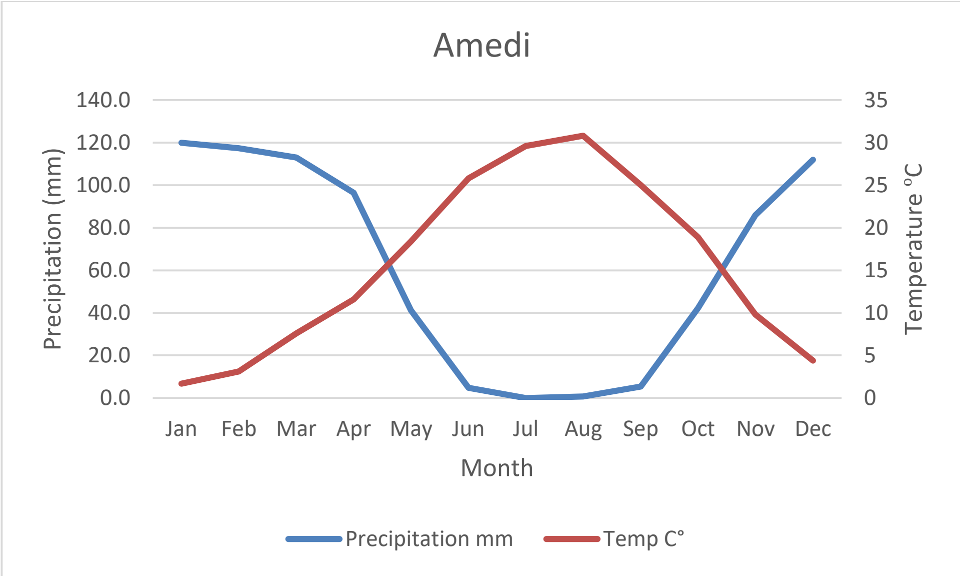


Figure 6.7 Amedi Station: elevation 1202 masl, annual average 734.9mm (1960-2012).

The climate diagrams demonstrate that despite the differences in elevation and annual precipitation (in absolute terms) the seasonal distribution of precipitation is similar. Excess precipitation (and hence: groundwater recharge and runoff generation) occurs from October (lower catchment: November) to April only. 85% of the annual precipitation is concentrated in half of the year (November to April) whereas the four summer months (June to September) contribute less than 5%.

6.4.1.2. Areal distribution of precipitation

Precipitation is generally increasing with elevation, i.e. from South West to North East (Fig 6.8). Average annual precipitation is:

- 300 to 500 mm in the lowlands plains (Erbil City 405.7mm), with lower values (down to less than 257.7 mm) found in Makhmur District (Erbil Governorate).

-500 to 900 mm in most of the central, karstified zone (Soran District 637.7mm). There are considerable variations according to the local topographic conditions, and it is likely that higher values occur (but are not measured) at high elevations.

-700 to >1200 mm in the high mountain zone along the borders with Turkey and Iran. Annual averages above 1000 mm are recorded in Mergasur, (Erbil Governorate).

A significant relationship exists between the elevation of the climatological station and the average annual precipitation. A linear relationship between rainfall and the elevation was found. The equation of the relationship can be expressed as

$$y = 0.3994x + 310.59$$

where x is the elevation and y is the annual mean precipitation. The coefficient of determination (R^2) value is almost 35%. Fig 6.8 shows the relationship between the altitude and mean annual precipitation recorded by the nine stations in the study area. The lowest elevation of a climatological station is 252 masl, which is located in the lower part of the catchment. The highest elevation of a climatological station is 1204 masl which is located in the upper part of catchment. The elevation clearly affects the amount of precipitation.

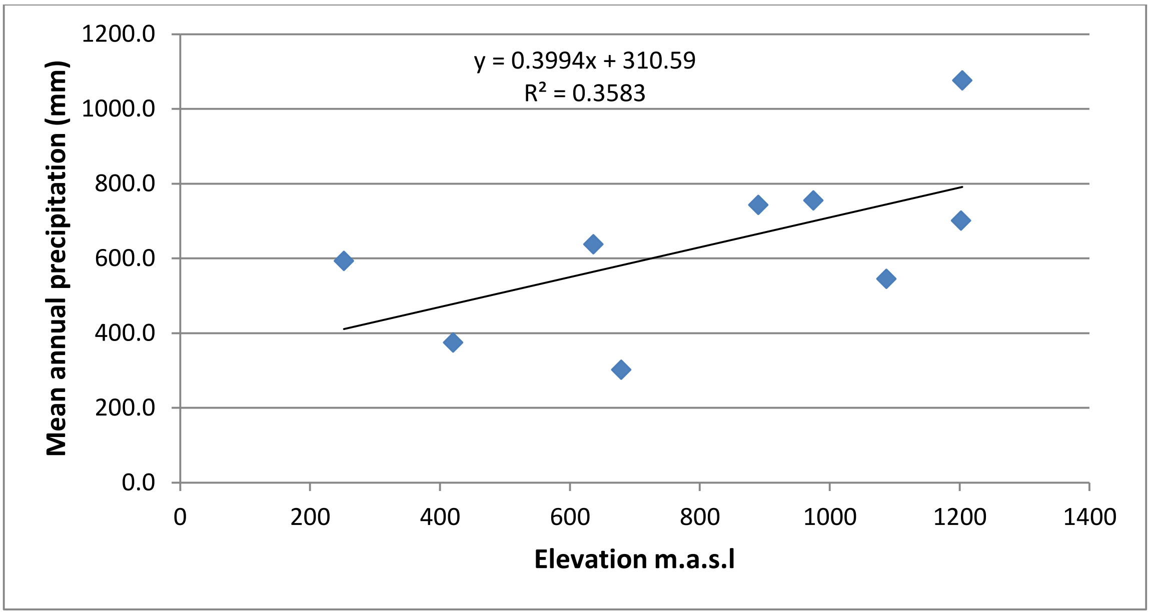


Figure 6.8 Correlation between altitude and precipitation in study area.

Precipitation in the high mountain regions is likely to rise well beyond 1000mm; however, some of the inner valleys surrounded by high mountains (Soran, Choman, Amedi, and Sidakan) seem to be shielded- a phenomenon that is well known from other mountain regions-and have moderate precipitation around 700mm/year.

6.4.1.3 Monthly analysis of Precipitation

The Mann-Kendall (MK) and Sen's Slop tests were applied on a monthly scale to detect trends in the precipitation series at different stations. Table 6.5 shows the results and illustrates that the results of both tests were similar to one another. Monthly trends tests showed a mix of negative trends at different stations. At Akri station, statistically significant decreasing trends at significance level of 95% were found from April to June and from August to October. Significant decreasing trends were detected at Khabat and Erbil stations in May and October at significance level of 95%, respectively and no significant trends were found for other months.

The Amedi station exhibited significant decreasing trends from August to December. In other stations, a mix of significant decreasing trends occurred for a few months of the year.

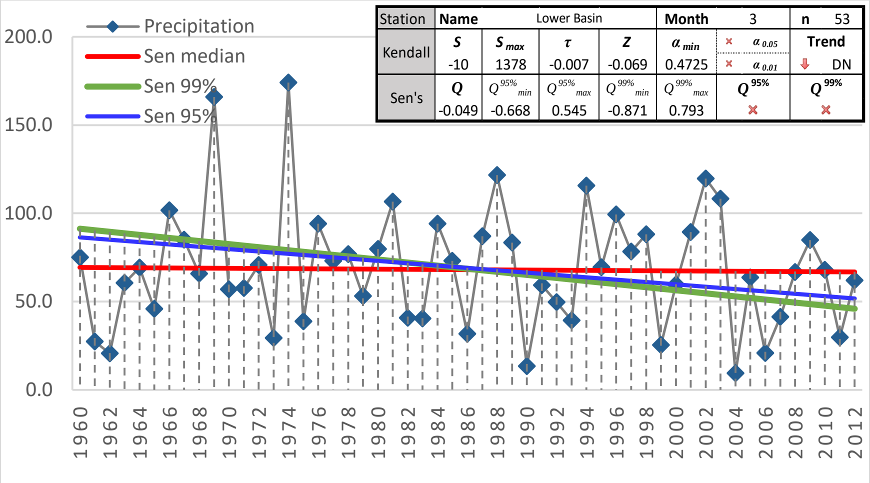
In general, significant decreasing trends were found at most of the stations in the months of June and November and July is the only month during which the monthly precipitation shows no trends for the entire basin. It’s interesting to note that there are several months during that precipitation trends in the upstream and middle catchment are of opposite sign to each other, such as January, February, September and November. It implies that the trends of precipitation are spatially heterogeneous among stations. The largest magnitudes of decrease for monthly precipitation occurred in June, July and August, which made the magnitude of the trend in summer the largest for all seasons and contributed more than 50% of the annual magnitude. The magnitude of the trend in June is about four times that of annual precipitation. A sample representation for this analysis is shown in (Fig 6.9) each of these figures represents one month (March, June, September, and December) where these months were selected to show the performance of both Kendal and Sen’s slops Methods under various precipitation series). All of the charts represents the precipitation trend of Upper, Middle and Lower stations.

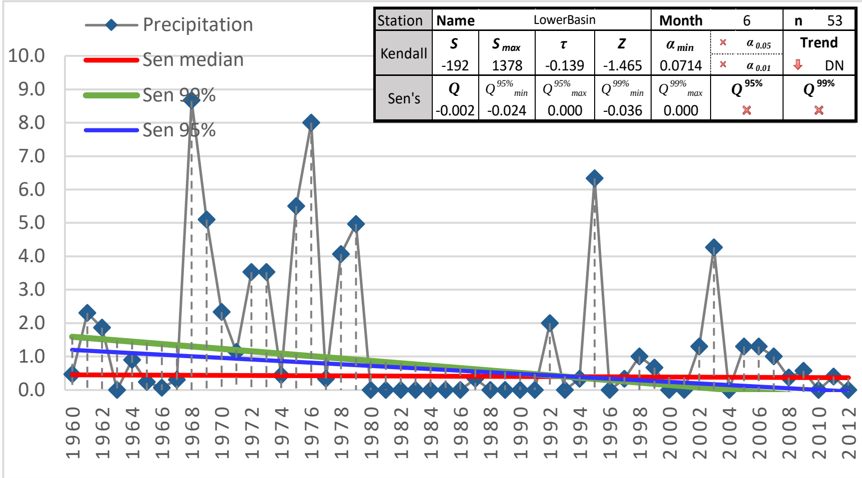
Table 6.5 Mann-Kendall and Sen's slope results for precipitation in monthly time series.

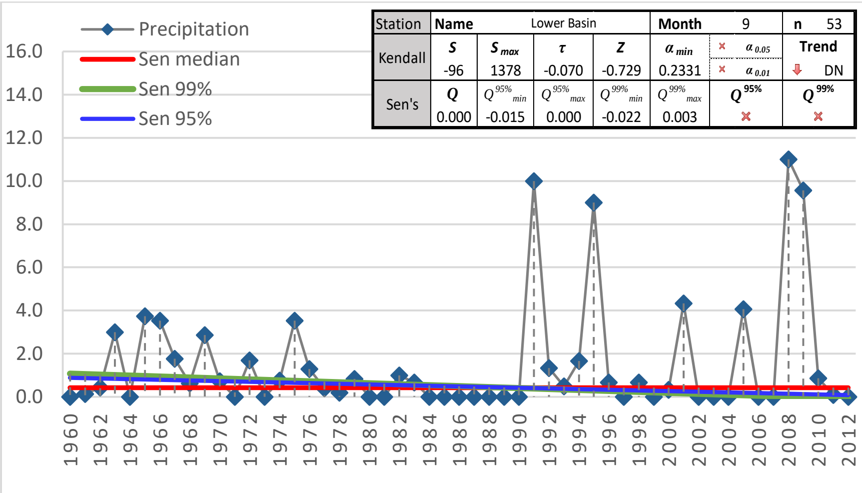
Station	Test	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Akre	MK	-0.02	0.10	0.014	-0.18*	-0.21*	-0.27**	0.00	-0.16*	-0.20*	-0.15*	-0.09	-0.01
	Q	-0.12	0.42	0.06	-0.72	-0.39*	0.0	0.0	0.0	0.0	-0.26	-0.39	-0.01
Amedi	MK	-0.21*	0.14	0.15	-0.05	-0.13	-0.41**	-0.07	-0.16*	-0.30**	-0.11*	-0.16*	-0.11*
	Q	-1.18*	0.63	0.72	-0.21	-0.33	-0.02	0.0	0.0	0.0	-0.36	-0.84	-0.45
Erbil	MK	-0.02	-0.0	-0.00	-0.03	-0.0	0.14	0.05	-0.03	0.13	0.19*	-0.10	-0.03
	Q	-0.05	0.0	-0.02	-0.09	0.0	0.0	0.0	0.0	0.0	0.14	-0.25	-0.14
Khabat	MK	-0.05	-0.03	-0.09	-0.06	-0.20*	-0.10	0.0	-0.06	0.02	0.06	-0.13	-0.02
	Q	-0.15	-0.10	-0.27	-0.16	-0.19	0.0	0.0	0.0	0.0	0.03	-0.26	-0.12
Mergasur	MK	-0.10	-0.01	-0.05	-0.10	-0.05	-0.35**	-0.04	-0.10	-0.14	-0.04	-0.10	0.04
	Q	-0.83	-0.08	-0.33	-0.45	-0.15	-0.02	0.0	0.0	0.0	-0.16	-0.38	0.31
Salahaddin	MK	0.01	0.14	0.01*	-0.23**	-0.18*	-0.13	0.02	-0.06	-0.07	0.01	-0.15*	-0.03
	Q	0.03	0.52	0.03	-0.89*	-0.30	0.0	0.0	0.0	0.0	0.03	-0.55	-0.20
Shaqlawa	MK	-0.08	0.14	0.19*	-0.14	-0.15	-0.33**	-0.05	-0.11	-0.21*	0.0	-0.10	-0.18*
	Q	-0.51	0.77	0.90*	-0.61	-0.30	-0.02	0.0	0.00	0.0	0.0	-0.42	-1.02
Soran	MK	-0.21*	0.08	0.15	-0.12	-0.24**	-0.30**	-0.05	-0.04	-0.14	0.05	-0.20*	-0.19*
	Q	-0.87*	0.31	0.54	-0.49	-0.49*	0.0	0.0	0.0	0.0	0.10	-0.69*	-0.91*
Zawita	MK	-0.06	0.22**	0.012	-0.19*	-0.24**	-0.36**	0.0	-0.19*	-0.27**	-0.15*	-0.19*	-0.02
	Q	-0.38	1.24*	0.082	-0.90*	-0.63*	-0.01	0.0	0.0	0.0	-0.43	-0.93*	-0.15

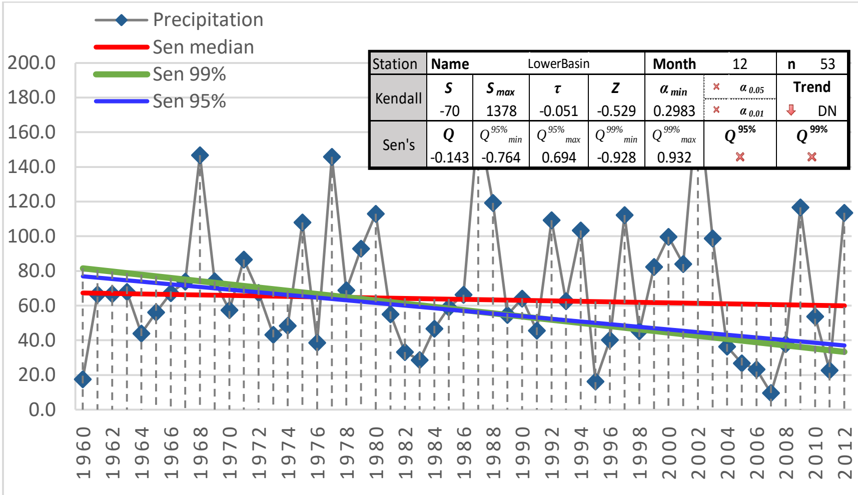
*Significant at 95%: **Significant at 99%

Lower catchment

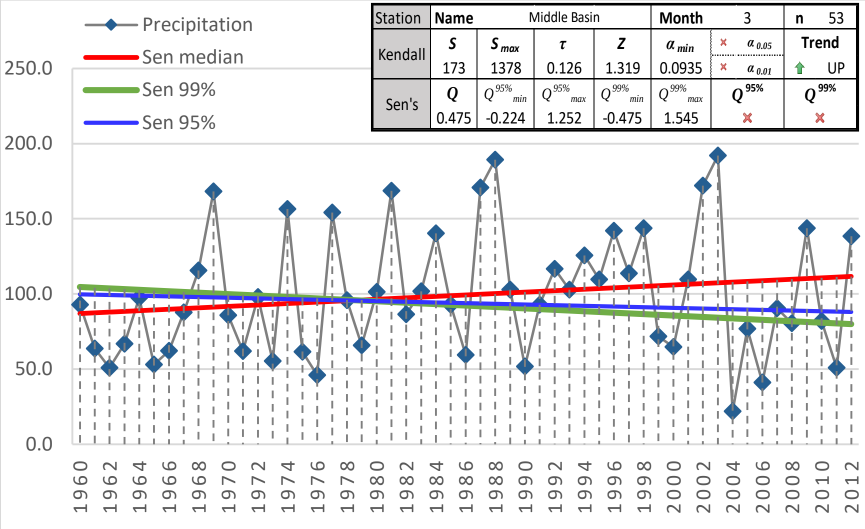




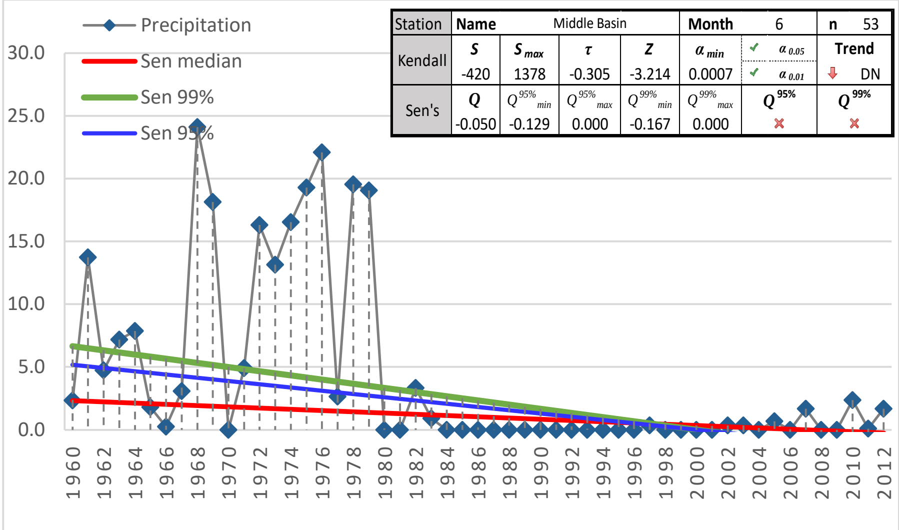




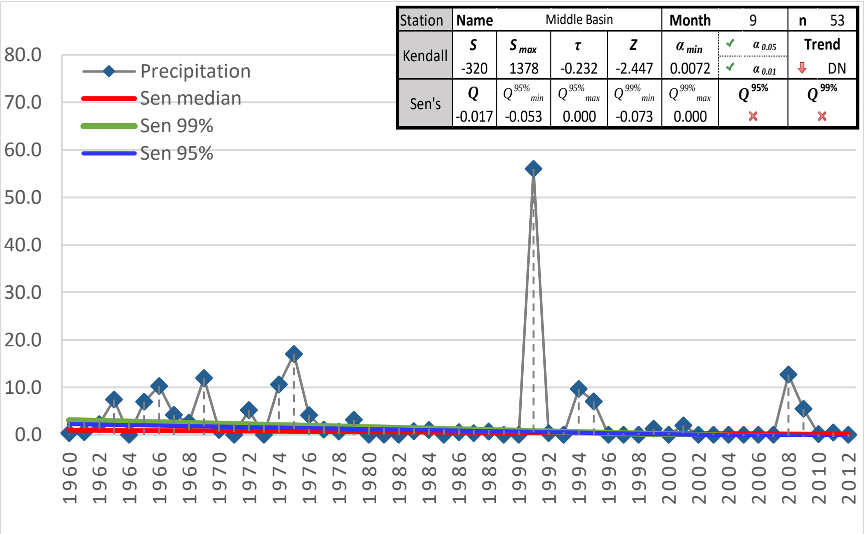
Middle catchment



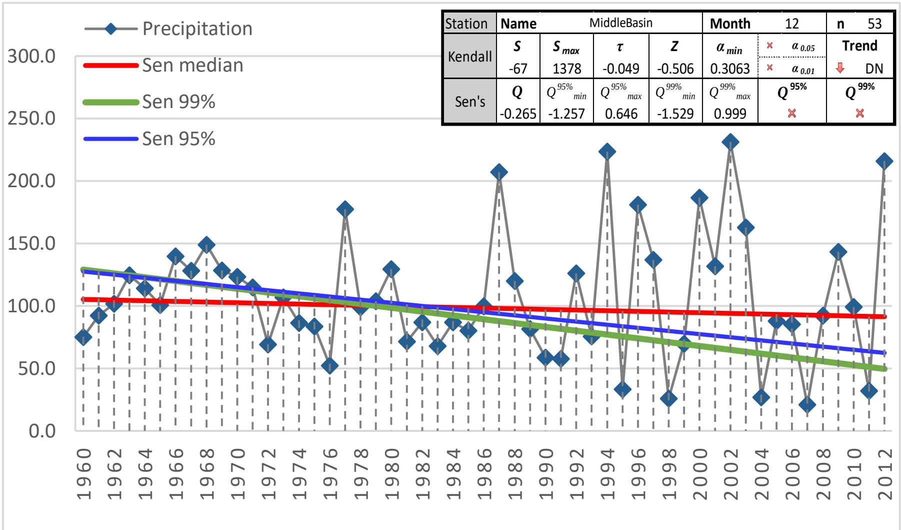
Station	Name		Middle Basin	Month	3	n	53
Kendall	S	S_{max}	τ	Z	α_{min}	× $\alpha_{0.05}$	Trend
	173	1378	0.126	1.319	0.0935	× $\alpha_{0.01}$	UP
Sen's	Q	$Q^{95\%}_{min}$	$Q^{95\%}_{max}$	$Q^{99\%}_{min}$	$Q^{99\%}_{max}$	$Q^{95\%}$	$Q^{99\%}$
	0.475	-0.224	1.252	-0.475	1.545	×	×



Station	Name		Middle Basin	Month	6	n	53
Kendall	S	S_{max}	τ	Z	α_{min}	✓ $\alpha_{0.05}$	Trend
	-420	1378	-0.305	-3.214	0.0007	✓ $\alpha_{0.01}$	DN
Sen's	Q	$Q^{95\%}_{min}$	$Q^{95\%}_{max}$	$Q^{99\%}_{min}$	$Q^{99\%}_{max}$	$Q^{95\%}$	$Q^{99\%}$
	-0.050	-0.129	0.000	-0.167	0.000	×	×



Station	Name		Middle Basin	Month	9	n	53
Kendall	S	S_{max}	τ	Z	α_{min}	✓ $\alpha_{0.05}$	Trend
	-320	1378	-0.232	-2.447	0.0072	✓ $\alpha_{0.01}$	DN
Sen's	Q	$Q^{95\%}_{min}$	$Q^{95\%}_{max}$	$Q^{99\%}_{min}$	$Q^{99\%}_{max}$	$Q^{95\%}$	$Q^{99\%}$
	-0.017	-0.053	0.000	-0.073	0.000	×	×



Station	Name		MiddleBasin	Month	12	n	53
Kendall	S	S_{max}	τ	Z	α_{min}	× $\alpha_{0.05}$	Trend
	-67	1378	-0.049	-0.506	0.3063	× $\alpha_{0.01}$	DN
Sen's	Q	$Q^{95\%}_{min}$	$Q^{95\%}_{max}$	$Q^{99\%}_{min}$	$Q^{99\%}_{max}$	$Q^{95\%}$	$Q^{99\%}$
	-0.265	-1.257	0.646	-1.529	0.999	×	×

Upper catchment

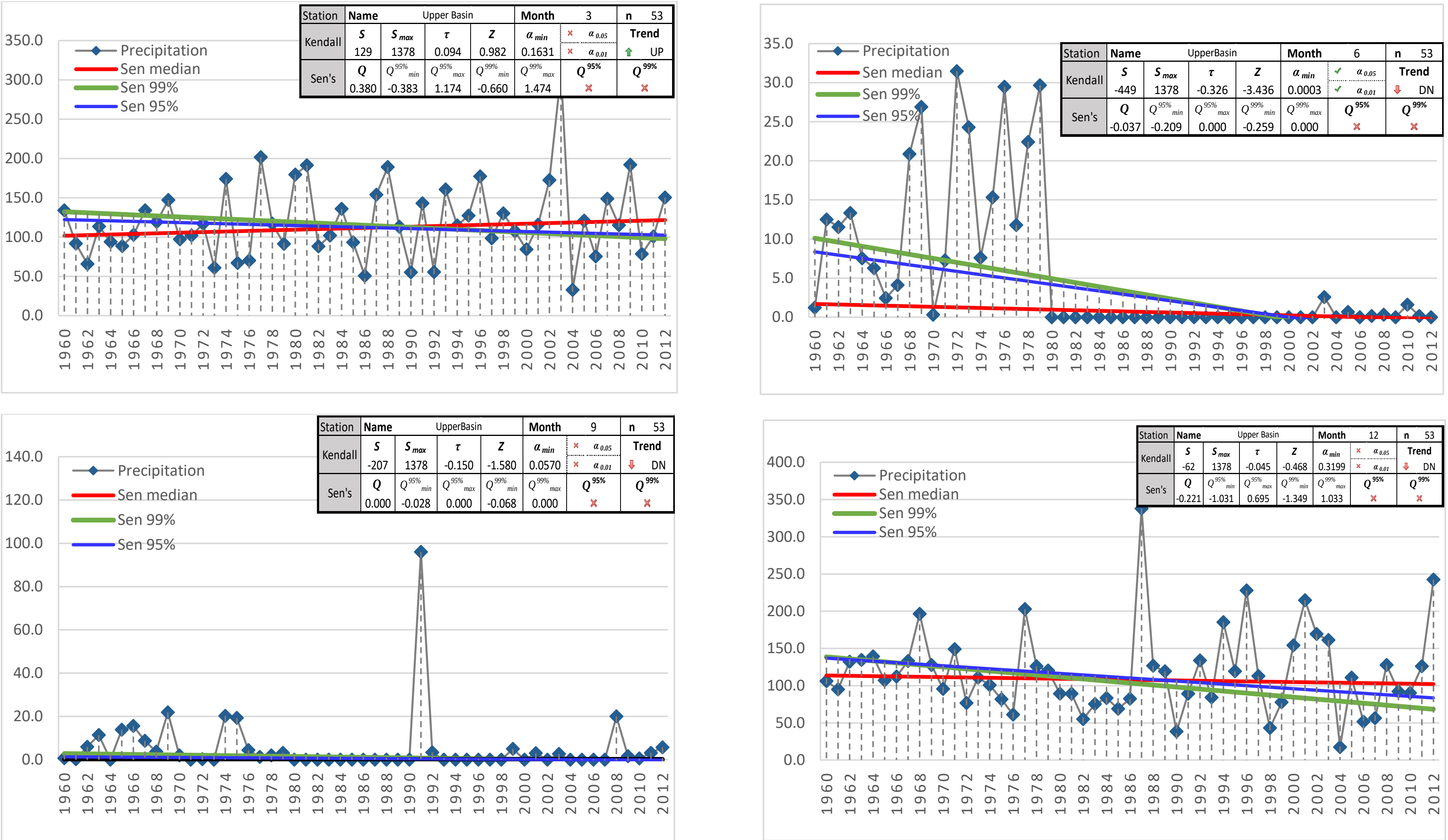


Figure 6.9 Analysis of precipitation trends using Mann-Kendall and Sen’s slope estimator and their significant tests parameters.

6.4.1.4 Seasonal and annual analysis of precipitation

The MK and Sen's Slop tests were used to identify trends in seasonal and annual hydroclimatic data from 1960-2012. Table 6.6 shows the results. Results from both statistical tests, MK and Sen's Slope, were consistent with one another. Significant decreasing trends were observed in autumn season time series only at Zawita station. For the annual precipitation series, significant decreasing trends were detected only at Soran station. At other stations, significant decreasing trends were seen for summer season. Fig 6.10, presents the spatial distribution of seasonal and annual precipitation trends.

Table 6.6 Seasonal and annual trends in precipitation as estimated from Mann-Kendall and Sen's slope statistics for various meteorological station.

Station	Test	Spring	Summer	Autumn	Winter	Annual
Akre	MK	-0.13	-0.40**	-0.13	0.0	-0.14
	Q	-0.29	-0.00**	-0.22	0.03	-0.13
Amedi	MK	0.08	-0.49**	-0.17	-0.12	-0.07
	Q	0.22	-0.00**	-0.44	-0.42	-0.11
Erbil	MK	-0.06	0.15	0.05	-0.06	-0.07
	Q	-0.14	0.0	0.06	-0.10	-0.07
Khabat	MK	-0.14	-0.26*	0.0	-0.06	-0.13
	Q	-0.25	0.0**	0.0*	-0.11	-0.12
Mergasur	MK	-0.09	-0.41**	-0.11	-0.07	-0.16
	Q	-0.28	-0.01**	-0.26	-0.41	-0.32
Salahaddin	MK	-0.14	-0.17	-0.07	0.09	-0.11
	Q	-0.35	-0.0	-0.11	0.19	-0.11
Shaqlawa	MK	0.02	-0.38**	-0.05	-0.03	-0.14
	Q	0.05	-0.0**	-0.07	-0.01	-0.10
Soran	MK	-0.03	-0.29**	-0.08	-0.17	-0.23*
	Q	-0.06	0.0**	-0.15	-0.43	-0.19*
Zawita	MK	-0.13	-0.42**	-0.21*	0.08	-0.07
	Q	-0.31	0.0**	-0.50*	0.31	-0.11

*Significant at 95%: **Significant at 99%

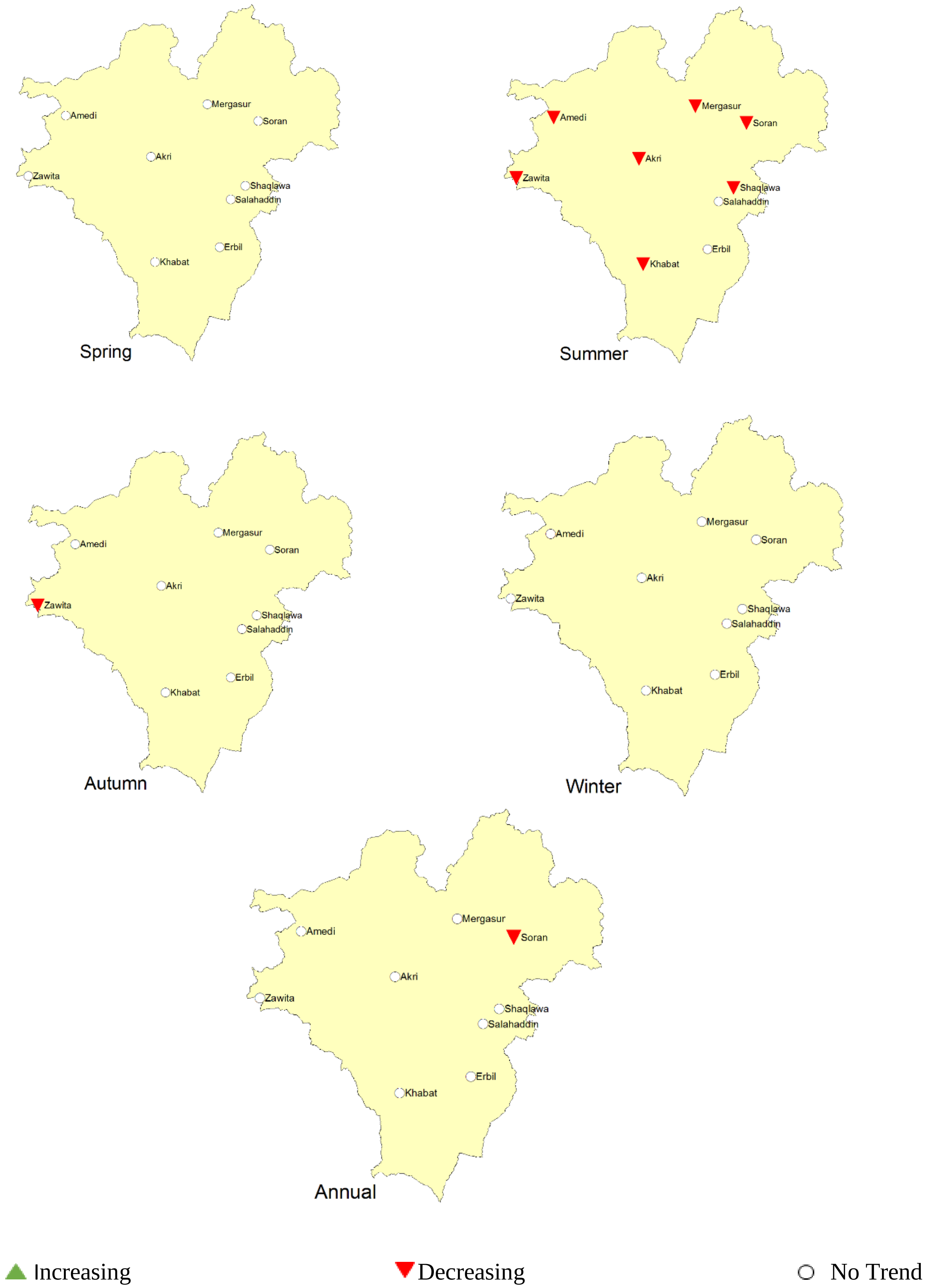


Figure 6.10 Spatial distribution of weather stations with increasing, decreasing and no trends for the seasonal annual precipitation time series.

6.4.2 Temperature

Similar to the precipitation data, temperature data for a 53 yeas (1960-2012) taken from meteorological stations. The average, maximum and minimum temperature data analysed. The mean annual air temperature of the study area is 20.1°C. The mean annual minimum temperature is 13.8°C and the mean annual maximum temperature is 25.8°C. The mean monthly maximum and minimum temperature are observed in August and January, which are 40.6°C and 2.4, respectively. The mean monthly, maximum and minimum temperature are presented in Fig (6.11). As it is shown in Table (6.7), the minimum air temperature is 6.9°C in January and the maximum air temperature is 33.4°C in July. The annual range of temperature is 26.5°C.

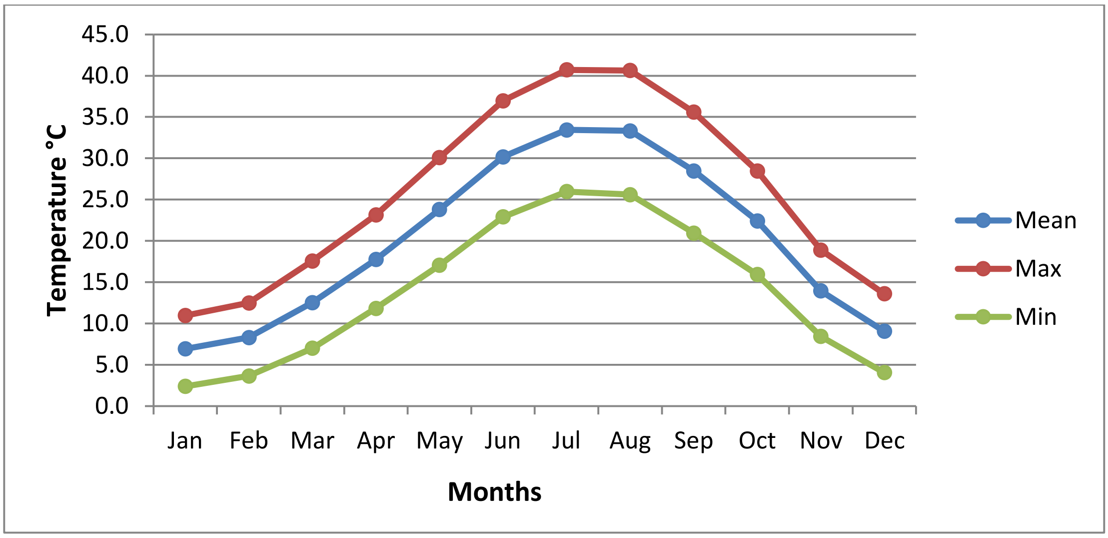


Figure 6.11 Monthly mean, maximum, and minimum temperature (1960-2012).

The maximum air temperature occurs only in June, July, August and September, low temperature values are observed during the rainy seasons. Months in the rainy seasons are cooler than months in dry seasons.

Table 6.7 Mean, max, min, standard deviation, and coefficient of variation precipitation 1960-2012.

Station	Season	Mean	Max	Min	Stdev	CV
Akre	Spring	19.6	12.6	15.9	1.5	10.3
	Summer	33.2	26.9	29.8	1.3	22.2
	Autumn	22.8	17.6	19.9	1.2	17.0
	Winter	9.6	4.1	6.5	1.2	5.3
	Annual	20.0	16.2	18.0	1.0	17.8
Amedi	Spring	16.1	10.5	13.0	1.3	10.0
	Summer	32.2	21.4	27.3	1.6	16.6
	Autumn	20.4	15.2	17.5	1.3	13.4
	Winter	7.0	1.7	3.7	1.2	3.1
	Annual	18.3	13.4	15.4	0.9	16.3
Erbil	Spring	22.3	14.4	18.4	1.8	10.4
	Summer	34.9	29.0	31.7	1.6	20.0
	Autumn	25.3	19.5	22.2	1.2	18.6
	Winter	12.5	4.4	8.1	1.6	4.9
	Annual	23.3	18.0	20.1	1.3	15.8
Khabat	Spring	21.5	15.1	18.6	1.4	13.7
	Summer	33.9	28.4	31.5	1.1	27.7
	Autumn	24.2	19.6	22.1	1.0	22.6
	Winter	11.6	5.2	8.3	1.2	6.7
	Annual	22.6	18.5	20.2	0.9	22.9
Mergasur	Spring	17.3	10.8	14.2	1.5	9.5
	Summer	31.3	22.0	28.0	1.7	16.4
	Autumn	21.4	15.8	18.3	1.3	13.8
	Winter	8.1	2.6	4.6	1.2	3.8
	Annual	19.4	13.7	16.3	1.1	14.4
Salahaddin	Spring	19.6	11.4	15.1	1.7	8.7
	Summer	32.1	26.2	28.9	1.3	23.0
	Autumn	22.5	15.7	19.1	1.3	14.6
	Winter	9.6	2.4	5.6	1.4	3.9
	Annual	20.0	14.5	17.2	1.2	14.8
Shaqlawa	Spring	19.5	11.3	15.3	1.7	9.2
	Summer	31.8	26.7	29.2	1.3	21.7
	Autumn	22.7	16.3	19.2	1.3	14.5
	Winter	8.7	2.8	5.7	1.3	4.4
	Annual	19.8	15.0	17.4	1.1	15.4
Soran	Spring	19.9	12.8	15.8	1.5	10.3
	Summer	32.3	26.7	29.4	1.3	23.1
	Autumn	23.2	18.5	20.3	1.1	18.3
	Winter	9.0	3.3	5.7	1.3	4.3
	Annual	20.1	15.8	17.8	1.0	17.8
Zawita	Spring	18.7	11.6	14.9	1.5	9.9
	Summer	31.5	23.6	28.5	1.5	18.5
	Autumn	21.9	16.8	19.1	1.2	16.6
	Winter	21.9	16.8	19.1	1.2	16.6
	Annual	19.6	14.6	16.9	1.0	16.6

6.4.2.1 Monthly analysis of temperature

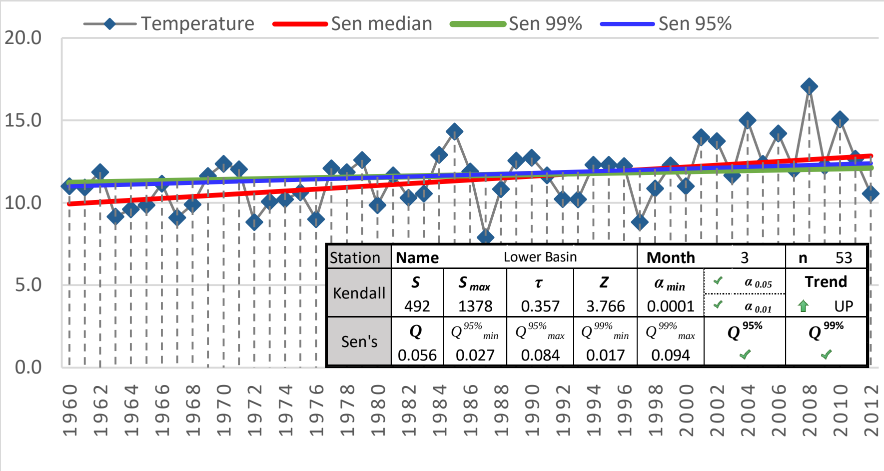
The result of Mann-Kendall and Sen's tests showed that all stations exhibited a statistically significant increase trend at the level of 99% and 95% for the period 1960-2012. Table 6.8 shows that the result is consistent with the annual and seasonal scale. In general, temperature increased in summer months from June to September for most of stations. Temperature in August increased more than other months of the year. In contrast, no trends were observed in November at all stations of the catchment. It was observed that during the winter months (December, January and February) temperature increased significantly but a decreasing trend was noticed in Zawita station in December. Spring and autumn have similar trends for all months with the exception of the Amedi station in the upper part of the basin and the Zawita station in the middle part of the basin. A sample representation for this analysis is shown in (Fig 6.12) each of these figures represents one month (March, June, September, and December) where these months were selected to show the performance of both Kendal and Sen Methods under various temperature series). All of the charts represents the temperature trend of (Upper, Middle and Lower) stations. These results indicate that the values of this parameter are season dependent with values generally higher for summer and spring months than those for winter and autumn months. In some cases, the later months tend to show even some increase trend in temperature indicated by the positive values.

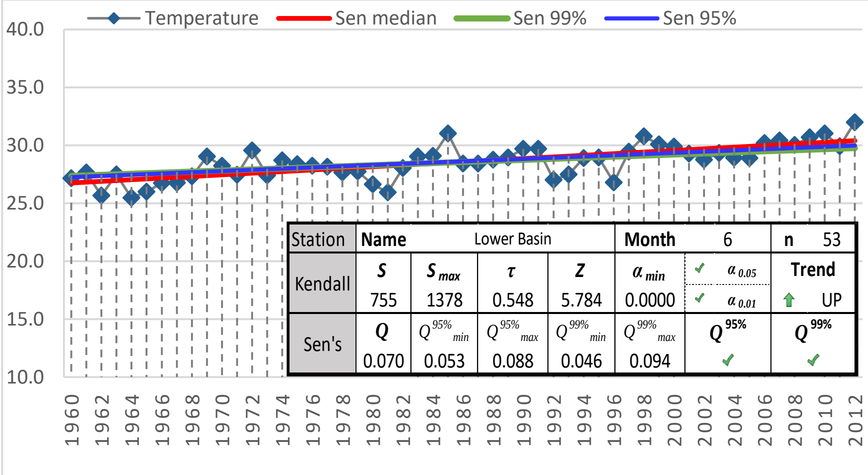
Table 6.8 Monthly trends in temperature as estimated from Mann-Kendall and Sen's slope statistics for various meteorological station.

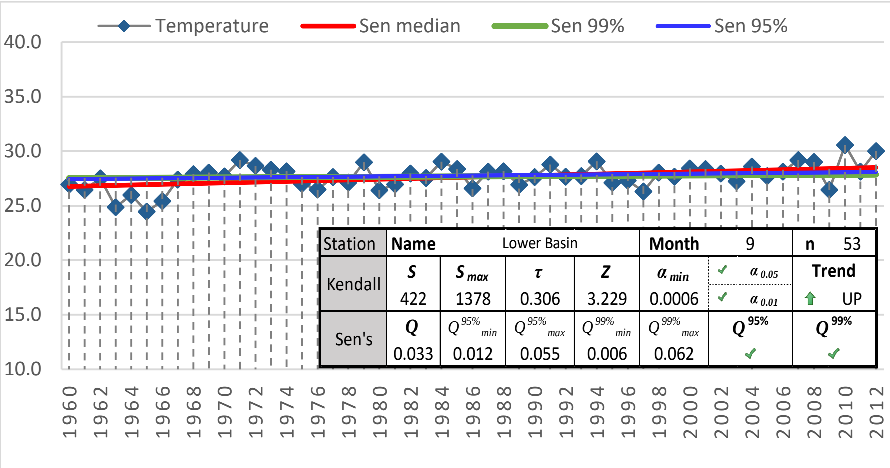
Station	Test	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Akre	MK	0.27**	0.23**	0.22**	0.30**	0.25**	0.53**	0.56**	0.42**	0.15	0.27**	0.09	0.36**
	Q	0.04**	0.04*	0.03*	0.06**	0.03*	0.07**	0.06**	0.04**	0.02	0.05**	0.01	0.04**
Amedi	MK	0.02	0.09	0.11*	0.05	0.05	0.35**	0.30**	0.27**	0.24**	0.31**	0.09	0.04
	Q	0.00	0.01	0.01	0.01	0.01	0.07**	0.03**	0.03*	0.03*	0.04**	0.01	0.01
Erbil	MK	0.39**	0.51**	0.38**	0.33**	0.39**	0.613**	0.47**	0.44**	0.38**	0.38**	0.14	0.41**
	Q	0.07**	0.10**	0.06**	0.06**	0.08**	0.09**	0.08**	0.06**	0.05**	0.06**	0.02	0.06**
Khabat	MK	0.25**	0.40**	0.24**	0.29**	0.25**	0.38**	0.44**	0.32**	0.10	0.19*	0.02	0.19
	Q	0.04**	0.07**	0.03*	0.04**	0.05**	0.05**	0.05**	0.03**	0.01	0.02	0.00	0.02
Mergasur	MK	0.23**	0.29**	0.32**	0.27**	0.19*	0.417**	0.52**	0.35**	0.34**	0.30**	0.18	0.22**
	Q	0.03*	0.04**	0.04**	0.06**	0.03	0.08**	0.06**	0.05**	0.05**	0.05**	0.03	0.03*
Salahaddin	MK	0.28**	0.37**	0.35**	0.30**	0.38**	0.46**	0.39**	0.39**	0.26**	0.43**	0.18	0.41**
	Q	0.05**	0.06**	0.06**	0.06**	0.05**	0.06**	0.04**	0.05**	0.03**	0.06**	0.03	0.06**
Shaqlawa	MK	0.30**	0.34**	0.28**	0.29**	0.23**	0.55**	0.56**	0.41**	0.27**	0.40**	0.11	0.35**
	Q	0.05**	0.06**	0.04**	0.06**	0.03*	0.08	0.07**	0.04**	0.03**	0.06**	0.02	0.05**
Soran	MK	0.19	0.41**	0.25**	0.30**	0.20	0.47**	0.55**	0.44**	0.21*	0.13	0.08	0.21
	Q	0.04*	0.06**	0.04*	0.06**	0.02*	0.05**	0.06**	0.05**	0.01	0.01	0.01	0.02*
Zawita	MK	0.19	0.37**	0.31**	0.24**	0.08	0.30**	0.46**	0.34**	0.13	0.09	0.05	-0.07
	Q	0.03	0.06**	0.05**	0.05*	0.01	0.06**	0.06**	0.04**	0.01	0.01	0.01	0.0

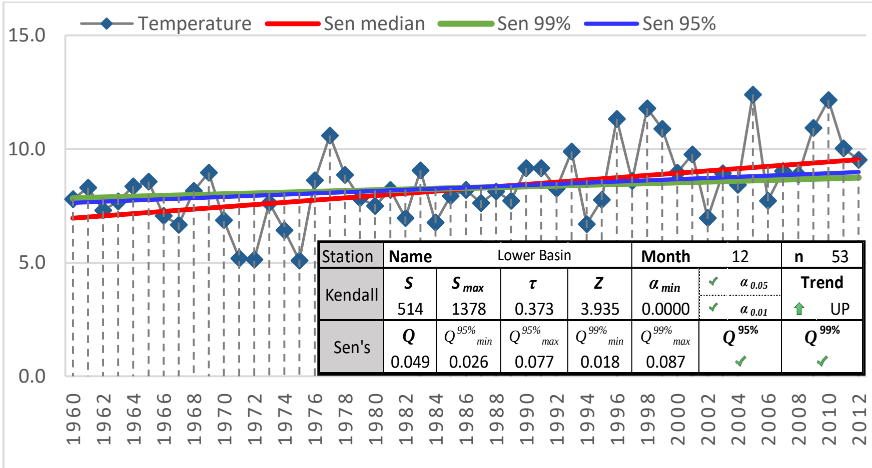
*Significant at 95%: **Significant at 99%

Lower catchment

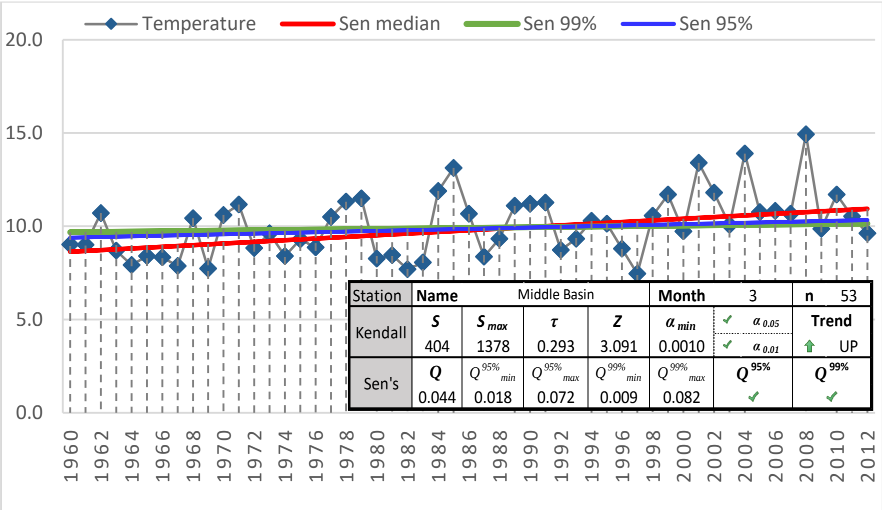


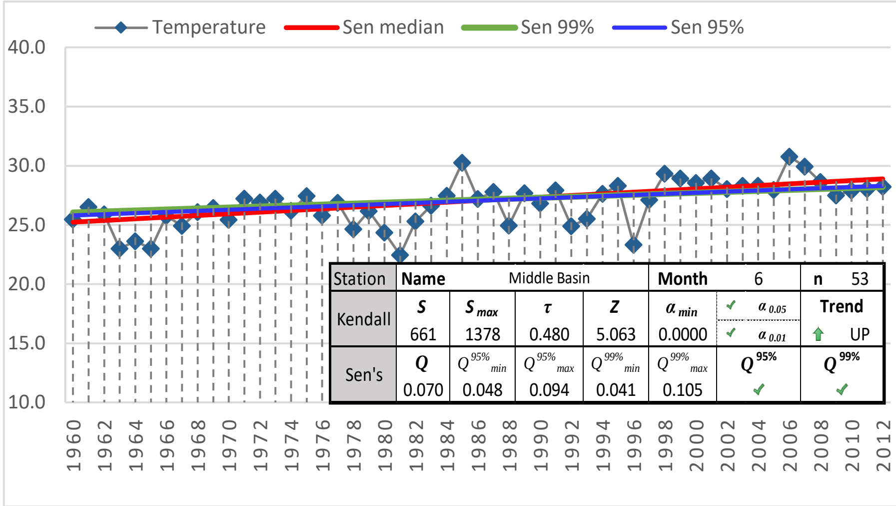


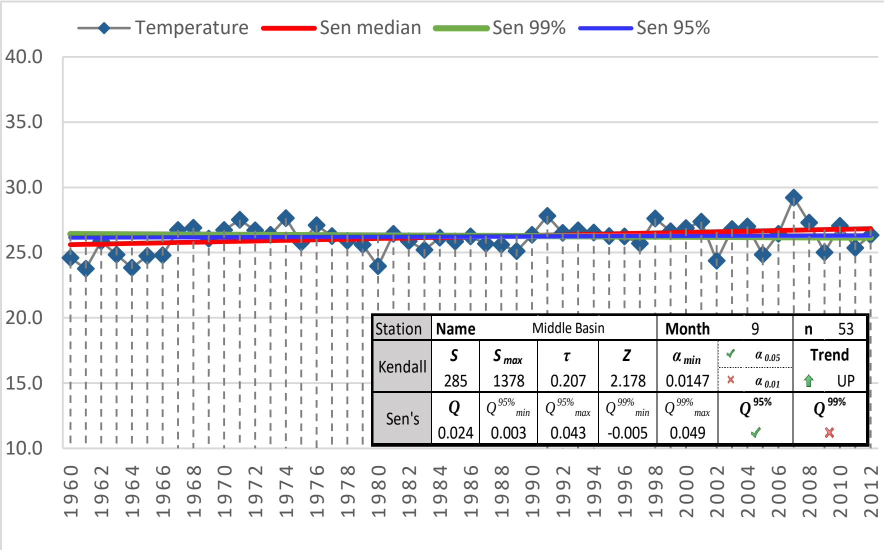


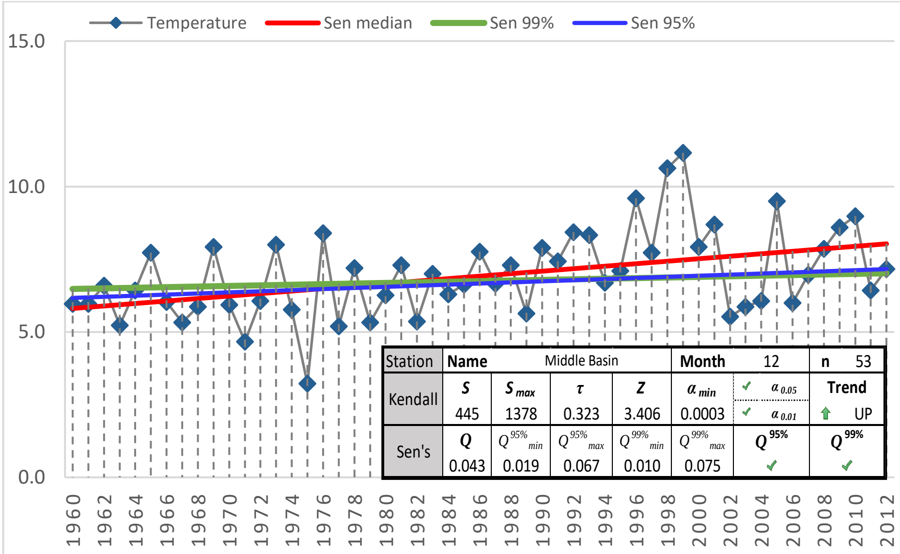


Middle catchment









Upstream- Stations

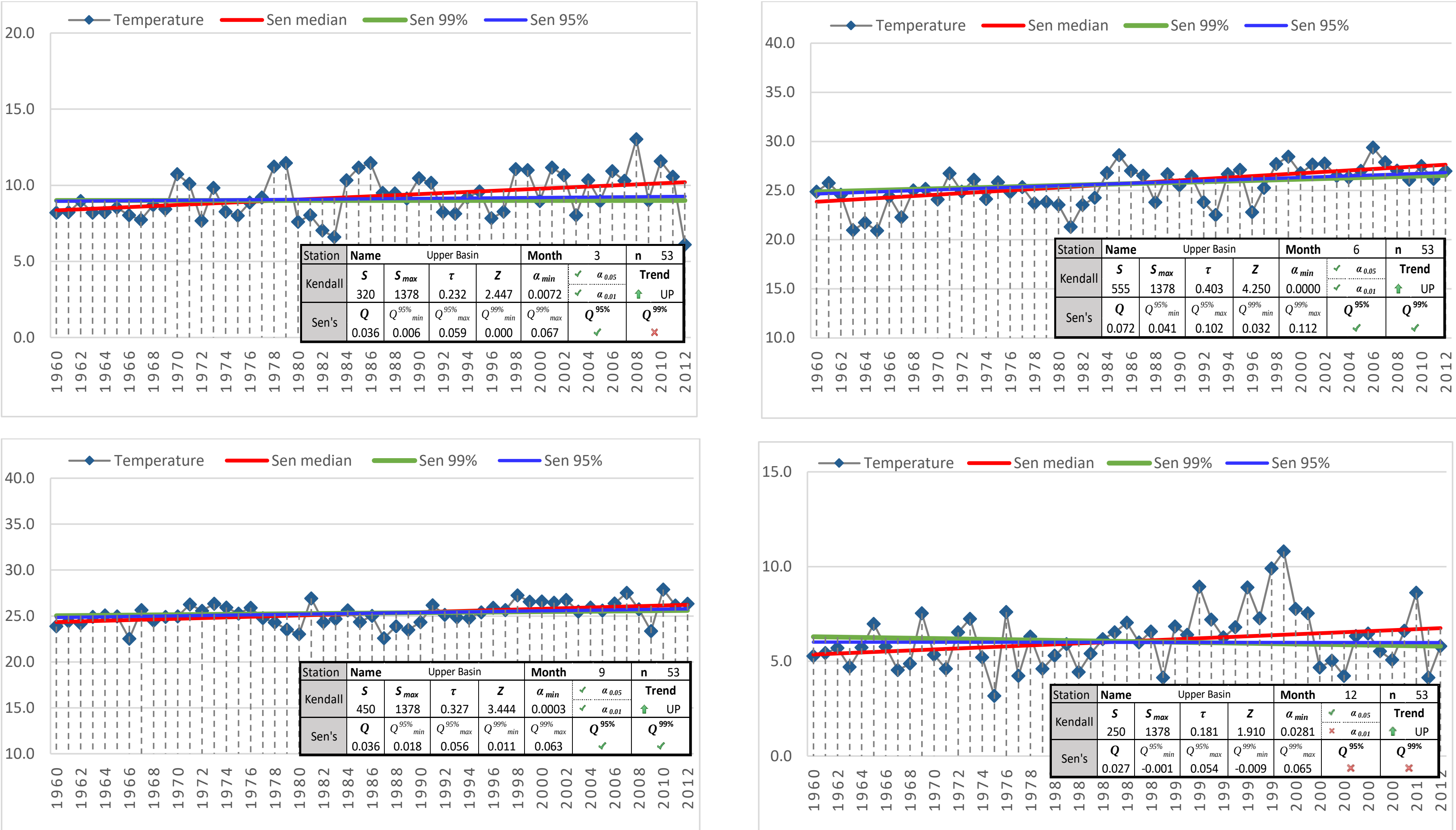


Figure 6.12 Analysis of temperature trends using Mann-Kendall and Sen's Slope estimator and their significant tests parameters.

6.4.2.2 Seasonal and annual analysis of temperature

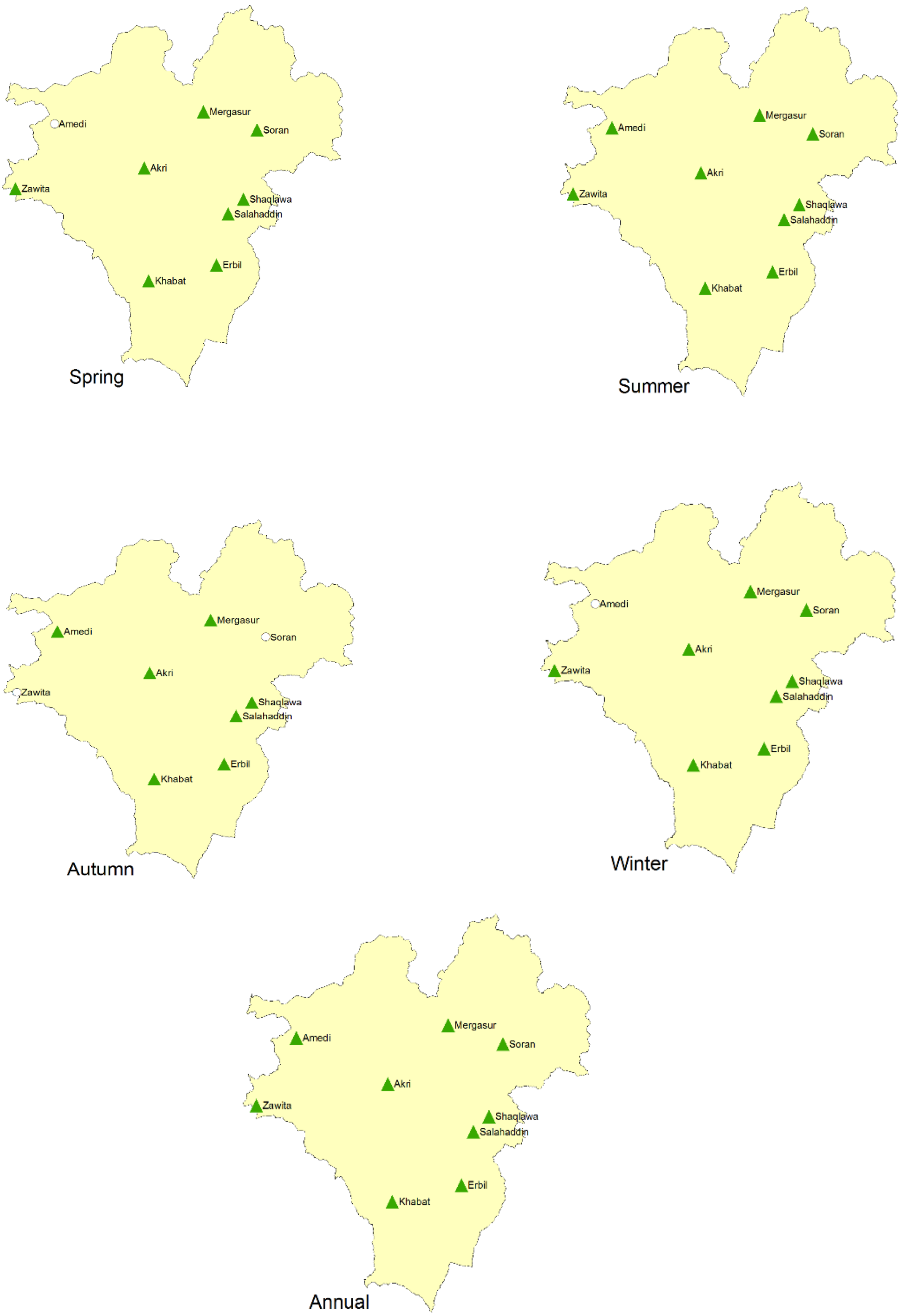
Table 6.9 shows the results. Similar to the monthly analysis, results from both statistical tests, MK and Sen's Slope, were consistent with one another. For the annual temperature series, all stations exhibited a statistically significant increasing trend at the level of 99% and 95%. Seasonally, spring and winter temperature shows highly significant increasing trends at significance level of 99% in all stations except for the Amedi station in the upper basin. Similar highly significant increasing trends at significance level of 99% were found at all station in summer.

Table 6.9 Seasonal and annual trends in temperature as estimated from Mann-Kendall and Sen's slope statistics for various meteorological station.

Station	Test	Spring	Summer	Autumn	Winter	Annual
	MK	0.32^{**}	0.58^{**}	0.21^{*}	0.37^{**}	0.51^{**}
Akre	Q	0.04^{*}	0.06	0.02	0.04^{*}	0.04^{*}
	MK	0.07	0.45^{**}	0.20^{*}	0.08	0.30^{**}
Amedi	Q	0.00	0.05^{*}	0.02^{*}	0.01	0.02^{*}
	MK	0.52^{**}	0.50^{**}	0.40^{**}	0.59^{**}	0.66^{**}
Erbil	Q	0.08	0.07	0.04^{*}	0.08	0.07^{*}
	MK	0.38^{**}	0.43^{**}	0.16	0.41^{**}	0.46^{**}
Khabat	Q	0.04^{*}	0.04^{*}	0.01^{*}	0.04^{*}	0.03^{*}
	MK	0.29^{**}	0.48^{**}	0.33^{**}	0.30^{**}	0.46^{**}
Mergasur	Q	0.04^{*}	0.06	0.03^{*}	0.03^{*}	0.04^{*}
	MK	0.45^{**}	0.47^{**}	0.36^{**}	0.48^{**}	0.58^{**}
Salahaddin	Q	0.06	0.05^{*}	0.04^{*}	0.06	0.05^{*}
	MK	0.33^{**}	0.59^{**}	0.31^{**}	0.46^{**}	0.53^{**}
Shaqlawa	Q	0.04^{*}	0.07	0.04^{*}	0.05^{*}	0.05^{*}
	MK	0.35^{**}	0.55^{**}	0.11	0.34^{**}	0.48^{**}
Soran	Q	0.04^{*}	0.06	0.01^{*}	0.04^{*}	0.04^{*}
	MK	0.29^{**}	0.43^{**}	0.09	0.32^{**}	0.41^{**}
Zawita	Q	0.03^{*}	0.05	0.01^{*}	0.03	0.03^{*}

*Significant at 95%: **Significant at 99%

Meanwhile, autumn season shows highly significant increasing trends in Erbil, Mergasur, Salahaddin and Shaqlawa at 99% significance level, while no significant trends found at Zawita and Soran station in the middle and the upper basin and at Khabat station in the lower basin. Fig 6.13 presents the spatial distribution of seasonal and annual temperature trends.



Increasing Decreasing No Trend

Figure 6.13 Spatial distribution of weather stations with increasing, decreasing and no trends for the seasonal annual temperature time series.

6.4.3 Discharge

6.4.3.1 Annual discharge variability

Available discharge data for the Great Zab River covers the period 1931-2012 and comes from the Deralok, Bekhme and Eski Kelek gauging stations (Table 6.10). In order to allow for comparison of the discharge along the Great Zab main stream, common periods have been selected (see Table 6.12). The records for the station at Deralok represent the river's natural flow after crossing the border between Turkey and Kurdistan Region and for middle of catchment at Bekhme and for measurement of downstream at Eski Kelek station.

Table 6.10 Summary of the discharge for the Great Zab River (1931-2012).

Station	Mean discharge (M^3/s)	Stdev	CV
Deralok	78.185	12.183	6.417
Bekhme	371.867	115.294	3.225
Eski-Kelek	389.515	122.480	3.180

Table 6.11 Monthly discharge (1931-2012).

Month	Great Zab at Eski Kelek (M^3/s)
Jan	251.3
Feb	373.7
Mar	572.3
Apr	857.7
May	831.7
Jun	512.5
Jul	271.8
Aug	154.8
Sep	120.5
Oct	124.7
Nov	159.9
Dec	201.8

Table 6.12 Summary of annual flow volume statistics for the Great Zab River BCM (1931-2012).

Station	Period	Mean	Minimum	Maximum	CV[a] (-)
Bekhme	1931-2004	12.1	22.3	3.5	0.29
	1931-1955	12.5	18.8	8.2	0.23
	1956-1984	12.3	22.2	8.4	0.26
	1985-2000	11.5	22	3.4	0.57
Eski Kelek	1932-2012	12.6	23.6	3.7	0.30
	1932-1955	13.3	20	8.7	0.23
	1956-1984	13	23.6	8.9	0.26
	1985-2000	12.7	23	3.7	0.51

Source: Compiled by research based on USGS; Ministry of Agriculture and Water Resources/ KRG

The mean annual flow for the entire period of record is 12.1 BCM at Bekhme and 12.6 BCM at Eski-Kelek. Maximum flow levels were recorded in 1969 with 22.2 BCM at Bekhme and 23.6 BCM at Eski-Kelek. This contrasts with the lowest annual flow of 3.5 BCM at Bekhme and 3.7 BCM at Eski Kelek in 1989.

6.4.3.2 Seasonality of the discharge

March, April, May and June contribute to around 60% of the annual mean discharge. September, October, November and December contribute more than 10% of the annual mean discharge. The highest peak happen in March, April or May according to the stations (around 17% of the annual mean), and the lowest in September or October (around 2.5% of the annual mean). Great Zab tributaries follow the same pattern of annual and interannual variations of flow. The overall water availability in the year is important, seasonal and interannual variations are to be taken into consideration especially in a context without developed reservoirs.

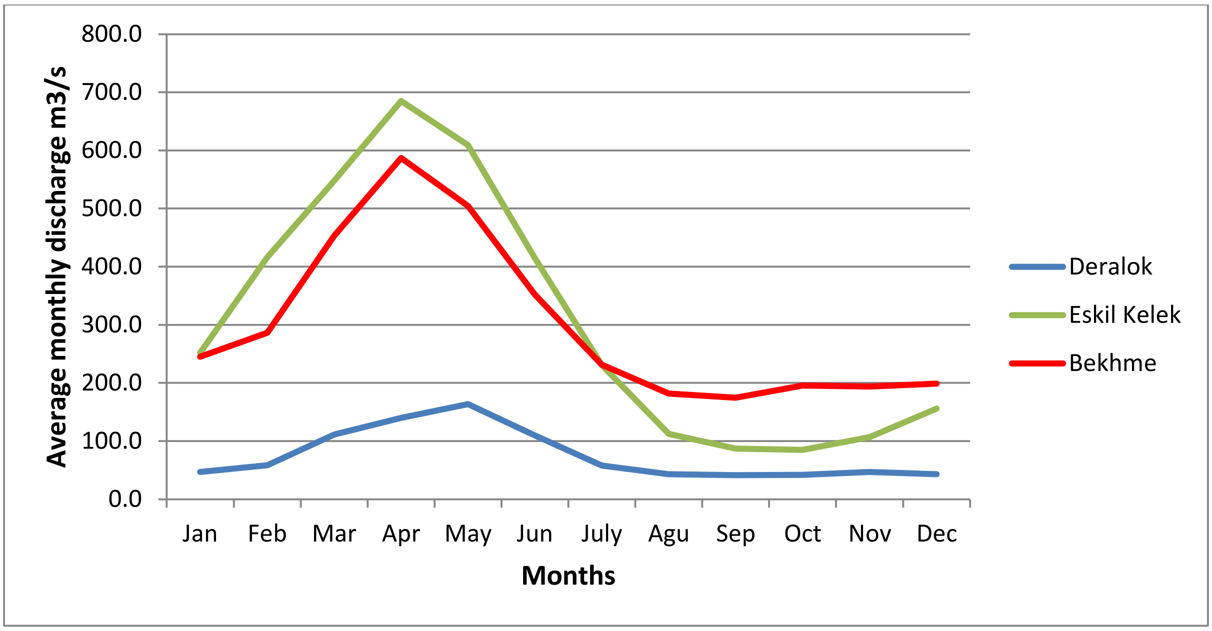


Figure 6.14 Monthly discharge for Great Zab at different station (1960-2012).

6.4.3.3 Trends and regime changes

Water resources availability and flow regimes in the Great Zab River are subject to change i.e. depletion. Apart from climate change, there are two other main factors that may cause reduction of flow:

- Increasing water abstractions in the upstream riparian country and/or within Kurdistan region, including increased groundwater use (which would result in reduced baseflow).
- Change of land use, however, it is unlikely that this is a major driver for the change of flow regimes as land use changes were moderate during the last decades.

The two longest hydrological time series of Great Zab have been examined for evidence of trends. Fig 6. 15 and 6.16 shows the mean annual discharge time series for gauging stations at Bekhme and farther downstream at Eski Kelek over the period 1931-2012.

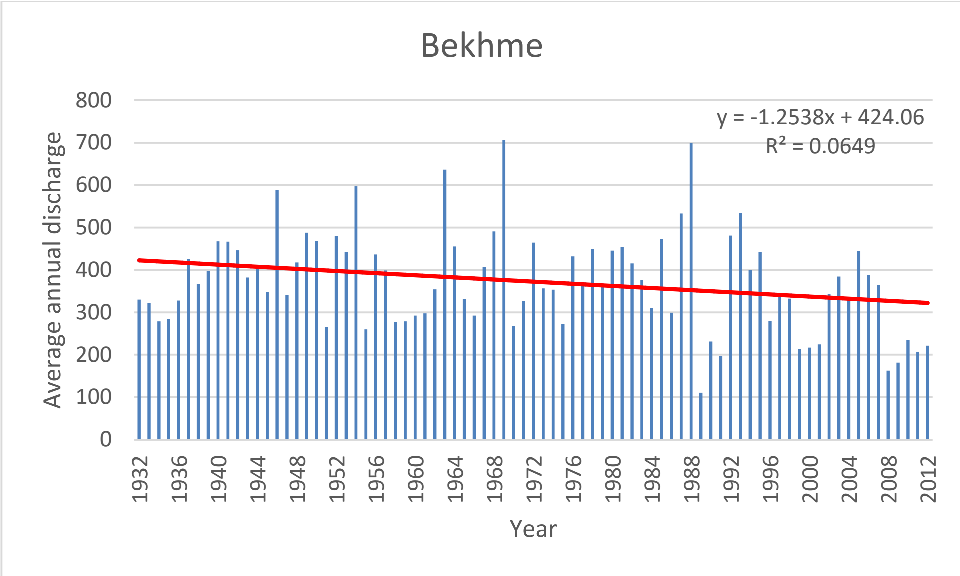


Figure 6.15 Long-term trends of annual mean discharge at Bekhme (1931-2004).

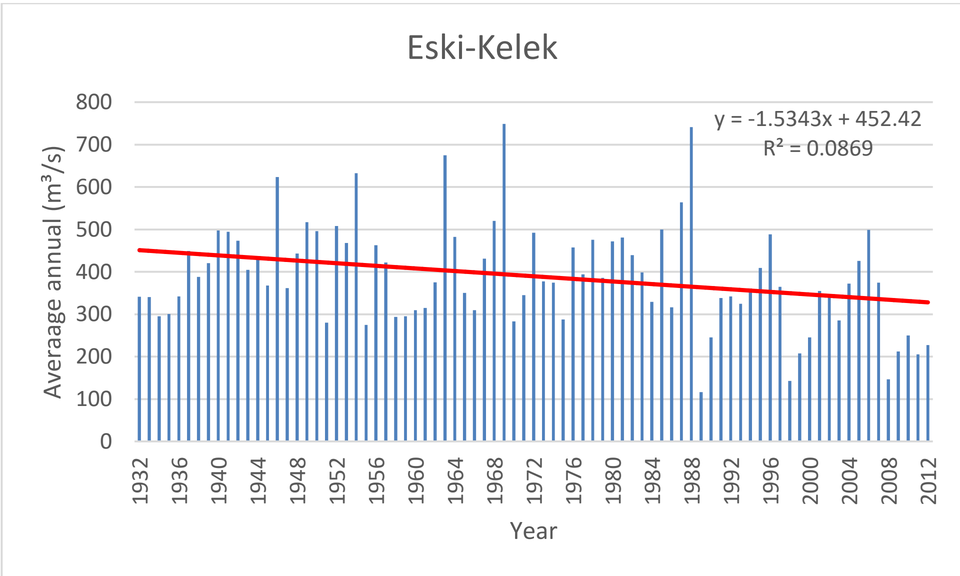


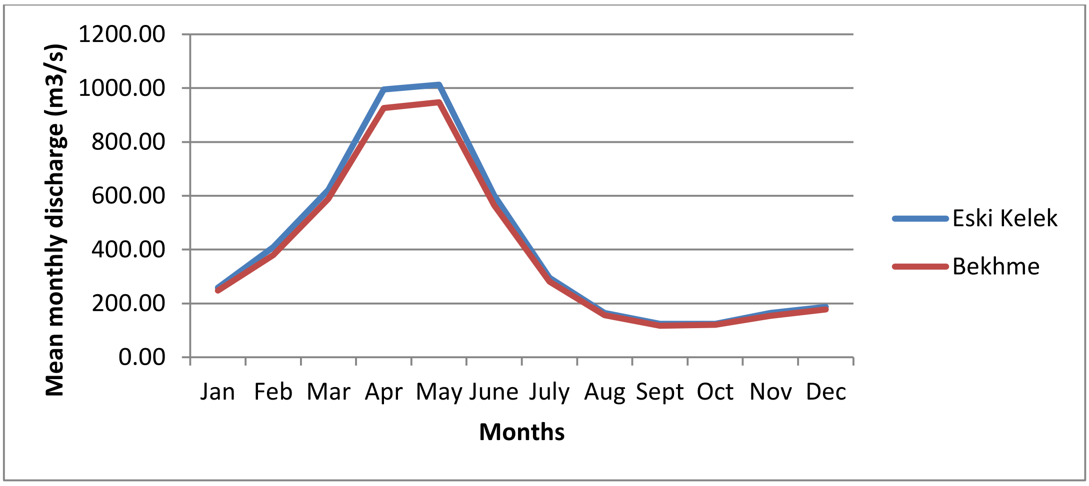
Figure 6.16 Long-term trends of annual mean discharge at Eski Kelek (1932-2012).

Data in Figure (6.15) seems to indicate a moderate negative trend for the annual mean flows of the Great Zab River at Eski Kelek station. At Bekhme station the apparent trend is much less significant and mainly due to the occurrence of four drought years since 1999. Both figures show the exceptional character of the drought period from 1999 to 2001 and the occurrence of another drought year in 2008. It should be noted that similar trends are found for precipitation measured at Khabat and Soran.

6.4.3.4 Flow regime

The natural flow regime of the Great Zab is represented in (Fig 6.17) shows a high-flow season from February to June and a low-flow from July to January with peak flows occur in April-May. The increased discharge during the high-flow period is typically generated by snow-melt and increased precipitation in the mountains area. Such a rainfall/snow-melt regime was typical for the 1931-2012 period of record at Bekhme and farther downstream at Eski Kelek. However if the stream-flow regime is split into a pre-1967 and past 1967 period, a significant modification with reduced high flows becomes apparent at Bekhme and Eski Kelek for the same period. The gradual melting of snow cover in the headwater region of the Great Zab River and its tributaries helps to maintain water levels.

a) Pre 1967



b) Post 1967

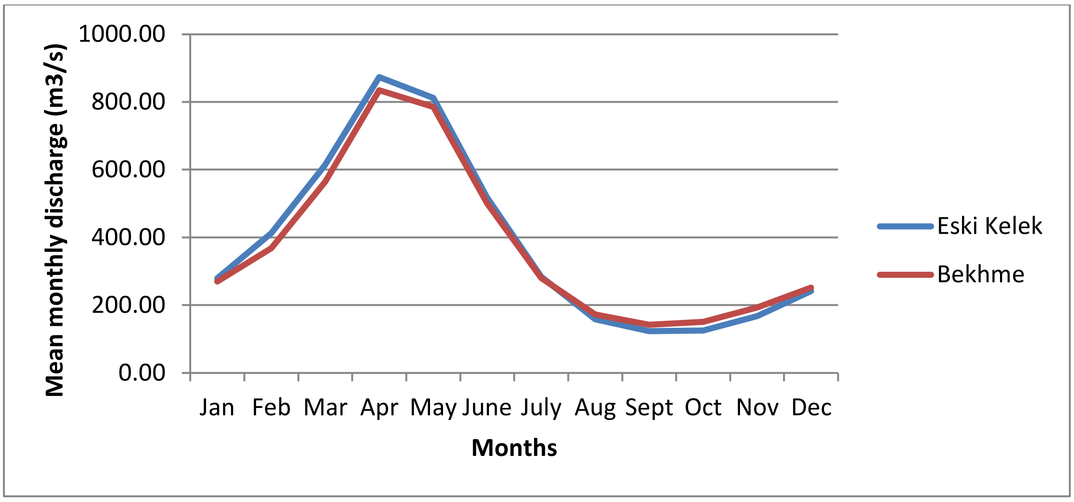


Figure 6.17 monthly flow regime of the Great Zab at different stations (1931-2012)

Peak discharge generally occurs in April. Maximum monthly discharge of 1681m^3/s was recorded in April 1969 at Bekhme, while measurement at the Eski Kelek indicated a maximum monthly discharge of 1781m^3/s for the same period. Minimum flow generally occurs in September. In Bekhme, a lowest monthly discharge of 33.1m^3/s was recorded in September 1989, while measurement at the Eski Kelek indicated a minimum monthly discharge of 35.1m^3/s for the same period.

6.4.3.5 Monthly analysis of discharge

The analysis of changes in monthly mean flow provides much greater temporal detail, and can help reveal and understand the cause of changes in seasonal and annual patterns (Table 6.13). For the lower part of the catchment at Eski-Kelek flow station, over the period 1960-2012, weak or no trends dominate the winter period from December to February, whereas decreasing trends dominate the period from June to August and from September to November at significance level of 99% and 95% respectively. In the middle part of the catchment at Bekhme flow station, highly significant decreasing trends dominate in month from March to June at significance level of 99%. Meanwhile, significant increasing trends occurred in

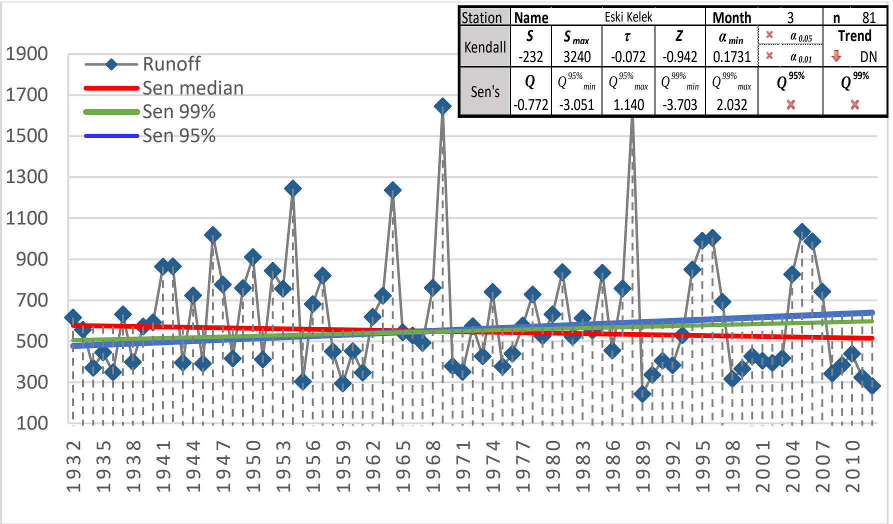
September and October at significance level of 99%, and in November and December at significance level of 95%.

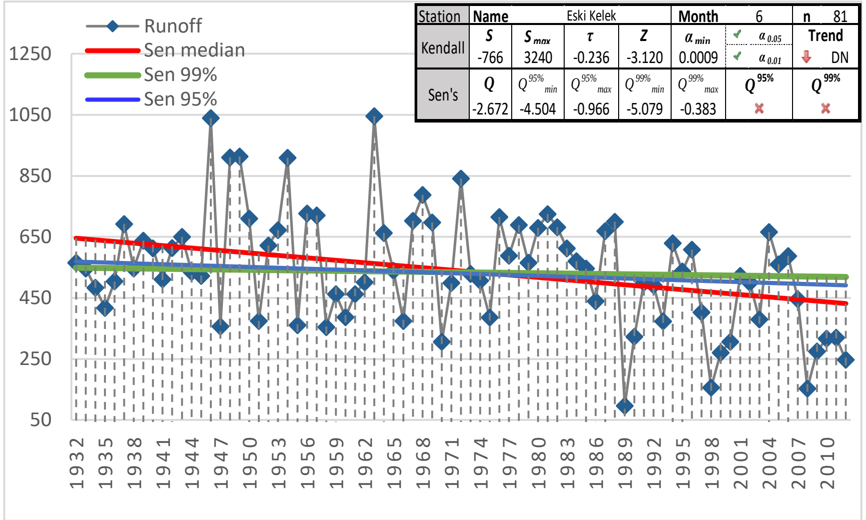
Table 6.13 Monthly trends in discharge as estimated from Mann-Kendall and Sen’s slope statistics for meteorological stations.

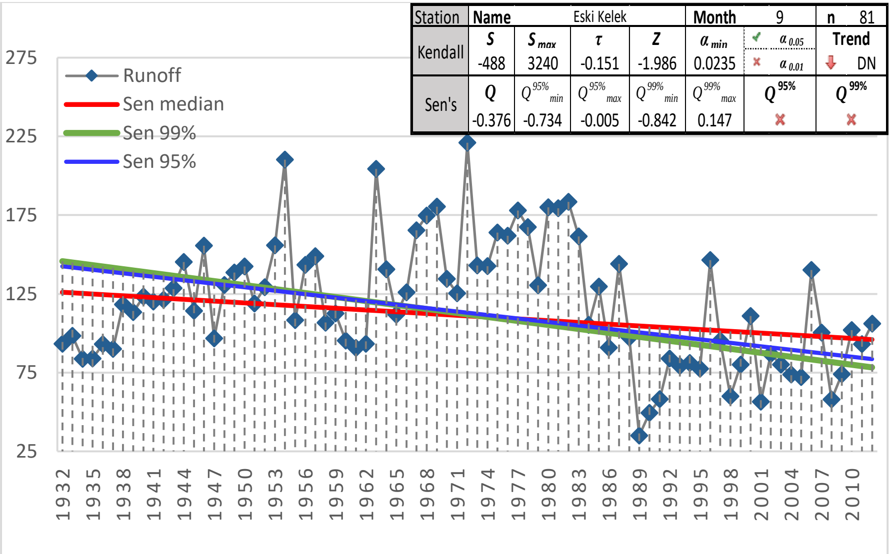
Station	Test	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bekhme	MK	-0.01	-0.0	-0.09	-0.2^{**}	-0.2^{**}	-0.2^{**}	-0.0	0.09	0.21^{**}	0.29^{**}	0.13^{*}	0.15^{*}
	Q	-0.08	-0.6	-1.21	-3.8^{**}	-6.3^{**}	-3.2^{**}	-0.4	0.27	0.46^{**}	0.86^{**}	0.64^{*}	0.63^{*}
Deralok	MK	-0.39	-0.3	-0.5^{**}	-0.27	-0.09	-0.24	-0.0	-0.37	-0.12	-0.15	-0.09	-0.36
	Q	-1.9^{*}	-1.7	-7.8^{**}	-3.59	-0.89	-2.92	-0.5	-0.78^{*}	-0.16	-0.27	-0.17	-0.69
Eski-Kelek	MK	0.02	-0.0	-0.07	-0.2^{**}	-0.3^{**}	-0.2^{**}	-0.1	-0.2^{**}	-0.15^{*}	-0.14^{*}	-0.1^{*}	-0.06
	Q	0.17	-0.6	-0.77	-4.7^{**}	-5.9^{**}	-2.6^{**}	-0.7	-0.6^{**}	-0.37^{*}	-0.37^{*}	-0.7^{*}	-0.33

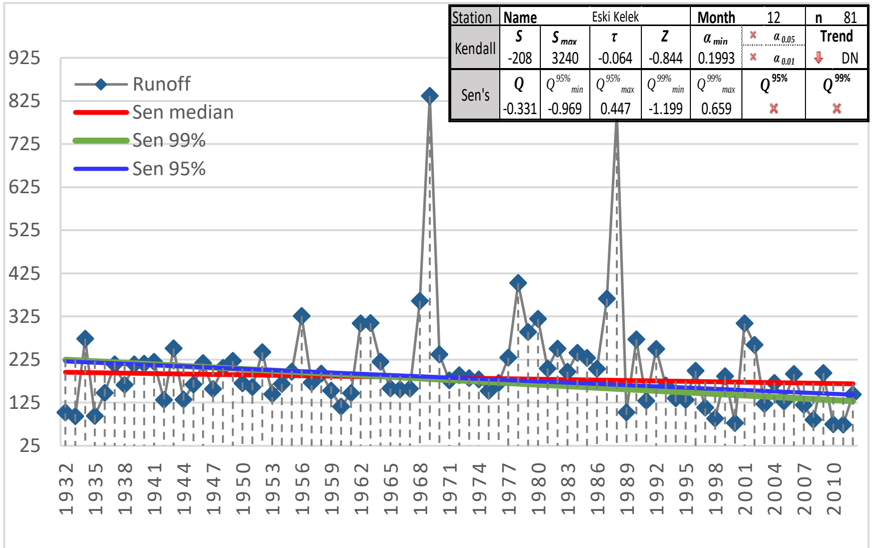
A sample representation for this analysis is shown in Fig 6.18 each of these figures represents one month (March, June, September, and December) where these months were selected to show the performance of both Kendal and Sen Methods under various discharge series). All of the charts represents the discharge trend of (Upper, Middle and Lower) stations.

Lower catchment

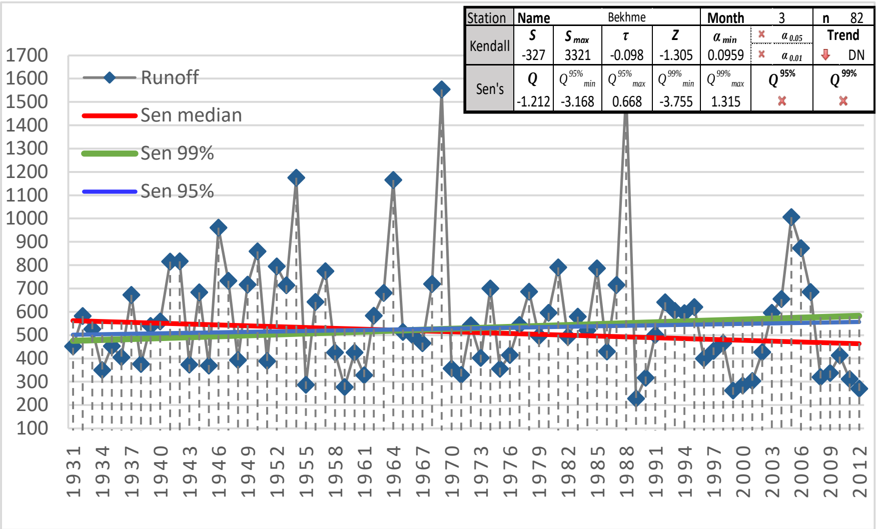


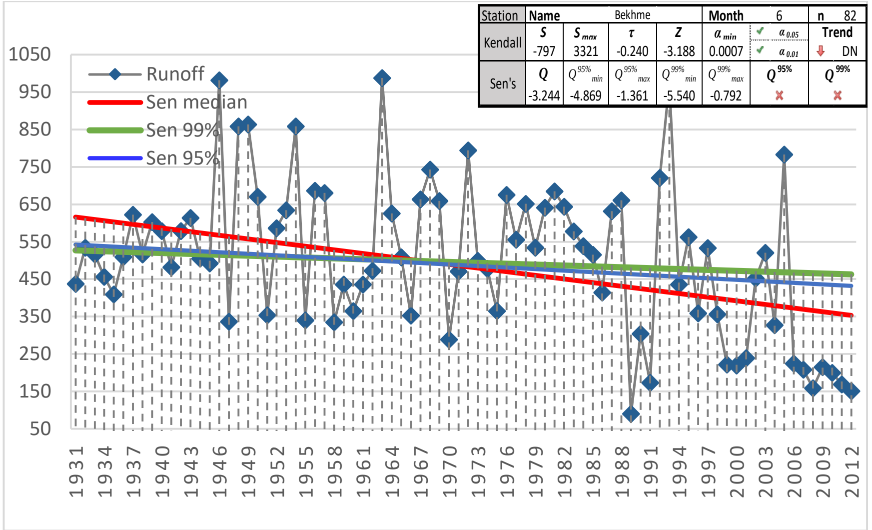


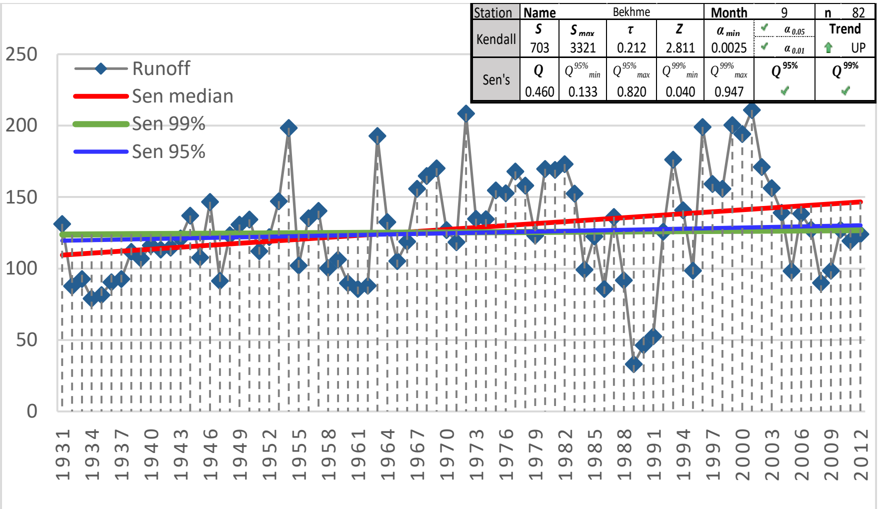


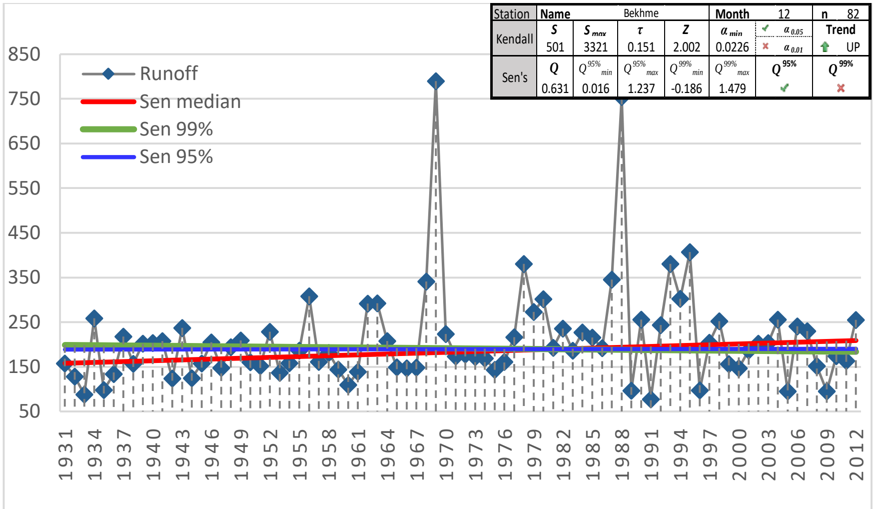


Middle catchment









Upper catchment

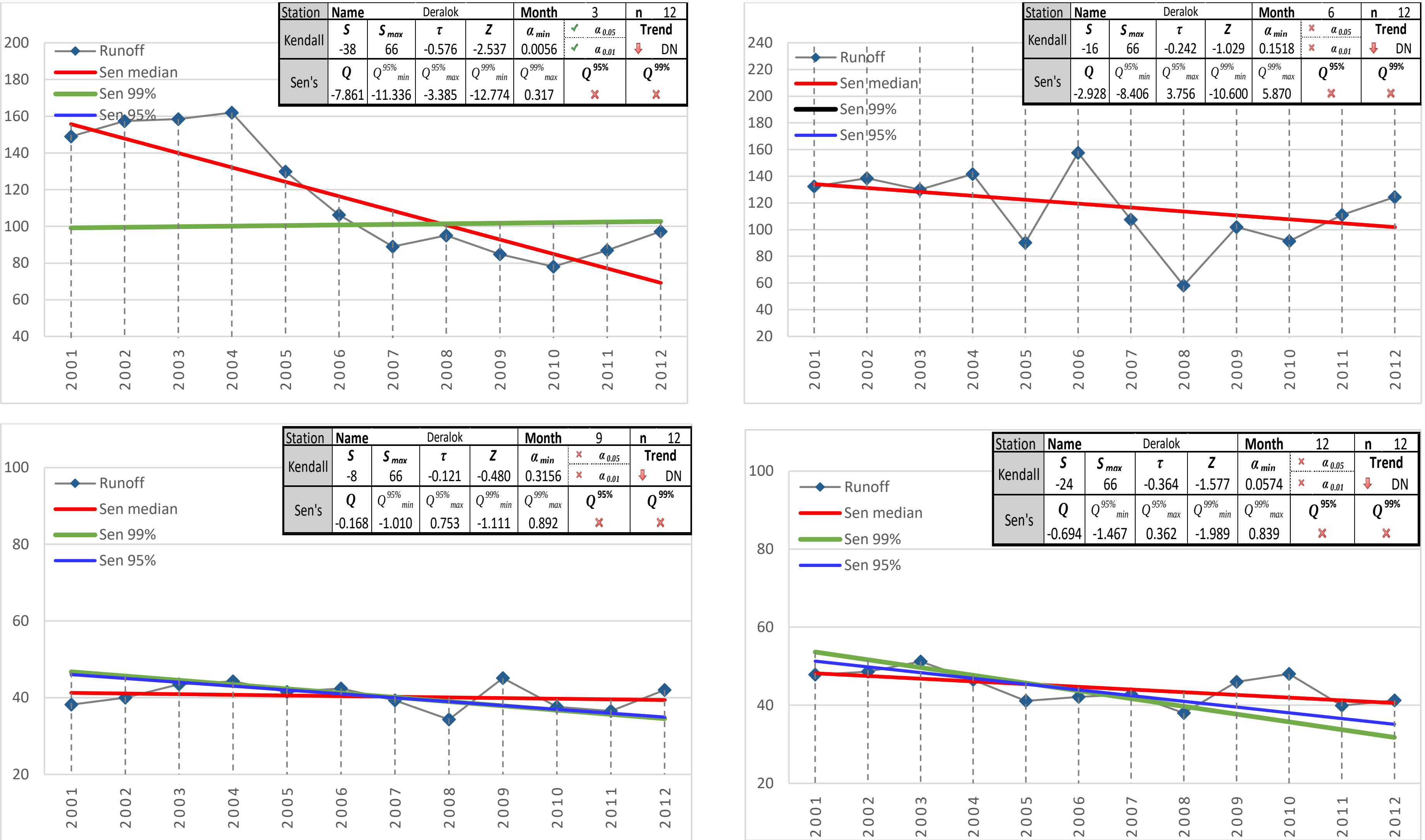


Figure 6.18 Analysis of discharge trends using Mann-Kendall and Sen's Slope estimator and their significant tests parameters.

6.4.3.6 Seasonal and annual analysis of discharge

The MK and Sen's Slope tests were used to identify trends in seasonal and annual streamflow between 1960 and 2012. Table 6.14 shows the results. The annual streamflow trend at Deralok station in the headwater catchment has shown no trend at significance level of 99% and 95%, while for the Bekhme and Eski-Kelek hydrological gauging stations in the middle and lower catchment, experienced a decreasing trend at significance levels of 95% and 99%, respectively.

Table 6.14 Seasonal and annual trends in discharge as estimated from Mann-Kendall and Sen's slope statistics for various meteorological stations.

Station	Test	Spring	Summer	Autumn	Winter	Annual
Bekhme	MK	-0.24**	0.19**	0.26**	-0.01	-0.15*
	Q	-3.92**	-1.21*	0.72**	-0.13	-1.15*
Deralok	MK	-0.31*	-0.21	-0.12	-0.36	-0.25
	Q	-4.11*	-1.42	-0.20	-1.44	-1.71
Eski-Kelek	MK	-0.26**	-0.23**	-0.14*	-0.05	-0.20**
	Q	-4.18**	-1.56**	-0.48*	-0.28	-1.57**

Seasonally, streamflow in the head catchment shows a decreasing trend in spring seasons at significance level of 99% and no trends show for other seasons. While trends for spring and summer in the middle and lower basin at shows decreasing trends at significance level of 99%, autumn season shows decreasing trend in lower catchment at significance level of 95%, meanwhile, increasing trends found in the middle catchment at significance level of 99%. Fig 6.19 presents the spatial distribution of seasonal and annual streamflow trends.

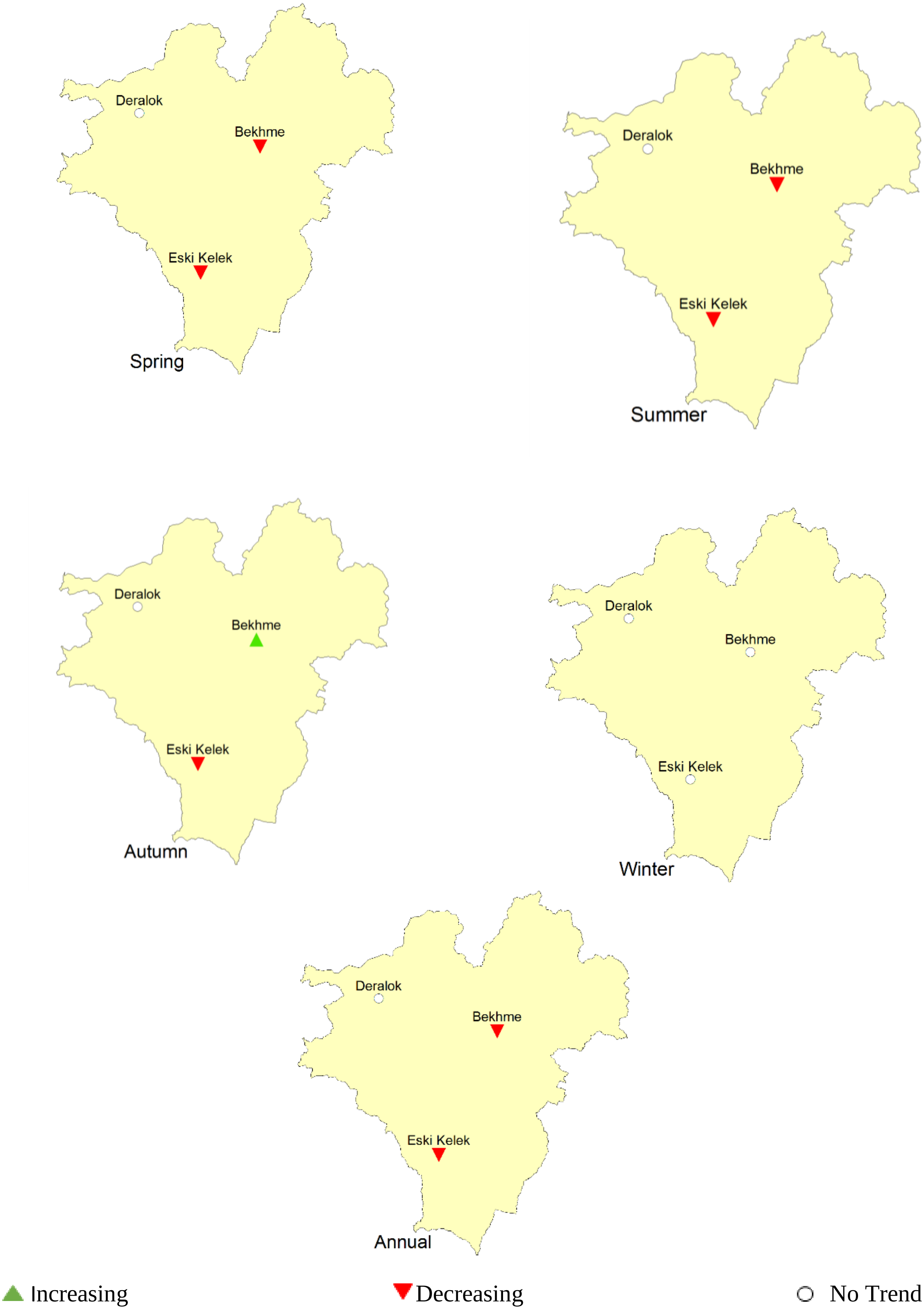


Figure 6.19 Spatial distribution of streamflow stations with increasing, decreasing and no trends for the seasonal annual streamflow time series.

6.5 DISCUSSION

The mean annual precipitation at different stations showed considerable variation, with a standard deviation of 147 mm from the mean annual rainfall of 636 mm. The Soran station in the middle of the basin, is the only station showed decreasing trend at significance level 95% in the annual precipitation series. Summer and autumn precipitation exhibit a uniform decreasing precipitation at all stations, where the precipitation is mainly due to the influence of the passage of cyclones coming from the Mediterranean Sea. Findings were consistent with results from Wang and Yan (2009), Ijaz et al., (2014) Hanif et al., (20) and Zhai et al., (2004) wherein they found statistically significant decreasing trends in autumn precipitation. As well as Altin et al., (2012) who also found that precipitation in autumn and summer experienced decreasing. The result of Mann-Kendall's test showed that the climate of the Great Zab catchment is warming during the last five decades. The increasing trends in air temperature series have been caused by several factors such as global warming, increased urbanized area and changes in atmospheric circulation (Smadi, 2006; Tabari et al., 2011a). Significant increasing trends in both temperature series will increase reference evapotranspiration and dry conditions in the study area. A increasing in air temperature will likely increase the summer snowmelt and the winter precipitation. The winter precipitation will be as rainfall instead of snow, thus decreasing glacier storage. Similar result found by Karaburun et al., (2012) who also found that the annual mean temperature experienced an increase of 1.86 ºC over the three decades period at Marmara region in the north west of Turkey and (Robaa and Al-Barazanji) (2013) who found an overall warming of 1.25 ºC in air temperature at Erbil station. In general, the temperature in most station has increased between months June to October Ageena et al., (2014), reported similar result across Libya during the period 1945–2009.

Mann-Kendall discharge trend analysis of the annual and seasonal results revealed that the station located in the upper part of the Great Zab with an important amount of snow coverage have revealed a decreasing trend only in spring. It was the case of station Deralok station, that may be explained by the fact that those flows being meanly fed by snow covers and vulnerable to the progressive change, which in the area has been reported as a retreat of the snow. This is supported by studies such as Casassa (1995), which has reported a retreat of snow in Chile due the large tropospheric warming. Recently, Sarikaya (2012) has also concluded that glaciers have been shrinking in the eastern part of Turkey between 1976 and 2011. Impacts of the increased air temperature on discharge have shown different characteristics depending on location and seasons: it has negative effect on the runoff at plain area downstream due to the increase of actual evaporation in summer. In addition, human activity contributed to the declining of discharge in the plain area at downstream of the Great Zab River Basin. Therefore, it can be concluded that the impacts of increase in air temperature on discharge of the Great Zab catchment have different effects depending on locations: it may result in the increase of discharge in upstream mountainous area due to snowmelt and glacier-melt, but may result in the decrease of discharge in plain area due to the increase of actual evaporation. It should be pointed out that the hydrological regime of the mainstream is strongly affected by human activities, such as domestic water uses, irrigation, and industrial. In fact, it is of no doubt that human activity is the predominate factor leading to the decline of discharge in mainstream of the Great Zab Basin during the past five decades.

6.6 CONCLUSION

Precipitation, temperatures and discharge amounts between 1960 and 2012 allowed us to visualize and evaluate climate changes on annual seasonal and monthly scales. The results of statistical trend analyses showed that both discharge and Precipitation amounts have decreased significantly, and the climate is becoming drier at many stations. Changes in climate occurred in some stations due to decreases in precipitation and increases in temperature. The quantity of precipitation received over a region is a significant factor in assessing the quantity of water available to meet the numerous requests of agriculture, and human activities. Based on the results, a decreasing precipitation trend during the 53-year time of this study occurred and if this trend continues in the future then it could have repercussions in the sustainability of surface water resources and groundwater recharge. In general, the results of using Mann-Kendall and Sen's slope estimator statistical tests pointed out the agreement of performance which exists in the detection of the trend for the hydro-meteorological variables. The findings of this study can help in further analysis of possible causes of the increase or decrease in these variables. Besides, further research in comparing between Mann-Kendall and another trend identification test is recommended.

CHAPTER 7: THE BALANCE BETWEEN SUPPLY AND DEMAND IN GREAT ZAB CATCHMENT

7.1 ABSTRACT

Water demand increases continuously with an increasing population and economic development. As a result, the difference between water supply and demand becomes a significant issue, especially in arid regions. The total recharge area of the Great Zab catchment is 16996 km^2. Climatological data from 25 weather stations and hydrological data from three stations were used to calculate annual precipitation values for the single sub-basins. The total precipitation volume in the Great Zab catchment from 2003-2012 was 630mm/year. In this study, irrigation demand took up more than 80% of the total water demand in catchment area. Areas with a large total water demand were mainly distributed in the central and southern part of the catchment. The total water demand in Great Zab catchment is less than the total annual volume of rainfall that we calculated. It has been estimated elsewhere that water stress occurs where total use exceeds 40 percent of the available supply. The spatial distribution of the water stress level for Great Zab catchment was highly water stressed in foothill zone in the lower part of the catchment because the water demand in the river basin here exceeded 40% of the available water volume.

7.2 INTRODUCTION

Ensuring continuous and adequate freshwater supply to growing population is a major concern across the world (Wang et al., 2017; Kim et al., 2014). Driven by increasing demands associated with the rapid growth of the world's population and social and economic development, global water consumption is growing rapidly (Julie et al., 2008). As a result, water supply is faced with many challenges, especially in water stressed regions of the world (Shen et al., 2014). Worldwide domestic water consumption is projected to increase from 280 to 600 km^3/year by the end of this century (Wada et al. 2013). Most of the countries in the Middle East region cannot meet their current water demand with seven of the world's ten most water scarce countries found in the Middle East region (Zyadin, 2013). With per capita water availability projected to fall by half by 2050, the situation is likely to be dire in the coming years (World Bank, 2007). Projections show that by 2035, 3.6 billion people will be living in areas with water stress or scarcity, as population growth causes more countries and regions to become water scarce (Mirkin, 2010).

As demand for water increases across the global, the availability of fresh water in many regions is likely to decrease because of climate change, population growth and economic development (Davies & Simonovic, 2011). In the Kurdistan region, the average annual population growth is currently 3% annually (Heshmati, 2009) and as a result, the already stretched water resources of the region are being severely exhausted; notably as water demand for irrigation is competing with high water demand for domestic consumption in the rapidly growing metropolitan areas (Mulder et al., 2015). The main consumers of water in the Kurdistan Region are households, agriculture, industry and municipalities services. The second largest user in terms of numbers is households who use water for drinking, cooking, hygiene and other household activities. Households' consumption differs by location and is grouped into urban and rural areas. The agricultural sector is the largest group in terms of water quantity usage. The industrial sector in the Kurdistan Region is small and its water usage is negligible (Heshmati, 2009). The balance between water supply and demand within a catchment area is important for an efficient water resources use and management (Hussain, 2011; Johnson and Curtis, 1994) and can provide basic information for planning of energy production, irrigation use, water supply and prevention against floods (Sebhat, 2014). There has been few attempts to undertake a water balance assessment in some parts of Great Zab catchment. This research work is designed to fill this knowledge gap for the Great Zab catchment and to develop a water budget for the catchment that could inform future water resource in the area.

7.3 METHOD AND MATERIAL

The water balance is defined by the general hydrologic equation, which is basically a statement of the law of conservation of mass as applied to the hydrologic cycle (Verstraeten et al., 2208). In its simplest form, this equation reads:

$$\text{Inflow} = \text{Outflow} + \text{Change in Storage.}$$

Water balance equations can be assessed for any area and for any period of time (Sebhat, 2014). The main inputs for a river catchment water balance are river flow and precipitation and the outputs will be evapotranspiration and water abstraction (Wang et al., 2011; Wilk et al., 2006). The water balance of any catchment depends on natural factors as its, climate, relief, geological situation, soil type and vegetation (Legesse et al., 2003). Can also be affected by human activities (Tate and Sutcliffe, 2001). In order to compare the natural water balance for the Great Zab with recent water consumption data, the catchment was subdivided into three sub regions: (1) the heavily populated Metropolitan Zone in foothill zone, including the capital city of Erbil, covering 5115 km^2; (2) the middle of catchment Imbricated high Folded Zone with an area of 6881 Km^2; and (3) the northern part of catchment; and the eastern mountain ranges (the Zagros Zone) that covers 4998 km^2. These units are based upon the major underlying geological units in the catchment and mirror those used in previous spatial analysis reported in Chapters 5 and 6. The second and third zone have a lower population density. That the first. The water balance estimates the quantity of water entering and exiting Great Zab catchment through various pathways. Components of the water balance were evaluated using monthly averages when available data allowed, and the monthly averages were totalled to estimate annual average. The overall water balance is presented on an annual basis. The computational model can be defined as:

Total Basin Inputs = SWI+ PPT

Where: SWI is the Surface Water Inflow (m^3/s) and PPT is precipitation (mm/year).

The quantity of water exiting the watershed is assumed to consist of the following components:

Total Basin Outputs = E + ND + SWO

Where, E is Evapotranspiration (m^3/year), ND is Net Demand (m^3/year) (which consists of domestic, irrigation and industry demands). SWO is Surface Water Outflow (m^3/year)

7.3.1 Estimations of available water resources

7.3.1.1 Precipitation

Precipitation in the form of snow and rain is the water input in the catchment. Within the Great Zab catchment, rainfall ranges from a minimum of 250mm/yr in the Makhmur (southern part of Great Zab catchment) to above 900mm/yr at the northern mountain area. The amount of snowmelt that contributes to the waters of the Great Zab River is unknown due to lack of measurements. However, with a global warming trend, faster melt of snow cover on the mountains of the catchment is expected. Average annual precipitation was computed from monthly totals for twenty five rainfall stations located in Great Zab catchment for the period 2003-2012 (Table 7.1). The rainfall stations were grouped into the three sub-basins described in previous chapters and for each sub-basin, an average precipitation value was extrapolated from isohyet map and from computed average annual precipitation data.

Table 7.1 Average Annual precipitation (mm/year).

No	Station	Catchment Area	Rainfall mm	Longitude	Latitude	Altitude
1	Erbil	Foothill Zone ($5015\ Km^2$)	423	44.039	36.196	420
2	Banaslawa		381	44.11	36.15	510
3	Bastora		368	43.35	35.43	270
4	Grdarasha		421	44.01	36.07	410
5	Makhmur		258	43.577	35.776	270
6	Khabat		356	43.65	36.266	252
7	Ankawa		380	44.012	36.221	434
8	Qushtapa		325	44.032	36.004	398
1	Akri	Imbricated high Folded Zone ($6881\ Km^2$)	667	43.866	36.732	636
2	Pirmam		562	44.209	36.378	1087
3	Shaqlawa		686	44.321	36.406	975
4	Qasrok		495	43.599	36.695	419
5	Soran		618	44.543	36.658	679
6	Bardarash		391	43.584	36.501	379
7	Hussenya		538	43.582	36.636	368
8	Harir		582	44.355	36.548	742
1	Amedi	Zagros Zone ($4998\ Km^2$)	756	43.487	37.089	1002
2	Mergasur		935	44.301	36.84	998
3	Zawita		785	43.141	36.904	890
4	Deralok		784	43.646	37.055	645
5	Kani Masi		716	43.438	37.229	1269
6	Choman		721	44.881	36.628	1090
7	Rawanduz		712	44.534	36.617	677
8	Haji Omran		960	45.04	36.675	1105
9	Khalifan		718	44.401	36.604	687

Complied with data from (MoA/KRG, 2011)

The isohyets method is a common method for determining the average amount of precipitation within a catchment or region (Balany, 2011), especially for non-uniform terrain (Radevski et al., 2015), as is the case with the Great Zab catchment. The Thiessen polygons method is a suitable alternative, for catchments with, flatter, more uniform (Berezovskaya et al., 2005). Using the isohyet method (Birkle et al., 1998), the mean annual precipitation was derived for each three sub-basins for 2003-2012. Average annual precipitation for the whole Great Zab catchment was calculated by using multiple linear regression, precipitation is treated as dependent variable and geographical latitude, longitude and altitude are treated as an independent variables (equation 7.1), which allows more precise construction of the isohyet map of the Great Zab catchment. This procedure is required for grid composed of isohypses turn into appropriate isohyets through math. Isohyet maps are just contour maps of precipitation. Each isohyet (each contour line) represents equal precipitation along its length.

$$P = -3132.9 - 77.984*\lambda - 0.595\varphi + 0.458h \qquad (7.1)$$

Where P is average annual precipitation, λ is geographic longitude, φ is the geographic latitude and h is altitude above the sea level. According to the grid obtained with ArcGIS raster calculator, the annual average precipitation across Great Zab catchment is 630 mm. The results for the three zone are shown in the (Table 7.2).

7.3.1.2 River flow

River flow and water level data are influenced by rainfall run-off and by hydromorphological changes of the riverbed, e.g. through river engineering. Furthermore, homogeneous time series are generally shorter than those for meteorological data. Therefore, substantially more time may be required before statistically significant changes in hydrological variables can be observed, especially with respect to extreme and exceptional events (floods and droughts). Water resources in Great Zab river basin consist of surface and groundwater. The focus here is on surface water as the interactions between groundwater and surface water is complicated to compute and the groundwater discharge to surface water minimal and can be neglected. In addition, there is no data regarding groundwater inflow and outflow in Great Zab catchment. Mean annual flows for the three sub-basins have been calculated from gauged records at gauging stations in each sub-basin (Table 7.2). Mean annual flows range from 75 to 295 m^3/s.

Table 7.2 Surface water resource in Great Zab catchment (m^3/s/year).

Catchment	Catchment area (Km^2)	Mean annul flow (m^3/s)
Deralok station Zagros zone	4998	75
Bekhme station Imbricated high Folded Zone	6881	210
Eski-Kelek station Foothill zone	5115	295
Total	16996	

Complied with data from (MoA/KRG, 2011)

7.3.1.3 Evapotranspiration

In general, the loss of moisture by evaporation and transpiration is a complex and ambiguous component of the hydrological balance (Birkle et al., 1998). Due to the almost complete lack of available field instrumentation for monitoring evapotranspiration in the Great Zab catchment, various semi-empirical equations were used to estimate evapotranspiration. Evaporation is that portion of the precipitation which returns back to the atmosphere through evaporation from a free water surface, a bare soil or interception on a vegetal cover and other objects and transpiration from plants (Tadesse & Mohammed, 2009). In this study, an attempt was made to estimate both potential evapotranspiration and actual evapotranspiration for the basin. The Thornthwaite method (Equation 7.3) was used to estimate the potential evapotranspiration of the study area due to lack of data to use other methods (e.g. Penman-Monteith). Potential evapotranspiration rates calculated for the station employed in this study is given in the Table (7.6). Monthly variation of potential evapotranspiration at a station also indicates variation in monthly air temperatures, since potential evapotranspiration is calculated from temperature data. This method uses air temperature as an index of the energy available for evapotranspiration, assuming that air temperature is correlated with the integrated effects of net radiation and other controls of evapotranspiration, and that the available energy is shared in fixed proportion between heating the atmosphere and evapotranspiration. There is no correction for different vegetation types.

The Thornthwaite's empirical equation is:

$$E_t = 1.6 \left(\frac{10T_n}{J}\right)^a \qquad (7.2)$$

Where

E_t = Potential evapotranspiration in centimetre per month.

T_n = Mean monthly air temperature (°C).

N = 1, 2, 3…….12 is the number of the considered months.

J = Annual heat index and it is given by the equation:

$$J = \sum_{N=1}^{12} j \qquad (7.3)$$

j = is the monthly heat index and it is expressed as:

$$j = \left(\frac{T_n}{5}\right)^{1.514} \qquad (7.4)$$

$$a = 0.49 + 0.0179J - 0.0000771J^2 + 0.000000675J^3 \qquad (7.5)$$

The computed monthly potential evapotranspiration in Eq. 5 is for a standard month with 360 hours of daylight. It must be corrected for the varying length of day with latitude using the appropriate correction factor. As it is depicted from Table (7.6), the highest monthly values of potential evapotranspiration in the basin in general come just before the onset of the rainy season; and lowest values during the rainy season, when the cloud cover reduced air temperatures and therefore potential evapotranspiration. Based on this method the mean annual potential evapotranspiration of the study area is (1313 mm/year).

7.3.2 Water consumption estimations

7.3.2.1 Agricultural water consumption

An overall estimation of net irrigation requirements has been calculated by the Kurdistan Ministry Agriculture using the FAO CropWat software (MoA/KRG, 2012). Climatic data, representative cropping pattern per agro-climatic zones are entered as input to the CropWat model, which calculates theoretical net irrigation requirements. Those values are estimated per month and are then divided by an estimated efficiency of irrigation per sub-basin. This efficiency depends on the on-farm irrigation systems, the type of distribution system (collective or private) and the source of water (from springs and rivers or from wells). Table 7.3 gives details of irrigated area by sub-basin.

Table 7.3 Irrigation consumption in Mm3/year.

Catchment area	Net water withdraw for irrigation
Foothill zone	518
Imbricated zone	159
Zagros zone	25
Total	702

Complied with the data from Ministry Agricultural and Water Resources, KRG, 2011.

7.3.2.2 Domestic water consumption

The domestic water consumption consist of urban domestic water consumption and rural domestic water consumption. The urban domestic water consumption consists of household and public consumption along with water use for the urban environment, businesses and construction. The rural domestic water consumption consists of household and drinking water for livestock. The urban and rural per capita domestic water consumption is respectively: 300 litres/capita/day and 250 litres/capita/day in Kurdistan Region at present (Ministry of Municipalities, 2011). This quantity is approximately the water produced in Kurdistan Region for use as drinking water because it includes system losses but excludes irrigation. In rural areas, consumption of poTable water is around 250 litres/capita/day see (Table 7.4). Overall water demand for domestic purposes is obtained by applying the method presented in Hussain et al. (2011) as follows:

$$\text{Annual demand (M m3)} = \frac{(P*C)}{E} \qquad (7.6)$$

Where P is population, C is consumption in m3/yr/capita and E is distribution network efficiency (%).

Table 7.4 Domestic water consumption (Mm3/year)

	% of population	Population	Consumption (L/day/capita)	Efficiency of networks (%)	Total water consumption (m^3/year)
Zagros zone	15	352, 844	250	30	1,073
Imbricated zone	36	872,739	300	30	3,185
Foothill zone	49	1,241,340	300	30	4,530
Total	100	2,466,923			8,789

Complied with the data from Ministry Municipalities, KRG, 2013.

7.3.2.3 Industrial water consumption

As those sectors are not yet developed, we considered the demand of those sectors close to null.

7.4 RESULTS

The processed isohyet map is obtained using blue coloured contours between isohyetes, and the distance between isohyets is 100 mm (see Fig 7.1). The southwest part of the catchment is arid and the northeast part of the catchment is wet. The spatial difference of annual average precipitation between mountainous eastern part and western lowland part of the catchment is 800 mm. Precipitation in the high mountain regions is likely to rise well beyond 1000 mm; however, isohyets of more than 1000 mm are only shown on the map where higher values are justified by measurements. Some of the inner valleys surrounded by high mountains (Soran, Choman, Amadia, Kani Masi) seem to be shielded, a phenomenon that is well known from other mountainous regions, and have moderate precipitation around 700 mm/year. In this study, the total water demand was obtained by aggregating the agricultural irrigation demand, and domestic water demand. The average annual precipitation of the Foothill zone is estimated to be 2121Mm^3/year. Approximately 356 Mm^3/year (17% of the precipitation) is lost to the atmosphere by evapotranspiration, 825 Mm^3/year is lost by infiltration to groundwater, about 4.5 Mm^3/year to domestic consumption and 518 Mm^3/year to agricultural consumption (see Table 7.5 and 7.6). Thus, 417 Mm^3/year is the remaining available surface water in Foothill zone. The hydrological balance of the Imbricated zone shows the highest annual precipitation due to the large area. In this zone, the highest proportion of precipitation, 1049 Mm^3/year, which is about 20% is lost to infiltration, followed by a loss of 436 m^3/year to evapotranspiration, a loss of 159 Mm^3/year and 3 Mm^3/year to agricultural consumption and domestic consumption respectively. The remaining available surface water in the Imbricated zone is 3554 Mm^3/year. Finally, for the Zagros zone the estimated annual precipitation is 5643 Mm^3/year. The highest proportion of precipitation, 1172 Mm3/year, which is about 21% is lost to infiltration, while evapotranspiration loss, agricultural and domestic consumption are estimated at 521 Mm3/year, 25 Mm3/year and 1.1 Mm3/year respectively. The remaining available surface water in the Zagros zone is 3924 Mm3/year.

Table 7.5 Estimation of hydrological parameters for three zones in Great Zab (Mm3/year).

Catchment area	Surface area (km^2)	Annual Rainfall	Annual snowfall	Infiltration	Evapotranspiration	Available surface volume
Foothill Zone	5115	2097	24	825	356	940
Imbricated high Folded Zone	6881	4403	798	1049	436	3716
Zagros Zone	4998	4248	1395	1172	521	3950
Total	16994	10748	2217	3046	1313	8606

Table 7.6 Potential evapotranspiration in Great Zab catchment.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.
T	6.9	8.3	12.5	17.7	23.8	30.2	33.4	33.3	28.5	22.4	13.9	9.1	
j	1.6	2.15	4.00	6.78	10.6	15.2	17.7	17.6	13.9	9.6	4.7	2.4	106.5
GPET	6.6	9.6	22.0	44.4	80.8	130.6	160	159	116.2	71.5	27.3	11.6	
LCF at 10° N	0.84	0.9	0.9	1.08	1.1	1.2	1.2	1.1	1.03	0.9	0.9	0.8	
CPET	8.5	12.7	39.9	78.2	124.5	188	242.0	279.7	174.2	97.5	54.8	12.8	1313

Where T = Mean Monthly Air Temperature (ºC); j = Monthly Heat Index; GPET: Monthly Gross or Unadjusted Potential Evapotranspiration (mm); LCF at 35º N = Latitude Correction Factor at 35º N; CPET = Corrected or Adjusted Potential Evapotranspiration (mm).

The distribution of water resources has considerable spatial and temporal variation. This may lead to differences between water supply and demand. In this study, agricultural irrigation demand took up more than 90% of the total water demand in the catchment area. The spatial distribution water demand was similar to the distribution of agricultural irrigation demand. Areas with a large total water demand were mainly distributed in the central and southern part of the catchment. The total water demand in each river basin were divided by the corresponding average annual precipitation. This provides a way to measure the water stress on available water resources. A common rule of thumb in water assessment considers that a region is in the condition of severe water limitation when the annual withdrawal exceeds 40% of the available resources and in medium to high water stress when the annual withdrawal occupies 20% to 40% of the available resources. The annual withdrawal refers to the total water demand for agricultural, industrial and domestic purposes (Vörösmarty et al., 2000; Shen et al., 2013).

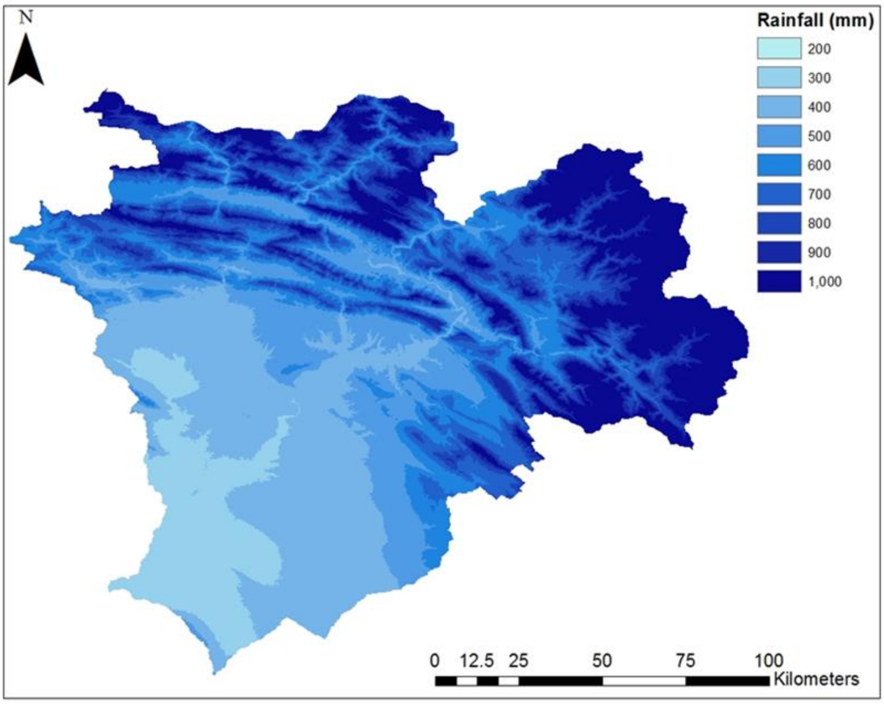


Figure 7.1 Isohyet grid of Great Zab catchment.

The spatial distribution of the water stress level for Great Zab catchment was highly water stressed in foothill zone because the water demand in the river basin here exceeded 40% of the available basin water volume, especially in the lower part of the catchment. Moreover, the Great river catchment faced high water stress during June-August as the water demand there nearly surpassed the river discharge with an assurance of 25% due to increase of temperature and dry season (summer). In general, the river discharges cannot sufficiently meet the water demand every month. With increasing water use, the water shortage situation could become more serious.

7.5 DISCUSSION

Due to the typical climate in the Great Zab, the distribution of water resources has substantial spatial and temporal variation. The total water demand in Great Zab catchment is less than the total annual volume of rainfall that we calculated. It has been estimated elsewhere that water stress occurs where total use exceeds 40 percent of the available supply (Jaafar et al, 2017). However, the water resources are not evenly distributed across the catchment. Overall balance calculations at the level of each sub basin hide significant local variations and hotspots of demand. In areas with more demand for water than available sources can supply, demands cannot be met or the water must come from groundwater. If the extraction of groundwater exceeds the annual recharge, it is considered to be over exploited. The annual water balance for the Great Zab River catchment shows that majority of the demand occurs in the foothill zone, due to high population and extensive farming areas. The foothill zone have higher demands than those in the imbricated and mountain areas. While population will be the primary factor driving overall water demand, urbanization of that population will also be important. Kurdistan has had a fast growing population over the past few decades, and Kurdistan's urban population is expected to continue expanding, perhaps doubling from present levels by 2025. Rural and urban domestic water reached 250-300 litres/person/day, which is considerably higher than the worldwide average for middle-income countries, which stands at 162 liters (World Bank 2015: 105). Therefore, the shift in population, coupled with increasing per capita use in both the urban and rural areas will lead to increase the demand in the future and especially in foothill zone. Moreover, the KRG is not currently adapting its policies to demographic pressures and urbanization (Ministry of Planning, 2012). Population growth and higher urban consumption lead to additional water demand, which appears to exceed the current institutional and infrastructural capacity in the region, which could increase domestic water demand by more than 50 percent over the next 25 years (Heshmati, 2009).

This increase in demand will be most keenly felt in the foothill zone, where population is expected to show the greatest degree of increase and urbanisation. Moreover, water availability, accessibilities, and sanitation in the Kurdistan region are below international standards (UNDP, 2015). In addition, water resources are increasingly under stress due to both climate change and bureaucratic mismanagement (UNESCO, 2013). Since 2007, Kurdistan region has been suffering from recurrent droughts, worsening desertification, and deteriorating standards of living in large parts of the country (UNDP, 2010). In the Kurdistan region, reduced rainfall and snowfall have rapidly resulted in declining water levels, including in springs and shallow wells, particularly in the driest districts of Erbil and Dohuk governorates (UNDP 2010). In addition, low water tariffs are insufficient to cover the cost of water supply and sanitation, as they cover only 2-5 percent of the costs of operation and maintenance (Heshmati, 2009).

Metering is not common; thus, the independence of water bills from consumption potentially translates to excessive consumption of domestic water. Additional quantities of water are wasted in rural areas due to the lack of information and training in advanced irrigation and water treatment systems. A substantial rise in water prices should be applied immediately, together with a proper price system for irrigation water. Nevertheless, mismanagement may be an even more serious threat than climate change. Water shortages are frequently the result of misallocation or neglect. Scarcities are indeed produced or exacerbated by a combination of political and socio-economic factors, such as insufficient environmental regulation and a lack of law enforcement; and old and poorly maintained distribution networks (Heshmati, 2009; UNDP 2010).

7.6 CONCLUSIONS

Based on above analysis, we conclude that water resources in the Great Zab River Basin, are not yet exploited as the water availability cover the current water demand in the catchment. The distribution of water availability and consumptions shows a spatial and temporal variation. High water demand occur in the middle and southern part of the catchment due to high population and large farming areas. There are some uncertainties in this study in estimating water demand and the pressure on water resources. Due to the lack of data, we distributed the statistical population and per capita domestic water-use according to the data in 2012. Thus, the water demand may be underestimated. Despite the uncertainties, the modeling results are helpful to assess the water scarcity issue and to provide appropriate sustainable planning measures. Water pricing policy is unreasonable in the Great Zab River area, and the water price is too low; according to a 2013 UN report, water prices in Iraq are extremely low compared to other countries. The low price rate, combined with the lack of awareness of water scarcity, leads to a daily consumption of 300 litres per capita that exceeds the international standard of 200 litres. Changes in environmental conditions can also significantly influence water supply and demand. Increased precipitation or decreased evapotranspiration are likely to increase water supplies and reduce the water demanded by irrigated agriculture. The procedures implemented in this study can be used as a guideline for increasing socioeconomic value of water as water demands are increasing and water supply is subjected to higher variability. As value of water is a function of Total Input and Water Demand, to increase value of water measures to increase total input and decrease water demand should be implemented simultaneously. The outputs are expected to help planners identify the underlying potential of a region to be self-sustaining in its water resource use and conserve an over-exploited water resource especially in lower part of catchment to achieve sustainability for future use. The methodology could be implemented in other similar catchments across Kurdistan Region.

CHAPTER 8: GENERAL DISCUSSION AND RECOMMENDATION

8.1 GENERAL DISCUSSION

The combination of climate change, population growth, and limited environmental awareness effectively limits water resource management in Kurdistan Region. Although the potential for use of the overall amount is still not affected, unbalanced situations happen in restricted geographical areas where one can see the degradation of water Table for instance or in short period of times. These are related to mismanagement of water resources inside Kurdistan Region, such as water losses in the distribution networks, overuse of water by inefficient irrigation systems, pollution of water resources by sewage return, increase water salinity…etc. Kurdistan Region suffers from many problems in its infrastructures whether those are related to water losses through its water distribution networks, water overuse in old irrigation schemes, pollutes fresh water sources by back water from irrigation and sanitation. The efficiency of the distribution network is poor (40-50 %) and it is deteriorating with time. Great Zab River and its tributaries flow through geological-morphological zones and losses and gains of water volume assume significant importance. In the Great Zab River system, losses to groundwater generally occur in the rising stage during the period from December to June. During the falling flows, covering the periods from end of July to November, the rivers usually gain water from baseflow (Rugel et al., 2016).

Due to the climate in the Great Zab, the distribution of water resources and its quality has significant spatial and temporal variation (chapter 4). One of the objectives of this study was to analysis the spatial and temporal trends in water quality. In order to achieve this objective the result of the analysis of water quality data from the 62 sampling sites showed that the all anion and metals concentrations measured in the Great Zab catchment fall below their respect WHO MACs with the exception of Ca. The high concentration of Ca may be related to the behaviour of metals in natural water and reflects primarily geogenic loading (Gutierrez et al., 2008). The influence of geogenic loading from underlying bedrock was identifiable within the observed spatial trends, with the most notable differences found between waters sampled from the relatively more volcanic-rich Zagros zone to the north and those sampled from the lower catchment underlain by younger clay-, sand- and siltstones. The greatest anthropogenic influence, identifiable through elements such as Cl^- and $NO3^-$, present in the more highly populated lower catchment. The high concentration of these metals may be due to discharge from small industries, sewages, various domestic and household sources. While, a majority of sites had SO_4^{2-} concentrations in excess of the world median, agricultural activities (e.g. the use of phosphate and urea fertilizers) are believed to be the major contributory factor to the concentrations of the in SO_4^{2-} the area. The pH of river water ranges from mildly acidic (5.6) to mildly alkaline (8.9). The mildly alkaline pH will primarily reflect the influence of bedrock geology in the catchment. The turbidity of water indicates that in general, river waters in Great Zab River catchment contains relatively low concentrations of suspended organic and inorganic material.

The higher concentrations for most of elements during winter (high discharge conditions) in the Great Zab catchment suggests enhanced delivery from the riparian zone via a combination of surface and sub-surface flows (Lintern et al., 2017). The spatial trends in water quality was influenced by geogenic and anthropogenic inputs, the data exemplify and indicate that whilst geogenic inputs are important in explaining large scale variability in water chemistry (Dragos et al., 2016), the spatially variable influence of anthropogenic activity is an important contributor to the water chemistry of the Great Zab catchment. Generally, highest concentrations trend to occur in the lower reaches of the Great Zab catchment, in waters from the Great Zab River itself, but also its tributaries, the Khazir River and the Gomal. Locations of relative elevation in concentration are likely to reflect site-specific conditions, and particularly point sources associated with anthropogenic activity.

The second objectives of this study is to establish the background water quality conditions in the Great Zab River catchment (Chapter 5). The comparison to WHO MACs suggests that the background concentrations defined by this study can be viewed as conservative if used as a guide for water quality based upon risks posed to human health. It is not suggested that the background concentrations derived here are adopted as a measure to protect human health, however, the concentrations quantified may act as valuable guide for identifying instances for anthropogenic pollution within the Great Zab catchment. The Great Zab catchment is likely to be significantly affected by climate change, associated with increases in the frequency and intensity of droughts and hot weather conditions (Osman et al., 2017; Heshmati, 2009; Stevanovic, Iurkiewicz, 2009). Long term expectations of the increase of temperature and decrease of rainfall due to global climate change will inevitably reduce the quantity of the water resources in Great Zab catchment (Osman et al, 2017). Changes in precipitation and temperature lead to changes in runoff and water availability. Runoff is projected with high confidence to decrease by 10 to 30% over dry regions, due to decreases in rainfall and higher rates of evapotranspiration (IPCC 2007). Precipitation has indeed decreased in Middle East countries which has caused problems of water shortage (Biswas 1994; Al-Ansari, 2013). Since the catchment is diverse in terms of elevation and climate conditions the impacts on water resource will be disproportional.

The climate of the Great Zab catchment is mostly hot and dry in summer and wet and cold in winter (Osman et al, 2017). In the southern of the catchment, a semi-arid and arid hot desert climate prevails, where precipitation is low. While in northern part of the catchment, over the Taurus and Zagros mountains, a Mediterranean climate prevails, where precipitation can reach up to 10000 mm/year, this is the main area from which the much needed water is supplied to the Great Zab River.

The third objectives of this study was to evaluate the spatial and temporal trends of hydroclimatic variables in Great Zab catchment (Precipitation, Temp, Discharge) for long term data 1960-2012. The outcome of this chapter allowed us to visualize and evaluate the climate change on annual, seasonal and monthly scales. The results of the analysis of precipitation (Chapter 6) revealed that the precipitation during the period 1960-2012 has decreased in general especially in the North East part of the catchment. The rainfall has shifted from autumn to the early winter and in some years to mid of winter and the decreasing autumn precipitation for all stations support that and similar results that have been reported in neighbouring countries (Tabari and Willems, 2017). The results showed that the climate of the Great Zab catchment is getting warmer during the last five decades. The increasing trends in air temperature series are believed to have been caused by several factors such as global warming, increased urbanized area and changes in atmospheric circulation (IPCC, 2014).

Significant increasing trends in temperature series will increase evapotranspiration and dry conditions in the study area. Increases in air temperature will likely to increase the summer snowmelt and the winter precipitation (Feng and Hu, 2007). The winter precipitation will be as rainfall instead of snow, thus decreasing glacier storage. Change from solid to liquid form of precipitation following the increase of the surface air temperatures could be quite important because such change could influence the timing of spring runoff and cause water shortage in summer (Feng and Hu, 2007). Changes in snowfall and snowpack can influence regional water supply (Dettinger and Cayan, 1995). In addition, the timing and rate of snowmelt runoff is often critical to spring flood development (McCabe and Clark). From a climate perspective, snow cover and snowpack significantly affect energy budget and water exchange at the surface and influence regional and global weather and climate (Hu and Feng, 2002). Lack of adequate spring melt would yield shortage and interruption of stream flows and lead to hydrological droughts in late spring and summer. Knowles et al. (2006) have showed some evidence of changes of snow and precipitation ratio in the recent decades. The trend analysis of the annual and seasonal discharge data (Chapter 6) revealed that discharge levels in the upper part of the Great Zab (Deralok gauging station), with an important amount of snow coverage, have shown a decreasing trend in spring months. This may be explained by the fact that those flows are mainly fed by snow cover and vulnerable to the progressive change in snow levels, which has been reported (Feng and Hu, 2007). Impacts of the increased air temperature on discharge have shown different characteristics depending on location and seasons: it has negative effect on the runoff at plain area downstream due to the increase of actual evaporation in summer (Nepal, 2016).

While population will be the primary factor driving overall water demand, urbanization of that population will also be important (Antrop, 2004). Urbanization is a well-known and important process. During urbanization, the population in cities and towns increases at the expense of the rural population. Since population growth is one of the major causes of urbanization, an urbanization increase can be expected over that period of time as well (Antrop, 2004). In some parts of the world e.g. Europe that has been noticing further urbanization since 1990. In other parts, urbanization has been taking place as well, resulting in the urban percentage of the world being 54% in 2014 (United Nations, 2015). Moreover, this increase in urban population is expected to continue until at least 2050. Kurdistan has had some fast growing population over the past few decades, and Kurdistan's urban population is expected to continue expanding, perhaps doubling from present levels by 2025 (Heshmati, 2009; Ministry of Planning, 2013). Urban domestic water use is higher than rural and so the shift in population, coupled with increasing per capita use in both the urban and rural sectors (Alobaidy et al., 2010). Furthermore, over-exploitation and misuse critically affect the regional water balance. The daily consumption per capita in urban areas reached 300-400 litres in 2011 (MoP 2012), which is considerably higher than the worldwide average for middle-income countries, which stands at 162 liters (World Bank 2015). Moreover, the unauthorized drilling of wells in concert with traditional irrigation methods pose the risk of depleting underground aquifers. Two other factors should be taken into consideration. First, the KRG is not currently adapting its policies to demographic pressures and urbanization. Population growth and higher urban consumption lead to additional water demand, which appears to exceed the current institutional and infrastructural capacity in the region (Heshmati, 2009). The last objectives of this study is to undertake a water balance analysis of supply and demand for surface water resources in the study area (Chapter 7). The distribution of water resources has spatial and temporal variation. This may lead to differences between water supply and demand. In this study, irrigation demand took up more than 80% of the total water demand in catchment area. Areas with a large total water demand were mainly distributed in the central and southern part of the catchment. The total water demand in Great Zab catchment is less than the total annual volume of rainfall that we calculated. It has been estimated elsewhere that water stress occurs where total use exceeds 40 percent of the available supply. The spatial distribution of the water stress level for Great Zab catchment was highly water stressed in foothill zone in the lower part of the catchment because the water demand in the river basin here exceeded 40% of the available water volume. Analysis of water supply and demand has shown that the majority of the water demand in the Great Zab Basin occurs in the plain zone, due to high urban population and extensive farming areas.

Although the water resources are abundant in the villages with the relatively good amounts of annual rainfall and the presence of rivers, streams and water springs, the water adduction system is weak with many households not connected yet to the drinking water network. Despite recent improvements to the water network’s infrastructure, the quality of services remains poor (World Bank, 2015) particularly in terms of the continuity of services, water pressure, and access to clean water (Ministry of Planning, 2012). The poor performance of water utilities in Great Zab catchment is, in most cases, due to lack of funding and mismanagement, low tariffs, difficulty retaining qualified personnel, the lacking of and application of necessary legislation (UNESCO, 2017). Therefore, we can see that the water supply in the Great Zab River Basin is not sustainable in the long term, and thus its future as a water resource is not guaranteed.

8.2. RECOMMENDATIONS

1. The integration and centralization of water management institutions is recommended as a way forward to achieve a more balanced allocation of increasingly limited resources.
2. To implement strategic projects including the construction of dams, projects for irrigation and the conservation of surface and groundwater quality using modern techniques.
3. Implement regular sampling of surface and groundwater quality in order to make proposals and recommendations for the protection of water quality and treatment. Furthermore, the development and improvement of irrigation services by supporting the implementation of the laws on agriculture, environment and water resources in compliance with international standards.
4. Water tariffs, including wastewater treatment fees and water resource fees, are generally too low and have to increase to reasonable price. To effectively address its water problems, Kurdistan needs to set the price to cover full delivery and environmental costs and, more ambitiously, also depletion costs. Although concerns over the pressure of tariff increases on the poor people are legitimate and should be taken into account in water pricing improvements, they should not be used to hold back water pricing changes.

5. There usually tends to be a lack of recognition of the importance of these interlinkages in the institutional and policy frameworks of country. Thus, the promotion of sustainable mountain development can play an import ant role to benefit lowland areas by ensuring adequate supplies of water, environmental stability, conservation of biodiversity, rural-urban population balance, etc.
6. There are policies that if implemented could help preserve the capacity of the Great Zab River to meet future demands. Most of the options relate to improving the efficiency of water use that is, they involve conservation and better use of proven technologies. Also being considered are policies that emphasize economic efficiency and reduce overall water use.
7. The most efficient irrigation techniques that is suitable for the local conditions of soil, water availability and quality, crops … etc. should be considered. Traditional irrigation techniques should be abandoned because they cause waste of water.
8. Reducing the use of chemical fertilizers and pesticides that can decrease the water quality when back irrigation water discharges to the rivers.
9. The government should use all available legal, institutional, and policy through them, mobilize the public and motivate the all sectors related to water management to ensure full compliance with all pollution control requirements.
10. Improve pollution control planning. Water pollution control planning in river basins should be improved, with the introduction of more realistic and tangible targets. Pollution control should not be regarded as the final target, but the way to achieve a clean and healthy water environment. This requires a long-term, integrated, but progressively targeted strategy for the protection of water quality.
11. Efficiency of distribution networks of drinking water specially diversion and supply down to the point of use which is most cost effective should be improved. Sewage

networks leakages should be repaired and their efficiencies improved to prevent any source of pollution from these networks.

12. There is an urgent need to put integrated water resource management (IWRM) high on the political agenda in order to enable decision makers to act effectively in the interest of sustainability. Taking an IWRM approach will also provide decision makers with critical information to allow them to commit the necessary financial and human resources to addressing this issue. An enabling environment (policies, legislations, organizational structures, institutional capacities, and financing) need to be established for effective water resources management.
13. There is an urgent need to strengthen and reinforce the capacity of water institutions to deal effectively with water issues in a holistic approach through legal and institutional framework. Participatory approaches, involving relevant water stakeholders and the private sector should be considered. Coordination mechanisms within the water sector and among water related and other development sectors, especially the agricultural sector is needed.
14. Surface water resources shared between riparian states should be given a high priority in order to reach agreements and form treaties regarding water allocation for the shared water resources according to international water laws. The existing agreement between Iraq and Turkey, on the shared surface water sources need to be implemented fairly and allow a high flexibility to regulate and monitor flows in term of quantity and quality and also undertake periodic review to ensure effectiveness.
15. Support research, monitoring, and information networking regarding climate change issues at national and regional level and assess impacts at regional level.

16. There is a need for understanding the effects of hydro-climatic changes on water resources, this will require regular periodic research on precipitation, temperature and runoff, in order to ensure that changes can be identified.
17. As many water issues need broad public support and understanding, raising awareness on issues surrounding water resources is increasingly seen as important. Public awareness means the general level of understanding of a certain topic. So raising awareness for water issues is a way to build a common understanding of water issues and to create shared values on how water should be used and managed.

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