Norwegian University of Life Sciences
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Philosophiae Doctor (PhD)
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Agriculture, livelihoods and climate change in Bosnia and Herzegovina – Impacts, vulnerability and adaptation

Landbruk, levevilkår og klimaendring i Bosnia-Hercegovina –Effekter, sårbarhet og tilpasning

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Summary

Bosnia and Herzegovina is still recovering from the shocks caused by armed conflict during the nineties, while being faced with a long and difficult path of institutional and economic reforms of transition from central to market economy at the same time. Nearly a third of the households in this predominantly rural country resorted to agriculture as a livelihood strategy to cope with the effects of the multiple shocks caused by these events, resulting in limited income opportunities, especially in rural areas. Agricultural sector of Bosnia and Herzegovina is facing many challenges, which are expected to be further exacerbated by climate change and variability.

This thesis analyses the impact of climate change on the agricultural sector; on the vulnerability and livelihoods of the rural population in Bosnia and Herzegovina; as well the different adaptation strategies, with the focus on conservation tillage. A multidisciplinary approach, using different conceptual and methodological approaches depending on the objectives of the individual papers, was used to define and discuss the research outcomes from different perspectives and scale. Research findings indicate that the agricultural sector in Bosnia and Herzegovina suffers from low general productivity, a weak and inefficient agrarian policy, low budget allocations for agriculture, imperfect markets and a general lack of information and knowledge. At the same time, the negative impacts of climate change are already being felt and will continue to increase according to the currently available climate projections.

The rural population is vulnerable to climate change due to present significant dependence on agricultural incomes as a particularly climate sensitive livelihood option. Quantitative analysis of vulnerability indicates that low adaptive capacity to cope with the negative effects of climate change and high sensitivity of the current human and environmental systems to climate impacts are currently the main sources of vulnerability in the most vulnerable rural municipalities, rather than the degree to which they are exposed to climatic variations. This finding is consistent with the results obtained at the micro-level, where rural households were found to be relatively asset poor, dependent on agriculture irrespective of location or total income, with their access to assets further constrained by the ongoing structures and processes. The studied households were found to be aware about the recent climate trends and did report to adopt a wide range of more long term adaptation strategies. In the context of agricultural production, the level of adoption of different agricultural practices and technologies shows the signs of the overall intensification of agricultural production in BH, as well as adaptation to the perceived changes in climate. Further adoption and adaptation at a farm level is constrained by a lack of asset access, most notably financial capital, as well by a lack of knowledge and labour.

Conservation agriculture was one of the least adopted agricultural practices in this study, despite its documented potential to offer both environmental and economic benefits for farmers. The results of the field experiments carried out in this study indicate that the reduced number of tillage operations has a potential to achieve high net returns due to decreased production costs, while maintaining the same level of crop productivity, when compared to conventional tillage. Reduced tillage cropping system was also less susceptible to weather extremes under differing weather conditions and was more Nitrogen efficient when expressed in yield-scaled N_2O emissions. The application of no-till, however, led to reduced yields and resulted in economically inacceptable returns.

The general conclusion derived from this thesis is that the rural dwellers and the agricultural sector in the current state are unlikely to cope with the consequences of climate change and undergo the process of successful adaptation without the support of other political, institutional, economic and social actors and policies.

Sammendrag

I Bosnia-Hercegovina (BH) arbeides det fortsatt med å gjenreise landet etter den langvarige væpnede konflikten på nittitallet. Samtidig står landet overfor en lang og vanskelig prosess med institusjonell og økonomisk reformer i en overgang fra planøkonomi til markedsøkonomi. For nær en tredjedel av husholdene i dette primært bygde- og landbruksbaserte landet har jordbruk vært brukt som en overlevelsesstrategi for å håndtere effektene av både eksterne hendelser og indre konflikter. Disse konfliktene har også ført til lavere inntektsmuligheter, spesielt på landsbygda. Jordbrukssektoren i Bosnia-Hercegovina har fortsatt store utfordringer på mange plan og disse kan bli ytterligere forsterket av økte klimavariasjoner og endringer.

Denne avhandlingen analyserer hvordan klimaendringer påvirker jordbrukssektoren i BH gjennom økt sårbarhet og mer marginale levevilkår. Den ser videre på ulike tilpasningsstrategier, med vekt på redusert jordbearbeiding. En bred tverrfaglig tilnærming med vekt på ulike begrepsmessige og metodiske tilnærminger er benyttet for å definere og diskutere ulike funn i de forskjellige artiklene. Forskningen viser at jordbruket i Bosnia-Hercegovina har lav generell produktivitet, delvis som følge av en svak og ineffektiv jordbrukspolitikk, et lavt nivå på budsjettoverføringer til sektoren, mange ikke-fungerende markeder, samt mangel på informasjon og kunnskap blant ulike aktører. Samtidig påvirker klimaendringer allerede i dag landbruket negativt, noe som vil fortsette og bli forsterket i følge nåværende framskrivninger for klimaendringer.

Landsbygd-befolkningen er svært utsatt i forbindelse med klimaendringer, både på grunn av stor avhengighet av inntekter fra jordbruket, og på grunn av landbrukets agro-økologiske sårbarhet for klimaendringer. En kvalitativ analyse av sårbarhet indikerer lav tilpasningsevne når det gjelder å håndtere negative effekter av klimaendringer. I tillegg viser analysen høy rapportert følsomhet for klimaendringer gitt dagens menneskeskapte og økologiske systemer. Kombinasjonen av lav tilpasningsevne og høy følsomhet er hovedkilden til sårbarhet i de mest utsatte landbrukskommunene; mer enn i hvilken grad de utsettes for klimatiske variasjoner. Dette funnet er i tråd med andre resultater på mikro-nivå, hvor husholdene viser seg å ha lite tilgang på kapital i ulike former. De er svært avhengige av jordbruk, uavhengig av beliggenhet eller total inntekt. Tilgang til kapital er ytterligere begrenset både av pågående politiske og økonomiske prosesser og av ytre strukturer og drivkrefter. Husholdene i denne studien har god informasjon om og forståelse for nylige klimatiske endringer, og de rapporterer at de benytter en rekke forskjellige langsiktige strategier for tilpasning. Innenfor jordbruket i BH viser tilpasningsnivået gjennom valg av forskjellige metoder/praksiser og teknologibruk tegn på en intensifisering av produksjonen, samt at valgene reflekterer en tilpasning til det man oppfatter som klimaendringer. Ytterligere tilpasning og endring på gårdsnivå hindres av mangel på egenkapital, primært finansiell kapital, i tillegg til mangel på kunnskap og arbeidskraft.

Miljøvennlige eller bærekraftige jordbruksteknikker (Conservation agriculture) var lite rapportert og brukt av bønder i dette utvalget, på tross av dokumenterte potensialer til å gi både miljømessige og økonomiske fordeler for bønder. Resultatet av felteksperimentene indikerer at redusert jordbearbeiding har et potensiale for høy netto avkastning grunnet reduserte produksjonskostnader samtidig som nåværende avlingsnivå og areal-produktivitet opprettholdes sam-

menlignet med konvensjonell jordbearbeiding. Landbrukssystemer med redusert jordbearbeiding viste seg også å være mindre sårbare for ekstremvær under forskjellige værforhold, og var mer nitrogeneffektive uttrykt som "avlingskorrigert N_2O utslipp". Innføring av tiltaket "ingen pløying" førte derimot til reduserte avlinger og en økonomisk uakseptabel avkastning.

Hovedkonklusjonene i denne avhandlingen er at hushold på landsbygda og jordbrukssektoren i sin nåværende situasjon i liten grad vil evne å håndtere konsekvensene av økte klimaendringer i BH, eller være i stand til på egen hånd å gjennomføre nødvendige tilpasningsprosesser. De vil være avhengige av økonomisk og politisk støtte fra andre aktører og av en omfattende omlegging av dagens politikk.

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List of abbreviations

BD – Bulk density (soil)

BH – Bosnia and Herzegovina

EU – European Union

FAO – Food and Agriculture Organization of the United Nations

FBiH – Federation of Bosnia and Herzegovina

GDP – Gross domestic product

GHG – Greenhouse gas(es)

HDI - Human Development Index

IPCC – Intergovernmental Panel on Climate Change

IPCC SRES - IPCC Special Report Emissions Scenarios

MDG – Millennium Development Goals

N – Nitrogen

N_2O – Nitrous oxide

NT – No-till

PD – Particle density (soil)

RS – Republic of Srpska

RT – Reduced tillage

SOC – Soil organic carbon

VSWC – Volumetric soil water content

WFPS – Water filled pore space

PART ONE: Synthesising Chapter

1. Introduction

1.1 Background

Climate change is widely considered as one of the main environmental challenges of the 21st century. According to the IPCC 5^{th} Assessment Report, the globally averaged combined surface temperature data as calculated by a linear trend show a warming of 0.85 (±0.20) °C over the period 1880 to 2012 (Stocker 2014). The natural greenhouse effect, which was a blessing for us for millions of years and without which our planet would have been a cold, lifeless place, is turning into a serious threat caused mainly by anthropogenic activities. The increased global human population, growth and industrialisation along with the emission of greenhouse gases (GHG) caused by burning of fossil fuels, deforestation, clearing of land for agriculture and agricultural intensification have caused these increased temperatures and further warming, and changes in all components of the climate system are likely if this trend continues. The increase of global mean surface temperature by the end of this century is predicted to be 1.5-4°C under most scenarios (Pachauri et al. 2014). In addition, it is expected that the incidence and duration of heat waves, droughts, floods, hail, storms, cyclones and wildfires, intensified melting of glaciers and other ice, sea level increases and soil erosion, will increase during this century. This may pose a significant threat to ecosystems and the vulnerability of many human systems is likely to increase (Pachauri et al. 2014).

Agricultural land covers 38.4% of the world's land area (FAOSTAT 2017) and is exposed to increased climate variability and change. Climate change and agriculture are interrelated processes, both occurring at a global scale. Agriculture is extremely vulnerable to climate change. Higher temperatures can reduce crop yields and can lead to increases in and the emergence, growth and frequency of weeds and pests (Rosenzweig et al. 2001). Heat waves can cause extreme heat stress in crops, which may limit yields if they occur during certain growth period, like pollination and ripening. Increased incidence and duration of droughts can cause yield reduction or crop failure, especially if the crops are not irrigated. Moreover, climate change is likely to increase irrigation water demands in agriculture subsequently increasing demand for water resources (Fischer et al. 2007). Furthermore, heavy rains can result in waterlogging and flooding, causing damage to farm infrastructure, crops and soil structure (Rosenzweig et al. 2002). Many plants do not survive for long in flooded, anoxic conditions. It is likely that cropping seasons will be extended in some regions of the world due to the increase in temperatures and one positive result may be the increase in opportunity to grow wider varieties of crops in certain areas (Porter 2005). However, the overall impacts of climate change on agriculture will be negative, threatening global food security (Rosenzweig et al. 2001).

The year 2015 was the end of the monitoring period for the first Millennium development goals (MDG) targets. The first target of MDG was to eradicate extreme hunger and reduce poverty by half in 2015 in relation to 1990 figures. While there are 216 million less undernourished people globally, despite significant population growth, there are still about 795 million people who are deemed undernourished currently (FAO et al. 2015). Most of these people are located in South Asia and sub-Saharan Africa. The main characteristics of these regions are large rural populations, widespread poverty and extensive areas of low agricultural productivity due to steadily degrading resource bases, weak markets and high climatic risks (Vermeulen et al. 2012). Climate change is expected to further exacerbate the risks that farmers face. It affects food production directly through changes in agro-ecological conditions and indirectly by affecting growth and distribution of incomes, and thus demand for agricultural produce (Schmidhuber & Tubiello 2007). Favourable macro-economic and trade policies, good infrastructure, and access to credit, land and markets are required for fast rates of economic growth (Gregory et al. 2005) in addition to the key pillars of food security, namely food availability, access, utilization and stability (FAO 2009). However, increased agricultural productivity is a key step in reducing rural poverty. Smallholder farmers constitute 85% of the world's farmers and are estimated to represent half of the undernourished people worldwide (Harvey et al. 2014). Most of them rely directly on agriculture for their livelihoods for survival and have limited resources and capacity to cope with the shocks/impact of climate change. Any reductions in agricultural productivity can have significant impacts on their food security, nutrition, income and well-being (Hertel & Rosch 2010).

Today's world is faced with the challenge of how to produce enough food to meet growing consumer demands and that is accessible for the hungry. In addition, food should be produced using environmentally and socially sustainable methods. The solution to both challenges lies partly in changing the way land is managed. Agriculture is both a victim and one of the main culprits of climate change. It is estimated that 24% of the global anthropogenic GHG emissions are derived from agriculture and deforestation (IPCC 2014). The most important GHG emissions from the agricultural sector are related to direct nitrous oxide (N_2O) emissions from soils, as a consequence of increased fertilization with synthetic nitrogen (N) or manures.

Following the industrial N fixation to produce bioavailable ammonia at a large scale, an era of widespread use of synthetic fertilizers in agriculture began and which has increased dramatically over the past 50 years (Erisman et al. 2008; Galloway et al. 2004). Synthetic N has contributed significantly to boost agricultural and industrial production, and to secure nutrition and food security. However, in order to achieve expected yields of today's high-yielding crop varieties, additional fertilization is needed, making N a nutrient on which the production of all crops depends. About 75% of the total amount of industrially fixed N is used in agriculture, creating severe environmental down-stream effects in the atmosphere and the hydrosphere (Galloway et al. 2003). Although the absolute quantities are small, increasing N_2O emissions play an important role in global climate change. N_2O is a potent GHG and the most important agent of ozone stratospheric destruction (Sutton et al. 2011). Improving the overall N efficiency in agricultural systems plays a key role for accomplishing this goal. The global potential of N availability through recycling and N fixation is far bigger than the current production of synthetic N. Therefore, changes should be made in agricultural practices, which could improve the efficiency of N use.

1.2 Context of Bosnia and Herzegovina

Bosnia and Herzegovina is faced with a major challenge of rebuilding the war-torn country and reviving the economy. The war in Bosnia and Herzegovina (1992-1995) resulted in devastation, emigration of more than two million people and massive internal displacements and migration, with significant and lasting consequences on the demographics and economy of its local communities. In addition to post-war reconstruction of the economy and infrastructure, the country is also faced with a long and difficult path of political and economic reforms in the transition from a centrally planned to a free market economy. The Dayton peace agreement, which ended the war, created a unique and very complex decentralized political and administrative structure in the country. This unique constitutional order includes two state entities - Federation of BH (FBiH) and Republic of Srpska (RS), and Brčko as a district municipality, forming three separate administrative units (Figure 1). In addition, FBiH is divided into 10 cantons. The lowest administrative units are municipalities, each of 143 of them with its own government and public services, which are under jurisdiction of the cantons (in

FBiH) or the entity (in RS). This unique structure profoundly affects every aspect of development, implementation and enforcement of every policy. The psychological effects of war still occasionally emerge on the surface and each political decision is carefully reviewed for its potential impacts on the existing three ethnic groups, as well as the balance of power and resources between the state, entities, cantons and municipalities. Consequently, it lead to “politicization” of public administration, election of politicians and public officials based on their ethnical belonging and political aspirations, rather than competence. There is a multiplication of horizontal and vertical levels of government, legislative overlaps, limited capacities and communication channels, as well as a lack of clear vision and failure to implement necessary reforms. This resulted in unsustainable level of public spending to sustain the bloated and inefficient bureaucracy, staggering amount of corruption and economic stagnation (Donais 2003).

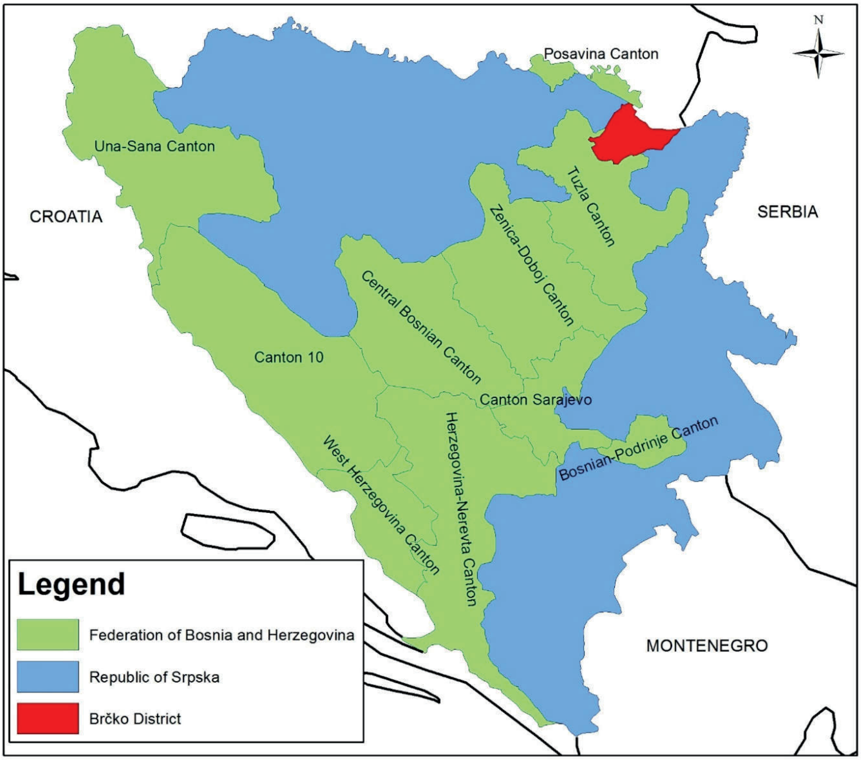

Figure 1. Administrative map of Bosnia and Herzegovina

Former centrally planned economy in BH economy was mainly based on heavy industry, which employed more than half of the total population and was a main driver of development in many rural areas. Agriculture was often seen as a cause of poverty, not a solution (Christoplos 2007). State farms were established to supply food, and the production of the remaining farmers was purchased under disadvantaged terms. Furthermore, the maximum private farm size was restricted to 10 ha. Coupled with the inheritance law, demanding the subdivision of farm holdings into equal parts among all heirs, resulted in further fragmentation of land. In the post-conflict period, many lost their jobs due to devastation, migration, privatization, bankruptcy and restructuring of the companies they worked in. This created big differences between rural and urban areas and increasing migration to urban areas. Still, a large proportion of smallholder farmers in BH today are former industrial and public sector employees, which have returned to farms owned by their families in the absence of other income opportunities. The renewed interest in agricultural development and its potential for economic growth and development in rural areas and post-conflict agricultural programmes have helped farmers to begin commercialising their products. However, the major proportion of smallholders is still producing food for subsistence, with the sales of surpluses. Agricultural sector in BH therefore has multiple roles - it provides income and food security to a large part of population, it mitigates a social burden of economic reforms and restructuring, and has a role in reduction of rural poverty (Bojnec 2005). The importance of agricultural sector in rural areas in BH also makes it one of the most vulnerable economic sectors, given its climate-sensitivity and the ongoing negative impacts of climate change (UNFCCC 2013).

1.3 Impacts of climate change in Bosnia and Herzegovina

The impacts of climate change are already observable in BH. Most notable is an increase in average temperatures. For the last hundred years, the average temperature in BH has increased by 0.8°C, with a tendency to accelerate - the decade of 2000-2010 was the warmest in the last 120 years (UNFCCC 2013). Although the amount of annual precipitation has not changed significantly, the number of days in which precipitation is recorded was reduced and the number of days with more intense precipitation was increased. Results of these changes are the increasing frequency and magnitude of droughts, as well as the increased occurrence of floods and other extreme weather events. Bosnia and Herzegovina has been experiencing serious incidences of extreme weather events over the past two decades, causing severe economic consequences. Six extreme drought periods were registered in the past 15 years, which resulted in an enormous economic damage in agriculture. In 2004, flooding affected over 300.000 people in 48 municipalities, destroyed 20.000 ha of farmland, washed away several bridges, and contaminated drinking water. In 2010, BH experienced the largest amount of precipitation recorded to that moment, which resulted in massive floods in many territories (IFAD 2012). The flooding situation culminated with an extraordinary rainfall in May 2014, surpassing even the amount from 2010, which led to severe flood and landslides. This led to temporary displacement of 90,000 people and more than 40,000 took extended refuge in public or private shelters. According to EC (2014), the floods in 2014 caused a damage equivalent to nearly 15 percent of GDP (ca 2.6 billion USD). Increased occurrence of other extreme weather events, such as hail, and increased maximum wind speeds in central parts of the country have also been recorded (UNFCCC 2013).

Based on available data and currently available climate projections, exposure to threats from climate change will continue to increase in BH (UNFCCC 2009). According to IPCC SRES scenario based on SINTEX-G and ECHAM5 climate models, the mean seasonal temperature changes for the period 2001-2030 are expected to range from +0.8°C to +1.0°C above previous average temperatures (UNFCCC 2013). Winters are predicted to become warmer (from 0.5°C to 0.8°C), while the biggest changes will be during the months of June, July and August, with predicted changes of +1.4°C in the north and +1.1°C in southern areas. Precipitation is predicted to decrease by 10% in the west of the country and increase by 5% in the east. The autumn and winter seasons are expected to have the highest reduction in precipitation. Further significant temperature increases are expected during the period 2071-2100, with a predicted average rise in temperature up to 4°C and precipitation decrease up to 50%. It is expected that the duration of droughts, the incidence of torrential flooding and intensity of soil erosion will increase during this century. In addition, a higher incidence of hail, storms and increased maximum wind speed may pose a threat to all forms of human activity in BH (Čustović et al. 2012). This will significantly affect the water balance in soil and groundwater, as the increased intensity of rainfall and frequent episodes of rapid melting of snow increases the amount of water flowing over the surface and steep slopes of the mountains (UNFCCC 2013). The likely result of this will be yield reduction due to reduced precipitation and increased evaporation; potentially reducing the productivity of livestock; increased incidence of pests and diseases of agricultural crops.

Addressing climate change in a meaningful way requires efforts on every level of governance. Being a Non-Annex I Party of UNFCCC, with net GHG emissions beyond more developed countries, BH as a country has to focus their efforts on adaptation to climate change. In order to do so effectively, the country needs to have the political and scientific knowledge, and public support system to do so, i.e. capacity to address climate change. Agriculture is a significant economic activity for the country, employing 20% of the total population and it is often a main source of income in rural communities. It is a well-known that investments made by this part of population are critical to overall improvements in agricultural productivity and adaptation. Yet investment in agricultural research and development has been declining, or stagnating at best, thus creating a knowledge gap between low and high-income countries (Beddington et al. 2012).

It is crucial to take a long-term, strategic view and to conduct research in order to meet future climate challenges and to develop approaches to facilitate transfer of new knowledge and technologies into practical application in BH. A critical review and analysis of challenges and opportunities is required. There is a paucity of information in this regard, particularly in the agricultural sector in terms of vulnerability to climate change and the related implications for rural livelihoods and adaptation strategies, which should be the important topic to explore in this early stage of climate change related research in BH. Furthermore, agricultural development in BH will depend on farmers adopting the appropriate technologies and management practices in the specific ago-ecological environment.

2. Objectives and research questions

The general objective of this thesis is to assess the impact of climate change on the agricultural sector, vulnerability and livelihoods of the rural population in Bosnia and Herzegovina, as well as to explore the effects of alternative tillage systems as one of the potentially sustainable adaptation options. In order to achieve this objective, the specific objectives and research questions were outlined as follows:

1. To present the current state of the agricultural sector and the impact of climate change on agricultural systems in BH
   - What are the main milestones in the history of agricultural development in BH and how are they reflected in the main characteristics of the agricultural sector today?
   - What characterizes agricultural sector of BH and what are the main challenges and possible opportunities?
   - How does climate change impact agricultural sector of BH based on both current conditions and future predictions?
   - What policy options could be derived based on the international literature to optimize opportunities and mitigate consequences of climate change in the agricultural sector of BH?

2. To quantitatively assess the current state of vulnerability of the rural population to climate change at the local level in BH
   - Based on the chosen vulnerability framework and list of indicators, what is the vulnerability index of rural municipalities in BH?
   - What is the influence of different components of vulnerability on the overall vulnerability index?
   - What is the difference between the chosen summarising and weighting methods? How much do they influence the overall vulnerability score?

3. To assess the structure of livelihoods of rural households and their livelihood strategies, the influence of geographical location and different agro-ecological conditions, to determine perceptions of climate change by rural households, choice of adaptation measures and factors influencing adaptation

- What is the structure of rural livelihoods in the different regions?
- What are the main factors and processes which influence rural livelihoods and household decision making?
- How do rural households perceive climate change? Is it identified as one of the main threats?
- What is the relationship between livelihoods and agricultural adaptation to climate change?

4. To investigate short-term effects of alternative tillage systems on N_2O emissions, soil properties, Nitrogen use efficiency and economics under current socio-economic conditions in cereal production system of central Bosnia and Herzegovina
   - What are the effects of reduced tillage (RT) and no-tillage (NT) on N_2O emissions and soil properties?
   - What is the difference in Nitrogen use efficiency between tillage systems?
   - What is the economics of different tillage systems and what is the likelihood for small-scale farmers to adopt alternative tillage systems under the current socio-economic conditions in BH?

3. Theoretical and conceptual framework

The core entry point for defining research framework in this thesis is impact of climate change on agricultural production in BH. Climate change affects agricultural production because climate is one of the key factors of production, providing essential inputs (water, solar radiation, and temperature) needed for plant and animal growth. The increased intensity and frequency of the adverse weather conditions is negatively affecting both crop and livestock systems, leading to production declines and losses. BH is a highly rural country and nearly a third of the total households in BH are engaged in agriculture. Thus, climate change directly affects the livelihoods of many who depend on agriculture as a source of income or food security. Changes in climatic conditions will require different adaptation strategies, in terms of both livelihood strategies and adjustments in agricultural production in order to alleviate the severity of climate change impacts. Adaptations can be either planned or autonomous (private) with the latter being carried out depending on how the perceptions of climate change are translated into agricultural decision-making processes (Smithers & Smit 2009). Currently, adaptation responses to climate change in BH have been reactive and an example of autonomous adaptation. However, the extent of autonomous adaptations likely will not be enough to cope with the negative effects of climate change. Thus, the "mainstreaming" of climate change adaptation into policies would be necessary to enable and facilitate effective planning and capacity building for adaptation to climate change (IPCC 2007).

Adaptation, whether analysed for purposes of assessment or practice, is closely associated with vulnerability, since the extent of sustainable adaptation depends on the magnitude of climate change and its variability, as well as the capacity to adapt to these changes (Smit & Wandel 2006). The limited access to livelihood assets and capabilities often shapes poverty and consequently the lack of adaptive capacity. If enhancing the adaptive capacity is a starting point of adaptation and reduction of vulnerability on the household level, it is essential to understand how the local livelihoods are composed, accessed and sustained. Therefore, based on the objectives and research questions of the individual papers, vulnerability and livelihoods approaches were used in this thesis to investigate the impact of climate change on agricultural systems in BH, with the focus on rural population, their adaptation and coping strategies.

Adaptation to climate change in agriculture can be achieved through a broad range of management practices and adoption of new technologies. However, there is no "one-size-fits-all" framework for adaptation and adoption of new practices and technologies. Successful adaptation should be based on adequate, local scientific knowledge and continuously updated based on new research findings. In this context, the application of conservation tillage was chosen as an example in this thesis. The documented ability of conservation tillage practices to minimize the risks associated with climate change and variability, as well as to improve resource-use efficiency were investigated when applied in the local conditions of BH.

3.1 Vulnerability

The ordinary use of the word 'vulnerability' refers to the capacity to be wounded, i.e. the degree to which a system is likely to experience harm due to exposure to a hazard (Turner et al. 2003). The scientific use of vulnerability has its roots in geography and natural hazards research, but this term is now a central concept in a variety of other research contexts, including climate impacts and adaptation (Füssel 2007). There are many different definitions of vulnerability, but the focus in this study is on use of vulnerability in climate change research.

Approaches to conceptualize vulnerability in the literature concerning climate change tend to fall into two categories. The end point approach views vulnerability in terms of the amount of (potential) damage caused to a system by a particular climate-related event or hazard (Brooks 2003; Kelly & Adger 2000). This approach, based on assessments of hazards and their impacts and in which the role of human systems in mediating the outcomes of hazard events is downplayed or neglected, may be referred to as physical or biophysical vulnerability (Brooks 2003). These are indicators of outcome rather than indicators of the state of a system prior to the occurrence of a hazard event. The starting point approach views vulnerability as a state determined by the internal properties of a system that exist within a system before the occurrence of a hazard event. Vulnerability viewed as an inherent property of a system arising from its internal social and economic characteristics is known as social vulnerability (Adger 1999; Brooks 2003).

Füssel and Klein (2006) distinguish three main models for conceptualizing and assessing vulnerability. The first model is known as the risk – hazard framework and has been cited in the technical literature on risk and disaster management (Dilley & Boudreau 2001; Downing et al. 2005; UNDHA 1992). It conceptualizes vulnerability as the "dose – response relationship between an exogenous hazard to a system and its adverse effects" (Füssel & Klein 2006). Since vulnerability is described in terms of the potential hazard damage to a system, this model can be related to biophysical vulnerability. The second model, the social constructivist framework, regards vulnerability as "an *a priori* condition of a household or a community that is determined by socio-economic and political factors" (Füssel & Klein 2006) and is common in political economy and human geography (Adger & Kelly 1999; Blaikie et al. 2014; Dow 1992). Therefore, vulnerability is conceptualized the same way as social vulnerability using this model. The third model of vulnerability assessment, which is most prominent in global change and climate change research, is based on the IPCC definition of vulnerability. The IPCC Third Assessment Report (TAR) describes vulnerability as "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity." (IPCC 2001). Such an integrated approach includes an external biophysical dimension, represented through exposure to climate variations, as well as an internal social dimension of a system, which comprises its sensitivity and adaptive capacity. According to the framework proposed by Füssel and Klein (2006), exposure and sensitivity together compose the potential impact, while adaptive capacity is the potential of a system to cope with these impacts (Figure 2).

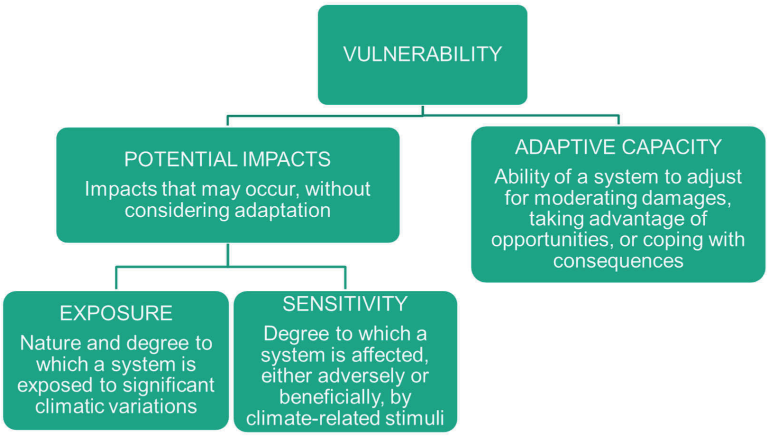

Figure 2. Schematic presentation of vulnerability framework based on IPCC (2001) and Füssel and Klein (2006)

Vulnerability is a useful integrative concept for evaluation of the potential effects of climate change, but it is also complex and can not be directly measured or observed. In such case, indicator-based methodologies are often used to measure vulnerability, as they can produce measurable outputs. In the context of this thesis, rural municipalities in BH are defined as vulnerable systems and climate change is seen as a stressor. Therefore, the chosen indicators (Table 1) are used as proxies to capture the biophysical aspects of climate change, the current state of the environment exposed to climate change, and the socio-economic situation that defines adaptive capacity at the subnational level in BH.

Table 1. Indicators used for the three components of vulnerability in this study

Exposure[*]	Sensitivity[*]	Adaptive capacity[*]
- Changes in average annual temperatures by between reference periods 1960-1990 and 1981-2010 - Changes in average annual precipitation by between reference periods 1960-1990 and 1981-2010 - Frequency of extreme months in the vegetation period (both dry and wet) in the analyzed period (1961 – 2010) according to Palmer moisture anomaly index (Palmer 1965) - Flood risk assessment for the housing sector	- Soil depth - Percentage of agricultural land - Percentage of households engaged in agricultural production - Percentage of rural population - Arable land per capita - Population density	- Unemployment rate - GDP per capita - Dependency ratio - Literacy rate - Percentage of population with higher education - Schools per 1000 population - Doctors per 1000 population - Road length per km^2 - Social capital (derived from total number of associations, NGOs and foundations) - Average yield for major crops (based on the yields of wheat, maize, potato and main fruits)

[*] Data sources for indicators and the rationale for their use are found in paper 2

3.2 Sustainable livelihoods approach

A livelihood as a concept is widely used in the recent literature linked to vulnerability, poverty and rural development. According to one of the earliest definitions of livelihood by Chambers and Conway (1992), "a livelihood comprises the capabilities, assets (stores, resources, claims and access) and activities required for a means of living. A livelihood is sustainable which can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and which contributes net benefits to other livelihoods at the local and global levels and in the short and long term". In this definition, capabilities are the options one possesses to pursue different activities to generate income required for survival and to realise its potential as a human being. Capabilities are determined based on the portfolio of assets one possesses, based upon which one makes decisions and construct the living. Five main categories of capital contribute to livelihood assets: natural, physical, human, financial and social capital (Scoones 1998).

While this economic asset-centred approach captures the essentials of what constitutes livelihoods, it has been criticised for the use of limited set of indicators (such as income and productivity) to define poverty. This led to development of more integrated approaches to assess livelihoods, with the focus on various factors and processes which either constrain or enhance poor people's ability to make a living in an economically, ecologically, and socially sustainable manner (Krantz 2001). Based on the proposed sustainable livelihoods framework by Scoones (1998), which views a livelihood as not just a question of assets and activities, but also composed and accessed within the certain institutional processes and social structures, Ellis (2000) proposed the following definition of livelihood: "A livelihood comprises the assets (natural, physical, human, financial and social capital), the activities, and the access to these (mediated by institutions and social relations that together determine the living gained by the individual or household."

The schematic representation of sustainable livelihoods framework developed by DFID (1999) (Figure 3) acknowledges the importance of assets and the activities engaged by individuals and households using the assets available for them, as it is defined in the original definition of livelihoods. The difference is that how the livelihoods are accessed and mediated by the ongoing institutional and social processes has the same importance and is viewed as a separate component. Such framework for livelihood analysis also has a vulnerability context, viewed in terms of shocks, seasonality and trends, which have a direct impact upon people's assets and over which they have limited or no control (DFID 1999). Therefore, the ability of a livelihood to be able to cope with and recover from stresses and shocks is central to the definition of sustainable livelihoods (Scoones 1998). Furthermore, the range and combination of activities and choices that individuals and households undertake, depending on the range and the degree of utilisation and diversification their available asset base in order to achieve their livelihood goals, results in different livelihood strategies. Livelihood strategies are composed of activities that generate the means of household survival (Ellis 2000). They are dynamic and respond to changing pressures and opportunities, resulting in adoption and adaptation over time.

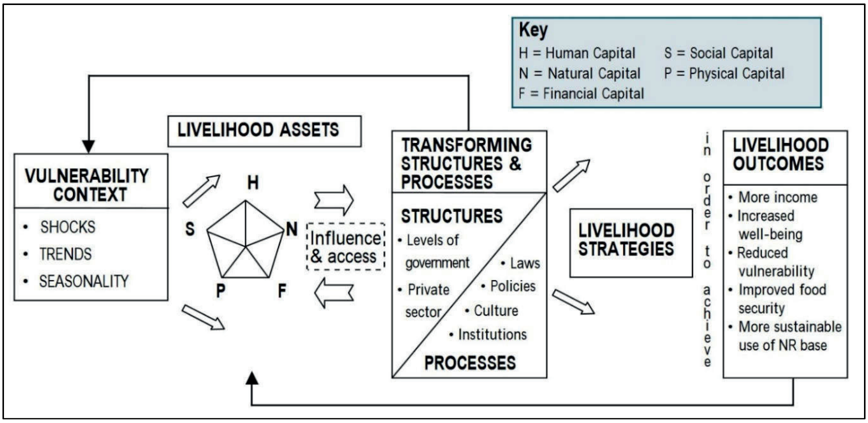

Figure 3. Sustainable livelihoods framework. Source: DFID (1999)

In the context of rural livelihoods, households with access to agricultural means of production have the choice between both agriculture and non-agricultural economic activities. Different adaptation strategies within agriculture can be also considered, such as extensification versus intensification, as well as "exit options" such as off- and non-farm activities, migration and remittance strategies. Many households allocate their assets differently, invest less time, labour and funds in agriculture and focus on diversification of their non-agricultural incomes (Weltin et al. 2017). People are also more aware of the opportunities outside their location and abroad. Information technologies, such as mobile phones, radio, television and internet, promise income opportunities and a different future, and reduced transport costs enable people to travel. As a result, many people decide to migrate to urban areas or abroad. Therefore, most rural households depend on a diverse portfolio of activities and income sources, where agricultural production is featured alongside a range of different activities, which contribute together on survival and increased wellbeing (Ellis 2000). Livelihood diversification is pursued for a mixture of motivations, and these vary according to context: from a desire to accumulate or to invest, a need to spread risk or maintain incomes, to a requirement to adapt to survive in eroding circumstances, or some combination of these (Hussein & Nelson 1998).

The sustainable livelihoods approach was used in the thesis to better understand the dynamic nature of livelihoods and what influences different livelihood strategies carried out by rural households in BH. Poverty in BH is mostly a rural phenomenon, as close to 80 % of the total poor live in rural areas. By understanding the livelihoods of rural households in terms of assets, activities and outcomes, as well as the main factors and processes influencing rural livelihoods and household decision-making, we can gain a better insight on the underlying causes of poverty. Furthermore, we can assess the impacts of climate change on rural households and how they response to experienced climate shocks with the available assets and how these conditions can be reflected and built upon for successful adaptation strategies and reduction of vulnerability.

3.3 Conservation tillage as an adaptation option for sustainable agriculture and climate change

Soils are living, complex systems, and in many ways the fundamental foundation of our food security (Reicosky 2015). As the world's population increases and food production demands rise, agricultural systems will have to produce more food from less land by making more efficient use of natural resources. Such production increases must also be sustainable, i.e. by minimizing negative environmental effects and providing increased income to help improve the livelihoods of those employed in agricultural production (Hobbs 2007).

At present, conventional tillage is almost exclusively applied in the cultivation of crops in BH. This traditionally adopted tillage method in BH and worldwide has its significant advantages, such as the incorporation of crop residues and weeds, optimum conditions for seed establishment and root growth, incorporation of organic and mineral fertilizers, accumulation of soil moisture in the autumn-winter period, disease and pest control. However, with all its benefits, conventional tillage also has its negative effects. Aggressive mechanical inversion of soil leads to unintended consequences of soil erosion, high rates of soil organic carbon (C) loss, compaction and loss of stable soil structure and disruption of the soil biology (Reicosky 2015). These processes can cause a wide range of environmental problems and lead to soil degradation, with the "Dust Bowl" of the 1930s in the US Great Plains as one of the most notable examples. In order to combat soil loss and preserve soil moisture, soil conservation techniques known as "conservation tillage" have been developed.

Conservation tillage includes a broad set of practices with a goal to minimise the disruption of the soil structure and to maintain the surface soil cover through retention of crop residues, what is achievable by practicing zero tillage and minimal mechanical soil disturbance (Baker & Saxton 2007). While the term conservation tillage encompasses different practices, the focus of this thesis were the experimental application no-tillage and reduced tillage under typical pedo-climatic conditions of continental BH. No tillage (NT) was carried out by direct drilling into the untilled, chemically mulched soil. Reduced tillage (RT) in this thesis was defined as a reduced number of operations and passages, without autumn ploughing, but disking to 15 cm depth in spring before seedbed preparation. Typically, conservation tillage is associated with improved water infiltration and conservation, reduced erosion, improved soil structure and reduced labour and fuel costs (Franzluebbers 2002; Hobbs et al. 2008). Therefore, the documented abilities of conservation tillage could have a potential to stabilise crop yields and improve soil conditions, while being less labour intensive and more cost-efficient, thus improving rural livelihoods in a country with prevailing low-input smallholder agriculture, such as BH.

It is likely that climate change will have a significant impact on soils, and therefore on the existing cropping systems. Increased temperatures, frequency and severity of droughts could potentially lead to yield reduction and crop failure and may increase mineralization and loss of the soil organic carbon (Choudhary et al. 2016). Climate change may also exacerbate the problem of soil erosion, as rainfall events become more erratic with a greater frequency of storms (Holland 2004). Conservation tillage could thus provide both sustainability in crop production systems and offer potential adaptation option to mitigate the effects of climate change and variability.

Recently, conservation tillage practices have been advocated as a measure to mitigate climate change through enhanced soil carbon (C) sequestration (Lal 2004). While the benefits of increased soil organic C (SOC) on soil structure, water-nutrient relationships and soil biota are well established (Johnston et al. 2009), the question whether or not agricultural soils lend themselves to sequester relevant amounts of C is currently under debate (Minasny et al. 2017; Powlson et al. 2011). One drawback of increased C sequestration into soils may be increased nitrous oxide (N_2O) emissions, offsetting the "cooling effect" of CO_2 draw down (Tian et al. 2016). Variable effects of conservation tillage on N_2O emissions have been reported (van

Kessel et al. 2013), varying from decreased to increased N_2O emissions, especially shortly after shifting from conventional tillage to NT (Rochette 2008; Six et al. 2002).

3.4 Biogeochemistry of Nitrogen and its link to climate change

Terrestrial N can be categorised in different compartments, namely soil and standing biomass (plants and animals), and is it relatively small compared to the abundant pool of inert N in the atmosphere. Notwithstanding, terrestrial N has an immense significance for the global biogeochemistry of N. Soils are the major reservoir of terrestrial N. According to Batjes (1996), global soil N in the upper 100 cm of the soil profile amounts to 133 – 140 Pg N (1 Pg = 10^{15} g). Compared to soils, only about 10 Pg N is held in the plant biomass and about 2 Pg in the microbial biomass (Davidson 1994). The transformations involved in N mineralization are entirely driven by soil microorganisms. A fraction of the mineralized N is lost from the system by NO_3^- leaching or by NH_3 volatilization. Furthermore, denitrifiers, a specialized group of microorganisms, have the capacity to use NO_3^- as terminal electron acceptor instead of oxygen, thus reducing NO_3^- to N_2 via the gaseous intermediates nitric oxide (NO) and nitrous oxide (N_2O). Gaseous N diffuses to the soil surface and is emitted to the atmosphere, thus closing the N cycle (Mosier et al. 2004). In non-cultivated soil-plant systems, the size of the organic and inorganic N pools often reach a steady-state or change very slowly, since N inputs from biological N_2 fixation, atmospheric deposition and N losses through leaching and denitrification are relatively constant (Vitousek et al. 2002). In agricultural systems, the amount of N circulating between the atmosphere, soil organic matter and living organisms is too small to satisfy the N required for high yields. In addition, a large quantity of N is removed from the system through harvest. Thus, the extra demand for N has to be satisfied by applying N-rich manures or synthetic N fertilizers to the soil. The additional N is either taken up by the crop, immobilized by the microbial biomass, stabilized as humus, or lost to water or atmosphere as nitrate or gaseous N. Therefore, understanding the cycling of N in soil-plant systems is pivotal for both sustainable agriculture and climate change mitigation.

As a consequence of anthropogenic inputs, the global N cycle has been significantly altered over the past century (Figure 4). Although the absolute quantities are small, increasing N_2O emissions play an important role for global climate change. Human activities account for over one-third of N_2O emissions, most of which are from the agricultural sector. Since the industrial revolution, an additional source of anthropogenic N input has been fossil fuel combustion, during which the high temperatures and pressures provide energy to produce NOx from N_2 oxidation. Activities such as agriculture, fossil fuel combustion and industrial processes are the primary cause of the increased nitrous oxide concentrations in the atmosphere. Together these sources are responsible for 77% of all human nitrous oxide emissions (Bernstein et al. 2007). N_2O emissions from the agricultural sector are mainly related to direct N_2O emissions from soils as a consequence of increased fertilization with synthetic N or manures. Livestock production is also a significant contributor to the global N_2O emissions, specifically during manure storage, livestock grazing or from paddocks. It is estimated that approximately 40% of the 270 Tg N yr^{-1} globally added to terrestrial ecosystems is removed via soil denitrification (Seitzinger et al. 2006).

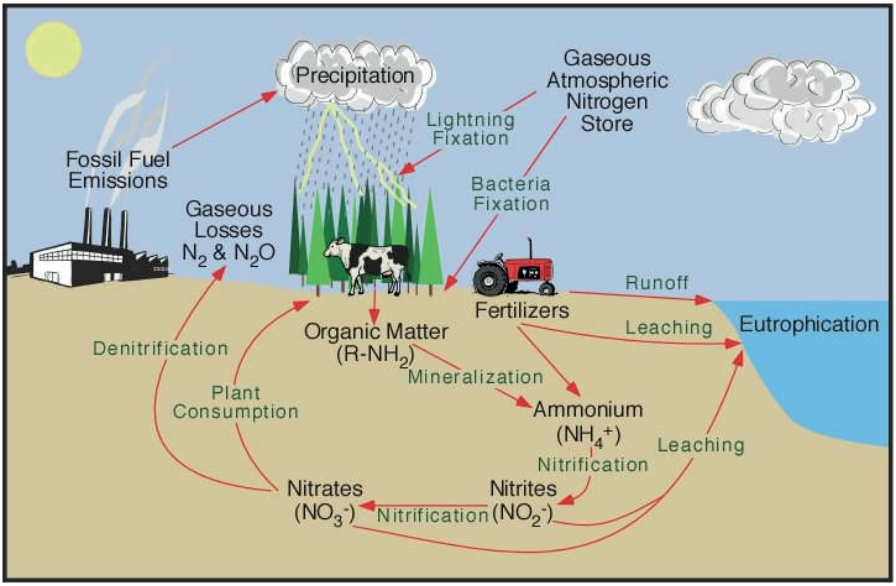

Figure 4. N cycle in terrestrial ecosystems. Source: Pidwirny (2006)

Nitrous oxide (N_2O) is a GHG with a 100-year global warming potential 298 times that of carbon dioxide (CO_2), contributing 6.24 % to the overall global radiative forcing and is the single most important depleting substance of stratospheric ozone (Butterbach-Bahl et al. 2013). According the same authors, atmospheric N_2O concentrations have increased by 19 % since pre-industrial times, with an average increase of 0.77 ppbv yr^{-1} for the period 2000–2009. N_2O is a product of denitrification, but it is also produced during nitrification and during the dissimilatory reduction of NO_3^- to NH_4^+ (Ward et al. 2011). Denitrification in soil produces both N_2O and N_2, hence this bacterial process may serve either as source or sink for N_2O. The rate of denitrification in soil is dependent on various factors such as the pH, temperature and soil moisture content (Maag & Vinther 1996). Most soil microbial processes are strongly influenced by temperature. Studies show that denitrification is most rapid at temperatures between 20 and 30°C, which is warmer than most soils in the temperate climates (Saad & Conrad 1993). The presence or absence of oxygen is one of the largest factors determining the extent and duration of denitrification. Denitrification can occur in aerobic conditions, but to a relatively insignificant degree. Soil moisture, especially during saturation, is generally the trigger for denitrification and the products of denitrification appear almost instantly after soil saturation (Bateman & Baggs 2005). However, the ratio of N_2 to N_2O tends to increase in favour of N_2 under higher soil moisture conditions (Weier et al. 1993). Denitrification in anaerobic soils is largely controlled by the supply of readily decomposable organic matter, from which the denitrifying bacteria obtain carbon as their energy source (Burford & Bremner 1975; Weier et al. 1993). Denitrification potential is greatest in the topsoil where microbial activity is highest and it decreases rapidly with depth. It is important to note that denitrification of NO_3^- does not occur only in soils. NO_3^- leached from the soils is transported to freshwater ecosystems and may enhance the biogenic production of N_2O through the same microbial processes, which occur ubiquitously in terrestrial and aquatic ecosystems (Burgin & Hamilton 2007).

In order to better understand the soil GHG fluxes, and to increase SOC and nutrient efficiency in the particular regions, it is necessary to conduct research on soils depending on their type and use, to identify natural and anthropogenic parameters and the corresponding relations between them. In relation to the natural factors, it is necessary to consider climatic elements (such as temperature and precipitation) and type of vegetation, while the most important anthropogenic factor to be considered is land management (tillage type, fertilization, irrigation, etc.). In this thesis, this was accomplished by setting up an experimental field in Sarajevo, where N_2O emissions and accompanying ancillary variables were monitored over two cropping seasons on the soil type and climatic conditions typical for humid continental climate of BH.

4. Materials and methods

4.1 Study area

Bosnia and Herzegovina is a country in South-eastern Europe, located in the Western Balkan region, with a total surface area of 51,209.2 km^2, composed of 51,197 km^2 of land and 12.2 km^2 of sea. The land is mainly hilly to mountainous, with an average altitude of 500 meters. Of the total land area, 5% is lowlands, 24% hills, 42% mountains, and 29% karst region. According to the most recent population census in 2013, the population is 3.53 million (AFSBH 2016a). It is estimated that 60% of the total population lives in rural areas, which makes it one of the most rural countries in Europe (UNDP 2013).

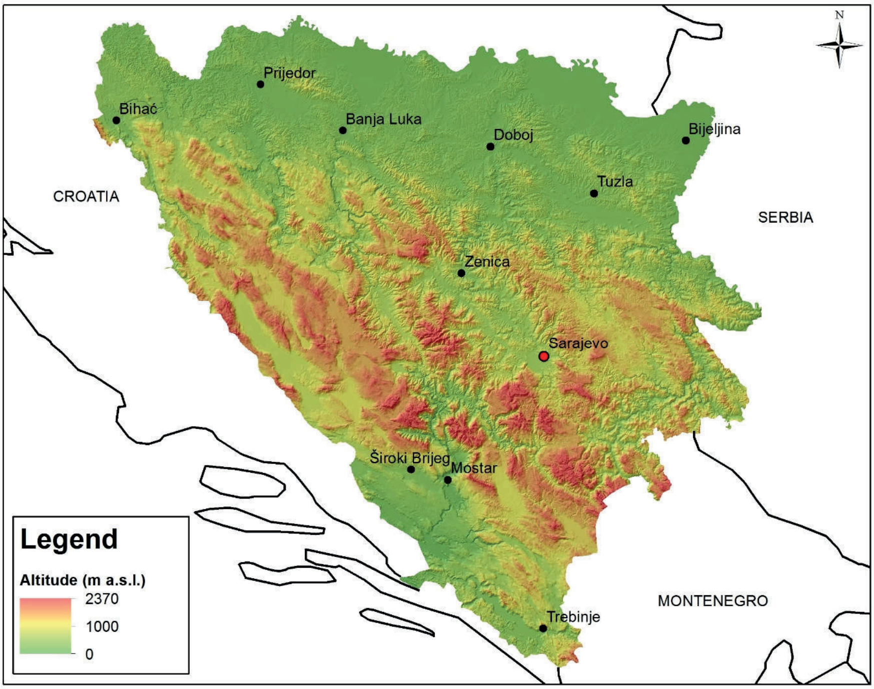

Figure 5. Geographical position and the digital elevation model of Bosnia and Herzegovina

Agricultural land covers 2.1 million hectares, 50.1% of which is arable land (MOFTER 2016). Fertile lowlands comprise about 20% of agricultural land in Bosnia and Herzegovina, most of it in the northern lowlands and river valleys across the country. These areas are suitable for intensive agricultural production of wide range of crops. Moderately to less fertile hilly and mountainous areas comprise 80% of the agricultural land, of which more than a half is relatively suitable for agricultural production, especially livestock production with the complementary pastures and fodder production. The harsh alpine environment (mountainous areas), steep slopes or aridity (especially in karst areas) usually limit agricultural production in the remaining areas. About 53% of the total area is covered by forests. Although the share of agriculture in GDP is relatively low (6.4% in 2016), agricultural production is still a backbone of rural economy, employing 20% of workforce (AFSBH 2016b).

The general atmospheric circulation and air mass flow, the dynamic relief, the orientation of mountain ranges, the hydrographical network and the vicinity of the Adriatic Sea have all created conditions for a wide spectrum of climate types in BH (Bajić & Trbić 2016). These include humid continental climate, represented mostly in the northern and lowland central parts of the territory; sub-alpine and alpine climate of the mountainous region of central BH, and semi-arid mediterranean climate represented in the coastal area and in the lowlands of Herzegovina (southern BH). This means that the effects of climate change and variability will be highly dependent on the geographical location and each region is facing specific challenges. For example, the mediterranean region, characterized with scarce and shallow soils, with the significant areas under karst, and northern BH with deep and mostly heavy soils, which has the same climate as most of central Europe, are both faced with the negative effects of increased temperatures and unfavourable rainfall distribution. At the same time, the hilly and mountainous regions of central BH might even benefit from the increased temperatures due to the increased vegetation season, allowing wider range of crops and higher productivity of grasslands.

When it comes to the territorial scope of research within this thesis, it covers different research units, depending on the objectives and focus of the individual papers. Paper 1 deals with the state of the agricultural sector and effects of climate change at the national level. The main focus of the research in paper 2 was the impact of climate change on rural municipalities, which form 136 of the total 142 municipalities in BH[1]. Paper 3 focuses research at the household level, more specifically on households within the different climatic regions, while paper 4 focuses on the field experiment conducted in a single field in central BH as a case study.

4.2 Research design

In order to gain more comprehensive and valid answers to the broad range of research questions posed in this thesis, a variety of methods were employed. While most of the methods were quantitative, they were in many instances supported with qualitative methods and observations. Therefore, the methodological approach in this study can be classified as a mixed methods approach. This approach has emerged over the last decades and is described as "increasingly articulated, attached to research practice, and recognized as the third major research approach or research paradigm along with qualitative and quantitative research" (Johnson et al. 2007). Climate change is a complex phenomenon and utilisation of hybrid research methods enables us to capture biophysical aspects of climate change, but also help us to define how this change impacts local communities in their socio-political and environmental conditions (Batterbury et al. 1997). The main rationale behind this approach is that when both qualitative and quantitative methods are used in combination, they tend to complement each other on the basis of pragmatism and a practice-driven need to mix methods and hence allow for analysis that is more comprehensive and can help to better understand the research problem (Denscombe 2008; Tashakkori & Teddlie 1998). Thus mixed methods research can also help bridge the schism between quantitative and qualitative research purists (Johnson et al. 2007). Due to the strong reliance on the quantitative data, this study could be more specifically classified as "quantitative dominant mixed methods", which is defined by Johnson et al. (2007) as "the type of mixed research in which one relies on a quantitative, postpositivist view of the research process, while concurrently recognizing that the addition of qualitative data and approaches are likely to benefit most research projects".

The quantitative methods in this study encompassed assessment of vulnerability using quantitative biophysical and socio-economic indicators (paper 2); analysis of household questionnaire data and micro-economic model to identify the major determinants of adaptation (paper 3); measurements of soil GHG emissions and the accompanying ancillary variables, soil

[1] A 143th municipality (Stanari) was established in 2014, but was not included in the study, since the statistical data from 2013 were used as a base for paper 2.

chemical and physical properties, crop yields, as well as economic indicators, such as total income from crop and variable productions costs (paper 4). Qualitative methods used in this study were key informant interviews and semi-structured interviews. Some of them were used to validate the obtained quantitative data, e.g. the indicators of vulnerability in paper 2 were discussed with key informants, or to gain more knowledge and to support some statements in the papers. The conducted rural household survey (paper 3) is also defined as a semi-structured interview, because it contained open-ended questions on farmers' perceptions and understandings of climate change, livelihoods, agricultural practices, coping and adaptation strategies.

4.3 Primary data collection

4.3.1 Household questionnaire

The main objective of the household questionnaire was to determine the access to livelihood assets and the main factors and processes that influence rural livelihoods and livelihood strategies, as well as perceptions of climate change and the responses carried out through various adaptation options. The questionnaire was mainly, but not exclusively, directed to the head of the households, which were mostly men and usually the main decision makers at the household level. In some cases, the questionnaire was conducted with multiple household members jointly, in case they showed interest to participate. Other household members (e.g. wives, sons/daughters, siblings) were interviewed in the physical absence or lack of will of the household head to participate, provided they were well informed about the household assets and on-farm activities. The questionnaire was drafted according to the research questions outlined in paper 3, tested in practice on some farmers and amended after every session if necessary, before its implementation in the field.

The household questionnaire was divided into four sections (Appendix 1). Section 1 focused on the basic details of the household, such as the duration of farm ownership and basic values and norms about being the farmer. Section 2 was concerned with the assets of the surveyed household, which were structured as natural, physical, human, financial and social capital. Section 3 was divided into two parts – the first one contained questions related to perceptions and personal observations about of climate change and its nature and extent, as well as questions about the damage caused by the selected extreme weather events in the past. The second part was focused on the awareness and implementation of the selected adaptation measures. Section 4 encompassed the questions related to various determinants of livelihood diversification and adaptation, recent investments and the biggest perceived challenges and obstacles for wellbeing.

The questionnaire contained mainly closed-ended questions, but some of the questions were open ended and allowed the respondent to elaborate some key issues in more detail. Therefore, this questionnaire may be considered as a semi-structured interview as well (Jamshed 2014). Closed end questions included dichotomous, multiple choice, Likert scale and fill-in-the-blank questions depending on the suitability and expected output (Burgess 2001). The questionnaire was designed and tested in a way that the duration of an interview with the single respondent does not last more than one hour. I personally administered a third of interviews with the respondents, and allowed field assistants to help me complete the required number of households after each of them spent some time with me on the field, in order for them to become familiar with the questions asked and the research objectives. The chosen field assistants were experienced and highly educated agricultural scientists and agro-economists. The choice of households, depending on the region, tended to be as randomized as possible. The only condition was that agriculture should be one of the income sources of the household. In order to overcome the issue of distrust, households were selected based on the recommendation of key informants in the field in the selected regions. In order to reduce the amount of bias, multiple key informants were selected and each of them selected no more than five households. Informed consent was obtained before the start of every interview and it was clarified that the questionnaire is anonymous and the information will be used for research purposes only. In total, 104 households from three different agro-climatic regions in BH were interviewed.

4.3.2 Field experiment

In order to accomplish the objectives of paper 4, a field experiment was set up in the chosen climatic and soil conditions of continental BH and weekly N_2O measurements were conducted in Maize-Barley rotation over two growing seasons, with the accompanying measurements of ancillary variables, soil, agronomic and economic parameters. This study was carried out on the research farm Butmir of the Faculty of Agricultural and Food Sciences in Sarajevo, Bosnia and Herzegovina (43°49'N, 18°19'E, 547 m a.s.l.) from December 2013 to December 2015 and encompassed two cropping seasons. The experiment had a strip design with four subplots per treatment (Figure 6), with three different tillage treatments as follows:

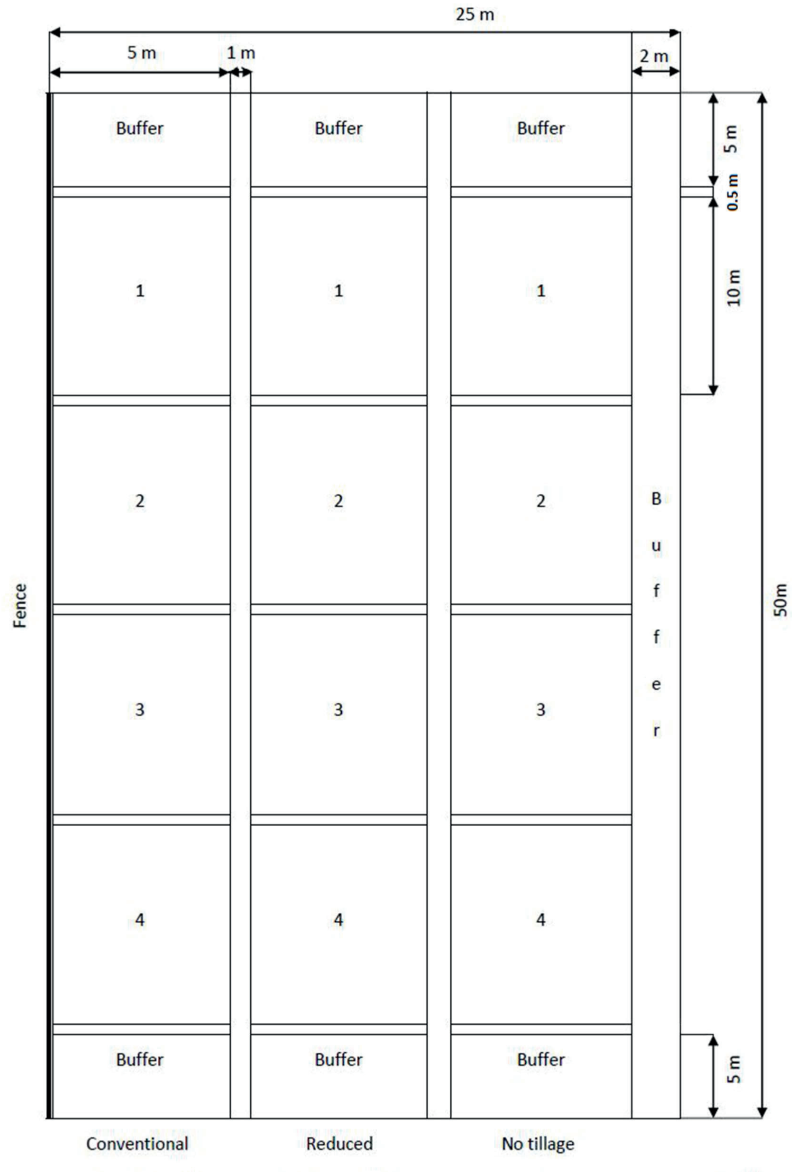

Figure 6. The experimental design

- **Conventional tillage (CT):** autumn ploughing to a 30 cm depth, secondary tillage with a roto-tiller in spring to 15 cm depth before seedbed preparation and sowing
- **Reduced tillage (RT):** spring disk harrowing to 15 cm depth and seedbed preparation before sowing
- **No tillage (NT):** direct drilling into the untilled soil. In the absence of the specialised NT seed drill, we used the traditional mechanical drill with an added ballast for increased penetration strength

Periodic measurements of N_2O emissions were carried out from December 2013 to December 2014 and from March 2015 to December 2015. The fluxes were measured following the methodology described by Nadeem et al. (2015), using static aluminium chambers. Gas samples were taken every 7-10 days throughout the entire research period and every 3 - 5 days in the month after fertilization in 2015. The gas samples were shipped to Norway and analysed at the Faculty of Environmental Sciences and Natural Resource Management (MINA), using a gas chromatograph (GC, Model 7890 A, Agilant, Santa Clara, CA, USA).

Cumulative flux in 2014 represents area-scaled emissions for the entire year, while in 2015 it represents the cumulative flux for 226 days of the year (flux measurements started on 20th of March) plus linearly interpolated values for the missing period, assuming low emissions like in the previous year. Emission factors were calculated as the fraction of applied fertilizer N emitted as N_2O-N (minus background N_2O emission of 1 kg N ha^{-1} $year^{-1}$) as a percentage (IPCC 2006). Alfalfa residue N in the first year was estimated based on the results from Kelner et al. (1997) adjusted for alfalfa yields from our studied field (see Junuzovic 2005). Yield-scaled N_2O emission was calculated as emission intensity, which is a function of fertilization rate and expressed as N_2O-N (g) emitted per ton of grain yield (Mosier et al. 2006).

Soil moisture and temperature at 5 cm depth were measured automatically every day using data loggers (Decagon EM50, Pullman, WA, USA) in three replicates for every treatment. ECH2O sensors (Decagon) were used to monitor volumetric soil water content (VSWC) and temperature.

Soil physical properties were analysed in undisturbed soil cores (100 cm^3 stainless steel cylinders) collected in July 2015 in four replicates per treatment. Particle density (PD) was determined using an air pycnometer according to Langer. Bulk density (PD) was determined gravimetrically. BD and PD were used to calculate total porosity, which was used to convert VSWC to water filled pore space (WFPS) by using the following equation:

$$WFPS = \frac{VSWC}{1 - \frac{BD}{PD}}$$

Soil water retention curves between pF 1.8 and 4.2 were determined using ceramic pressure plate extractors (Klute & Dirksen 1986). These results were then used to determine soil pore size distributions in different tillage treatments.

In 2015, soil samples were taken from 0 to 15 cm depth at each gas sampling date. Multiple cores from each treatment (4 per subplot) were homogenized, bulked and frozen. Immediately after thawing the samples, 45 g fresh weight soil was extracted by 30 minutes of horizontal shaking in a 50 ml 2M KCl solution. The extracts were filtered and soil mineral N (NH_4^+, NO_3^-) analysed by colorimetry according to Keeney (1982).

Yields were measured as dry grain corn in 2014 and barley in 2015. Samples were taken from every subplot and standardized to 14% moisture content. Production costs were estimated for each of the three tillage systems. Input items such as seed, fertilizer and chemicals applied were purchased from local retailers and the exact prices were recorded. Average purchase market prices for the crops used in the experiment are taken from Agency for Statistics of Bosnia and Herzegovina (AFSBH 2015; AFSBH 2016c) for the respective years. For an approximation of labour and tillage operation costs, we used data from the local agricultural extension service, which was cross-validated with farmers in the same area. An economical comparison between tillage systems was shown as a difference in net return per hectare, which was calculated from net income for crop after deducting all variable costs. We refrained to estimate fixed costs for production systems in this study due to high variability in possession of tractors and other necessary mechanisation and assets, which often have a long depreciation life and the general tendency to become obsolete (MAWFFBH 2015).

4.4 Secondary data collection

Various secondary data sources were used in this thesis and the first two papers were mainly based on them. Paper 1 collated information from journal articles, conference papers, national reports, official statistical data, strategic and policy documents. These documents were mainly related to the history of agricultural development, main characteristics of agricultural sector today and impact of climate change on agricultural systems in BH. In the case of significant knowledge gaps at some stages of research, some statements and conclusions were derived from the international literature or the statements from key informants combined with my personal observations. Both biophysical and socioeconomic secondary data for the purposes of paper 2 were obtained from various sources, such as statistical yearbooks, census data, climate data from hydrometeorological institutes and other public databases and archives. Based on these datasets, the sets of indicators at the local level (municipality) were chosen as proxies for exposure, sensitivity and adaptive capacity, in order to compose an overall vulnerability index and quantitatively assess vulnerability to climate change.

4.5 Statistical analysis

The chosen method in **paper 2** was to use a quantitative approach to assess vulnerability by constructing a vulnerability index based on specific sets or combinations of indicators, which serve as proxies. Each indicator is measured in different scales and units. Therefore, they had to be normalized to ensure that they were comparable. The values of all indicators were normalized based on the calculation of Human Development Index (HDI) (UNDP 1990) to values between 0 and 1, depending on the functional relationship between the indicators and vulnerability. Two different weighting methods were used to analyse and present the results. Using equal weights as a method, normalized indicators were integrated in two calculated composite sub-indices in accordance with their belonging to particular components of vulnerability (O'Brien et al. 2004). The final value of the vulnerability index for every municipality was obtained from the arithmetic sum of these two sub-indices. In the second weighting method, Principal components analysis (PCA) was used to extract the linear combinations that best capture the information from a large group of variables. One of the methods was to use PCA to generate composite indices is by using "eigenvalue-greater-than-one" rule proposed by Kaiser (1960). After retaining all the components with eigenvalues greater than one, factor analysis was used to generate factor loadings for all indicators, which were used as weights. In order to summarize all weighted indicators into the single composite index, the following equation proposed by Gbetibouo et al. (2010) was used:

$$V_j = \sum_{i=1}^{n} w_i (x_{ij} - \overline{x_i})/s_i \qquad i = 1 \dots n; \;\; j = 1 \dots J$$

Where V is a vulnerability index, *w* is the weight, *i* is the indicator, *x* is the indicator value, *j* is a specific municipality, $\overline{x}$ is the mean indicator value and *s* is the standard deviation.

Due to the dichotomous outcome of the variables regarding individual adoptions of agricultural practices and technologies (1 – adopted; 0 - not adopted) in **paper 3**, binary logit model was used to analyse the determinants for their adoption. This model considers the relationship between a binary dependent variable and a set of independent variables, whether binary or continuous. The model in its simple form can be presented as:

$$Y_i = \alpha + \beta_i \sum_{i=1}^{n} X_i + \varepsilon_i$$

where Y_i is the dichotomous dependent variable for an individual adaptation option (1 = adapted; 0 = not adapted), α is the Y-intercept, β_i are a set of regression coefficients, X_i denotes the set of explanatory independent variables and ε_i is an error term.

For the purposes of **paper 4**, rates of N_2O emission were estimated by fitting either linear ($R^2 \geq 0.85$) or polynomial functions to the observed N_2O accumulation over time. N_2O flux was calculated according to the following equation:

$$F_{N2O} = \frac{d_{N2O}}{dt} \times \frac{V_c}{A} \times \frac{M_N}{V_m} \times 60$$

where F_{N2O} is the N_2O emission flux (µg N_2O-N m^{-2} h^{-1}), d_{N2O}/dt is the relative change in N_2O concentration in the chamber headspace (ppmv min^{-1}), Vc is the chamber volume (L), A is the area covered by the chamber (m^2), M_N is the molecular mass of N in N_2O (g mol^{-1}) and Vm is the molecular volume of gas at chamber temperature (L mol^{-1}).

Furthermore, cumulative N_2O fluxes were calculated by plotting daily average N_2O fluxes against time, interpolating linearly between them, and integrating the area under the curve (Dobbie & Smith 2003). To test the effects of treatment and year, repeated measures two-way ANOVA followed by Bonferroni post-test was performed for N_2O flux data, soil temperature and WFPS. One-way ANOVA followed by a Tukey's multiple comparison post test was performed for soil NH_4^+ and NO_3^-, cumulative N_2O emissions and yield-scaled N_2O emissions. Prior to these analyses, N_2O emission rates and ancillary variables were log-transformed to ensure normal Gaussian distribution.

The data in every paper were analysed using SPSS ver. 24 (IBM Corp, USA).

4.6 Research challenges

Most of the challenges in this study were a consequence of the very complex, decentralized political and administrative structure in BH. There is limited coordination and an insufficient level of cooperation between institutions at different levels (especially between two state entities) in a context of distribution and acquisition of data, which leads to inability to establish an efficient data collection, monitoring and reporting system. As a result, there were difficulties collecting significant quantity of necessary data. It was challenging and a time consuming process to summarise the certain datasets at the national and local level. The members from each institution were more or less reluctant to share the requested datasets, even though such data was publicly available. Many publicly or donor funded studies were carried out in the last two decades, but there is a problem with their accessibility or even knowledge of their existence. The institutions or researchers involved in such studies are usually reluctant to share their main project outputs or datasets, unless it is in their self-interest. Luckily, I managed to overcome most of these challenges with the immense help of my network, which I developed during my previous work experiences in BH and during this research project.

While I was designing my research proposal in 2012/13, preparations for the first post-war census in BH and the first one since 1991 were under way. Therefore, the data analysis and writing of paper 2 relied on some indicators available only from the results of this census. However, the publication and processing of census results in 2013 was followed by a series of problems, irregularities and the lack of political consensus, which delayed publication of the results until June 2016. After many postponements, uncertainty about the future of the mentioned paper and many alternative considerations, I did finally succeed and finished the paper using the limited BH census datasets available to me and published to the present time.

Another problem, or more of an anecdote, happened shortly after establishment of the field experiment in Sarajevo. A pack of stray dogs, which have taken residence nearby, took an interest in the installed soil moisture and temperature sensors, which were connected to the data logger via network of cables. They decided to play and chew through most of the cables, which resulted in absence of soil measurements for nearly three months. Luckily, new sensors were ordered and installed as soon as possible and the experiment continued.

5. Results and discussion

5.1 Agricultural sector of Bosnia and Herzegovina and climate change - challenges and opportunities (Paper I)

There is a striking lack of knowledge regarding climate change and its impacts on the most vulnerable sectors in BH. Local scientific studies concerning the impact of climate change on agriculture have been modest at least for the past two decades. Some previous attempts were made to summarise the impact of climate change on agricultural production, either through scientific papers as a part of the regional initiatives in the Western Balkan area (Čustović et al. 2012; Kovačević et al. 2013), or as a part of the National Communications under the United Nations Framework Convention on Climate Change (UNFCCC 2009; UNFCCC 2013). After an extensive review of the existing literature concerning the impacts of climate change on the agricultural sector of BH, I reached the conclusion that a comprehensive review paper was necessary as a starting point, with the main objective being to present the current state of the agricultural sector in BH and the impact of climate change on agricultural systems there, based on local scientific knowledge and supplemented with the most recent findings from the global literature.

The first sections gives an overview of the agricultural sector in BH, history of its development and significance, as well as the most important current features and challenges faced. The general conclusion is that the challenges in the agricultural sector are mainly derived from the legacy of the past socio-political system and further exacerbated in the present by inefficient and complex governance. This has led to low productivity in both livestock and crop production, small and fragmented farms, low budget allocations for agriculture and farm investments, imperfect markets and a lack of knowledge and technology transfer.

The first part of the second section of this review paper assesses the impact of climate change on the agricultural sector of BH based on current conditions and future predictions. Based on the findings in this chapter, the agricultural sector in BH is found to be vulnerable to climate change. It is reflected in the serious incidences of extreme weather events over the past two decades, which caused severe economic losses. Higher incidences of droughts, floods, hail, storms and increased maximum wind speed may subsequently lead to yield reduction and the emergence of new pathogens and diseases, crop failures and long-term production declines. According to available data and currently available climate projections, the exposure to such threats will continue to increase. The second part of this section gives a brief overview of the main climate institutions in the country. Research findings show that there is a political will to build the necessary capacities and policies in order to promote low-emission and climate resilient development, as witnessed by the recent reports and development strategies. However, climate change has yet to be mainstreamed into national and regional development policies.

The third section is concerned with policy implications and proposes some socio-political and technological options that could form the basis for further strategic planning and development of necessary institutions in BH, and which should address adequately the problem of climate change in agriculture. These processes are roughly grouped into two groups – 1) policy and research capacity and 2) technological development. It is pointed out that the main priorities concerning policy and research capacities should be the formation of a national Ministry of Agriculture, harmonised policies, vulnerability assessments on every level, investments in agricultural research and development, capacity building and strengthening of public agricultural extension services. Technological development should be focused on developing local crop varieties, weather and climate information systems (including early warning systems) and investments in irrigation systems.

5.2 Quantitative assessment of vulnerability to climate change in rural municipalities of Bosnia and Herzegovina (Paper II)

It was concluded in the previous paper that the agricultural sector in BH is vulnerable to climate change and that the exposure to threats from climate change will continue to increase, according to the available data and projections. Assessment of vulnerability was also pointed out as one of the priorities for future development in this sector. Vulnerability assessment is an important tool for the analysis and presentation of data at different scales, where the current and potential consequences of climate change are presented to stakeholders in a convenient way and where it serves as a base for further adaptation policy decisions (Füssel & Klein 2006). Paper 2 builds upon these conclusions and recommendations, with the main objective to quantitatively assess the current state of vulnerability of the rural population to climate change at the local level in BH, with rural municipalities chosen as the main units for this study. A combination of both biophysical and socio-economic indicators as proxies was used to construct composite vulnerability indices for rural municipalities. Given the lack of scientific consensus on the different approaches and indicators used to assess vulnerability in the literature (Adger 2006; Hinkel 2011), the chosen set of indicators in this study was analysed using two summarizing and weighting methods for increased validity and demonstration of the differences between them.

Based on the results obtained using the different summarizing and weighting methods to generate the overall vulnerability indices, the most vulnerable municipalities are found to be mostly located across the north of BH, with a gradual decrease in vulnerability towards the central, eastern and western parts of the country. In the south, most of municipalities in the lowland region of Herzegovina are classified as highly vulnerable, while municipalities in the surrounding regions are mostly classified as low or moderately vulnerable. Least vulnerable municipalities are those with larger cities and towns within their territory and those located in central-south and south-east. Although half of municipalities were classified differently based on the weighting method, the differences were not fundamentally different and the general geographical distribution of vulnerability indicators did not change notably for the different regions of BH. Compared to the first method, the use of weighted indicators led to differences in the classification of vulnerability in case of half of the studied municipalities (53.7%). Most notable was the increase in number of highly vulnerable municipalities, and the decrease in number of municipalities with low vulnerability index.

While representing vulnerability with the single index might bring an insight about the degree of vulnerability on a sub-national level and identify the most vulnerable regions, this approach may also be too simplistic and misleading as it does not explain the main sources of vulnerability (Gbetibouo et al. 2010; Saisana & Tarantola 2002). Therefore, the overall vulnerability index was decomposed into the components that generate vulnerability and these components are discussed separately. When the results were analysed and discussed in this way, it was shown that the most vulnerable rural municipalities are those with the highest degree of potential impact (PI), as well as low adaptive capacity (AC) to cope with this impact. Furthermore, when the two components that generate PI (exposure and sensitivity) were analysed separately, the sensitivity index was the main determinant of PI in almost every highly vulnerable municipality. This indicates that the current socio-economic conditions and the increased environmental pressure as a result of the present human-environment interactions are the main determinant of vulnerability in the most vulnerable municipalities, rather than the degree to which these municipalities are exposed to significant climatic variations, i.e. social vulnerability is the main determinant of vulnerability to climate change in BH.

5.3 A case study of rural livelihoods and climate change adaptation in different regions of Bosnia and Herzegovina (Paper III)

This paper is linked to the previous one in a sense that it continues to explore vulnerability, but this time in the context of livelihoods at the micro level, exploring rural households from the three agricultural regions in BH. It was concluded in paper 2 that vulnerability to climate change depends on the potential impact, which is composed of exposure and sensitivity, and adaptive capacity of an affected system to cope with the impacts and risks of climate change, which is mainly determined by socioeconomic characteristics. In the context of rural households, low adaptive capacity is mainly related to poverty, which is reflected in limited access to capital assets and capabilities that comprise livelihoods (Scoones 1998). Poverty reduction requires an understanding of how local livelihoods are constructed, accessed and sustained, as the assets and capabilities that comprise livelihoods often shape poverty and the ability to reduce it (IISD 2003). The studied households were grouped based on their belonging to one of the three agro-climatic regions in BH, as well by income level, in order to explore the difference in access to assets, livelihood strategies, impacts and perceptions of climate change and adaptation strategies.

Generally, people were found to be asset poor. This is most notable in the limited access to natural and financial capital. Access to different types of assets significantly differed by region and income level. Most notable difference was found in total household income, which was much higher in the southern region.

A striking feature in the overall sample was a very high dependence on agricultural incomes, constituting 72.4 % of the total average income. Relative agricultural income in the central region, which was somewhat lower (55.9 %), compared to the northern (78.1 %) and southern region (83.2 %). There was no significant difference in the relative contribution of different income sources to the total household income. However, the total income from agriculture in the south is more than twice that of the other regions, as well as being a significantly higher contributor to total household income. The wealthiest group also had more than 5 times higher agricultural income than the poorest group.

The substantial difference in total incomes by region and wealth group, as well as high dependence on agricultural incomes irrespective of region and income, lead to the conclusion that the total household income mainly depends on how the available assets are used in agriculture. The less poor own more land and are able to produce more. However, the example of the southern region shows that significantly higher agricultural incomes can be achieved with significantly lower access to land. This is mainly attributed to more favourable climatic conditions in this region, which enables the farmers to time their production in order to exploit the opportunities on the market and to produce more lucrative crops. Furthermore, households in the southern region have better access to technology (e.g. irrigation, greenhouses) and are more often part of agricultural associations. Lastly, less poor households show a higher degree of entrepreneurship, reflected in more variable market outlet choices.

This difference in livelihood outcomes however, can not only be attributed to asset structure and activities. High dependence on agriculture in rural areas is mainly driven by a lack of alternative income sources. The main constraints to improved rural livelihoods result from the shocks brought by war devastation and post-conflict transition from the centrally planned to market economy. This resulted in poor and inefficient governance and policies, imperfect markets and number of other derived from the aforementioned.

High dependence on agriculture makes rural households more vulnerable to negative effects of climate change, some of them already affecting the studied households. The negative effect of droughts were most common and more stressed in the humid continental climate of the northern and central region than in the south, which is traditionally more resilient due to the prevalent semi-arid climatic conditions that present production systems are designed for. The negative effects of other adverse weather conditions were less common and more region-specific.

Studied households were well aware of the recent climate trends. Most respondents in our study perceive an increase in average temperature in line with the actual climate data. The way changes in precipitation are perceived, in terms of both amount and distribution, varied depending on the region. This inconsistency between perceived and actual precipitation is likely influenced by a decrease in water availability under the increased frequency and intensity of droughts and higher temperatures.

Respondents reported a wide range of adaptation strategies. While it is hard to differentiate whether it is climate change, agricultural intensification, or some other factor that are the main motives behind certain adaptation options, especially within agriculture, the number of adopted measures shows that there are signs of an overall intensification strategy of agricultural production in BH, as well as marked adaptations to climate change. Most notable were the application of both organic and mineral fertilizers, changes in crops and crop varieties, and a surprisingly high degree of irrigation. Other common agricultural practices were those that require no or little investments. Conservation agriculture practices were found to be less common and only a small part of the respondents was familiar with their existence and implementation. The main reported constraints for further adoption and long-term adaptation within agriculture were lack of funds, knowledge and labour. Certain agricultural practices carried out were in some cases more region-specific, but overall were similar in relation to income level. The results also indicate that increased access to different types of assets in most cases influence the likelihood of adaptations in agriculture, most notably social capital and access to technology (tractors).

5.4 Effects of tillage practice on soil structure, N_2O emissions and economics in cereal production under current socio-economic conditions in central Bosnia and Herzegovina (Paper IV)

This paper explores the application of conservation tillage, a widely recognised environmentally sound and sustainable management practice, and one of the measures of agricultural adaptation to climate change, in agro-environmental and socio-economic conditions of BH. It was concluded in paper 1 that low agricultural productivity is often a consequence of the absence of clear specialization, inferior technical equipment and high dependence on weather conditions. Another finding was a significant technological and knowledge gap in the agricultural sector compared to the rest of Europe, as a consequence of, among other things, inefficient agrarian policy, low budget allocations for agriculture and underdeveloped agricultural extension services. While the results from paper 3 show that there are some signs of an overall intensification strategy of agricultural production in BH, as well as adaptations in response to changing climatic conditions, the adoption of conservation tillage is very limited and negligible in size to date and so is the knowledge and awareness about it. This can be also clearly seen from the survey results in paper 3, where only 10% of the surveyed households adopted the different types of reduced tillage (RT), while only 3% of them adopted no-till (NT). Not that only the adoption of conservation tillage is low, but so is the knowledge about the existence of such practices, with only 35% and 23% of surveyed households being aware of the existence of RT and NT, respectively. Considering a significant knowledge gap when it comes to the implementation of sustainable farming practices in BH, the objective of this study was to examine the effects of the alternative tillage systems on crop productivity and soil properties in the pedo-climatic conditions of central BH. Agricultural soils are also the largest anthropogenic source of N_2O, associated with the use of synthetic nitrogen (N) and manures. Given the fact that N_2O emissions and its underlying variables have never been studied before in BH or the Western Balkan region, another objective was to study the impact of different tillage systems on soil N_2O emissions and to assess the Nitrogen use efficiency in these systems. Lastly, while the agronomic benefits of alternative tillage methods are easy to recognize, the likelihood of their adoption is also constrained due to uncertainties about the economic benefits, given that a majority of farmers is also strongly motivated by profits. Therefore, the economics of the different tillage systems was evaluated in order to assess the likelihood of their adoption by farmers under the current socio-economic conditions. In order to accomplish these objectives, a field experiment was set up in Sarajevo, on the experimental farm of the Faculty of Agriculture and Food Science, where the measurements of N_2O in Maize-Barley rotation over two cropping seasons were carried out (2014 and 2015), with the accompanying measurements of ancillary variables, soil, agronomic and economic parameters.

Fertilization was found to be the main driver of N_2O emissions irrespective of tillage treatment. However, clear treatment effects outside the period directly affected by fertilization were noted, indicating the importance of crop residue management and tillage on soil structure, temperature and moisture. In the much wetter 2014, N_2O emissions were in the order of CT > RT > NT, while in the drier 2015, the order was RT > CT > NT. The emission factors were within or slightly above the uncertainty range of the IPCC Tier 1 factor, if taking account for the N input from the cover crop (alfalfa) preceding the first experimental year. Saturated soils in the spring, formation of soil crusts and occasional droughts adversely affected yields, particularly in the second year. In 2014, yield-scaled N_2O emissions ranged from 83.2 to 161.7 g N Mg^{-1} grain (corn) but were much greater in the second year due to crop failure (barley). RT had the smallest yield-scaled N_2O emission in both years. Reduction in variable costs associated with NT was small due to the increased costs of weed control. Moreover, low yields in NT in both years resulted in economically inacceptable returns. On the other hand, the reduced number of operations in case of RT generated higher net returns due to reduced production costs.

The results of this study indicate that a wider adoption of NT in BH would likely not be realistic at this moment, especially by smallholder farmers who lack knowledge and financial capital. However, the results also show that reduced number of tillage operations can be both N efficient, economically acceptable and less susceptible to weather extremes in the differing weather conditions, compared to conventional tillage system. While some of these findings were discussed for the first time in the region, it is important to note, however, that these were just short-term effects of tillage in the markedly different weather conditions compared to the average values of the reference weather parameters in the studied area. Further research, especially long-term, in the same and other agroclimatic zones of BH would be needed in to infer overall effects on a national level, with the objective to mitigate N_2O and other greenhouse gas emissions and improve N use efficiency from agricultural systems. Integration of the different agronomical and agroecological approaches through the experimental work is needed in order to develop the optimal production system in BH, which is both environmentally and economically sound and likely to be adopted by farmers.

6. Synthesis and conclusions

The general objective of this thesis was to assess the impact of climate change on the agricultural sector of BH and the rural population as one of the most vulnerable parts of the population. Different concepts and approaches, depending on the scope and the objectives of the individual papers, have been applied in order to understand the impact of climate change from multiple perspectives. Every paper deals with different aspects of climate change and its impact at various scales, starting from the overall impact at the national level and policy implications, vulnerability at the local level, to livelihoods and adaptation at the micro-level. In addition, the objectives of this thesis go beyond just generation of new knowledge about the impacts of climate change. Another objective was to apply the latest global knowledge and experiences related to agronomical practices through experimental work in the agro-environmental and socio-economic conditions of BH. As such, this thesis also contributes to the global and local knowledge about the agro-ecological practices, conservation agriculture and the importance of Nitrogen use efficiency, as practices that could potentially increase the production while being environmentally and socially sustainable, as well as being the measures of climate change adaptation and mitigation.

The agricultural sector of BH, while rich in natural resources, biodiversity and with climatic conditions that are mostly favourable for agricultural production, is also faced with many challenges. Some of these challenges are partly inherited from the past socialist state, where agriculture was marginalized in favour of industrial development, but are further exacerbated by massive demographic, economic, social and political changes caused by armed conflict and the slow process of post-conflict transition from a centrally planned to a market-oriented economy. The main challenge in the agricultural sector is low productivity, resulting from extensive farming practices and obsolete technologies, carried out on small and fragmented farms. Furthermore, agricultural development is constrained by inefficient asymmetrical administrative structure and policies, low budget allocations for agriculture, imperfect markets and a general lack of information and knowledge.

BH is a predominantly rural country. A significant part of that population previously employed in industry and other sectors became unemployed after the war that led mass migration, devastation and economic decline in rural areas. In the absence of income options, a significant part of that population resorted to agriculture as a main or additional source of income. Thus, the already weak agricultural sector has received an additional role - as a social buffer in terms of food security, mitigating a social burden of economic reforms and restructuring, as well as rural poverty reduction. This significant dependence on agriculture as a climate-sensitive livelihood option also means that the livelihoods of many are vulnerable to present and expected impacts of climate change and climatic variability.

The negative impacts of climate change are already felt in BH. Serious incidences of extreme weather events in the past two decades and the severe economic losses have been reported by many studies and reports. The impacts of climate change on agriculture are primarily reflected in increased average temperature and frequency of extreme weather events, which subsequently lead to yield reduction, crop failure and the consequent reduction in livestock productivity. Based on available data and currently available climate projections, exposure to threats from climate change will continue to increase in future. Therefore, climate change is increasing vulnerability for many rural dwellers in BH, already exposed to multiple stressors.

Another feature of BH as a country is its pronounced heterogeneity in terms of geographical, agro-ecological and climatic conditions, all of them modifying the extent of climate impacts and the access to different types of assets. Therefore, certain regions and certain communities within each region are more vulnerable to climate change than others. Their vulnerability is determined by exposure to climate variation, sensitivity to climatic stresses and adaptive capacity moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Based on the quantitative assessment of vulnerability to climate change, carried out for 136 rural and semi-rural municipalities in this thesis, the most vulnerable municipalities are mostly found across the lowlands in the north and south, while the municipalities located in the hilly central, eastern and western regions are in most cases less vulnerable to climate change. Least vulnerable municipalities are those with bigger cities within their territory, which provide more diverse livelihood options and non-agricultural income opportunities. There was a considerable degree of variability in terms of the main determinants of vulnerability, depending on the geographical location. Some regions, most notably in the continental humid northern region of BH, experience a higher degree of exposure to climate variations, most notably higher temperatures and increased incidence of floods. However, the main determinants of vulnerability for the most vulnerable municipalities and their population results from low adaptive capacity arising from low level of economic development, less developed infrastructure and weak access to assets, and the increased sensitivity of present livelihood activities under climatic variations.

The most important factor shaping the adaptive capacity of rural households is their access to capital assets and the resulting livelihood activities and outcomes. Rural households in this study were highly dependent on agriculture as a source of income, irrespective of their location in the country and total income. Livelihood assets, activities and outcomes of rural households in BH are generally constrained by inefficient institutions and policies, inadequate infrastructure, services and imperfect markets and access. The observed differences in both total and agricultural income of studied households mainly result from how the available assets are used in agricultural production. Clearly, wealthier households have better access to assets. However, access to certain types of assets in three studied agricultural regions is also modified with the prevailing variations in terms of landforms, climate, and natural resources.

The studied households were well aware of the recent climate trends and the number of adopted agricultural practices indicate that there are signs of an overall intensification of agricultural production in BH, as well as marked adaptations to perceived changes in climatic conditions. Most notable were the application of both organic and mineral fertilizers, changes in crops and crop varieties, and a surprisingly high degree of irrigation. The main reported constraints for further adaptation in agriculture are lack of funds, knowledge and labour. It was also shown that increased access to different types of assets in most cases has a positive influence on the likelihood of adaptations in agriculture.

Conservation tillage was one of the least adopted agricultural practices by rural households in BH and the awareness about such practices is still very limited. Nonetheless, the results from this study indicate that conservation tillage has a potential to improve productivity and sustainability of cropping systems relative to conventional tillage practices. There is a serious need to gain more knowledge about the potential effect of conservation tillage and other agroecological practices on crop productivity, Nitrogen efficiency and the potential of conservation tillage as an adaptation strategy to cope with the extreme weather conditions, whose severity and frequency will be further increased by climate change. The experimental results in this study showed that the reduced number of tillage operations under the current climatic and socio-economic conditions of central BH has a potential to achieve high net returns due to decreased production costs, while maintaining the same level of productivity, expressed in crop yields, relative to conventional tillage. Cereal production in reduced tillage cropping system was also less susceptible to weather extremes in the differing weather conditions and was more Nitrogen efficient when expressed as yield-scaled N_2O emissions. It was concluded that wider acceptance of no-till would not be realistic at this moment in BH, especially by smallholder farmers who lack knowledge and financial capital and are risk averse. However, these results should not be discouraging, but rather encourage further research in the same and other agroclimatic zones of BH, especially the long term studies, since the results of the study and the conclusions were drawn from the short-term effects.

6.1 Concluding remarks

This thesis employed some contemporary research methods and approaches for the first time in BH, promoting mixed methods, interdisciplinary and multidisciplinary approaches to generate new knowledge, to assess the situation and tackle the issues in a more integrated, holistic way. However, it has only scratched the surface of the many discussed issues and challenges and established a baseline for future research. The ultimate goal of this thesis was to popularize common, internationally used research approaches in BH and the Western Balkan region. This, it is hoped, will ultimately lead to improved data collection and implementation of resultant knowledge in BH.

Agricultural development in BH faces many challenges. The challenges are largely a result of poor governance, imperfect markets and a general lack of information and knowledge, which, has led to slow agricultural and rural development processes. The high degree of vulnerability and constrained livelihoods in rural areas are mainly a reflection of the economic recession in the country and a lack of income generating possibilities, resulting from the shocks suffered over the last three decades. Climate change enters this stage as an additional stressor, which could potentially further threaten the vulnerability and livelihoods of the rural communities in BH. Extreme weather events have always occurred in the region. However, increased incidences of such events are reported and they are expected to further increase in the coming decades. Therefore, the inappropriate response and adaptation to climate change may further undermine the development efforts and entrench poverty.

Given the current conditions, agriculture may still be the main driver of rural development in BH. Potential increased incomes from agriculture can lead to investments here and in other sectors in rural areas. However, there are constraints for such developments, in terms of production, markets and institutions. There is a general lack of investments, in terms of on-farm infrastructure and technologies, as well as overall rural infrastructure. Therefore, future policies and public investments should shift away from being dominantly agriculture-focused and viewing agriculture as a social buffer in the overall rural development, and be more focused towards rural infrastructure, availability and accessibility to technologies and inputs, easier land transactions, accessibility to markets, farming associations, better extension and accessible and favourable credits.

Lastly, as a country that is a potential candidate to the EU-membership, BH has the strategic goal to implement the necessary reforms in agriculture and other sectors. There is a potential in such a situation to facilitate development and implementation of future policies. One of the future priorities should be the strengthening of institutional and professional capacities for agricultural development and implementation of development-related policies, as well as mainstreaming adaptation and mitigation to climate change. The effective use of EU pre-accession funds could significantly alleviate the financial burden associated with agricultural and rural development. This should be accompanied concurrently by adequate scientific and technological advances, which, can aim to meet future challenges and develop regional and context-specific approaches to facilitate transfer of new knowledge and technologies into practical application and successful adaptation strategies.

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Appendix 1. Household questionnaire

Interviewer: Region/Place: Number:

VALUES AND NORMS

1. How long do you own this farm? ______ years
2. How have you acquired it? Bought Inherited
3. If inherited, how long is the farm owned by your family/kin? ____ years
4. Are you happy with the independence and self-reliance which you achieve by working on your farm, or would you rather change it for a stable and equally/better paid work as an employee somewhere else?
   a) Yes, I am happy b) I would be happier somewhere else c) Not sure
5. Are you planning one of your children to be the successor of your farm? Would you be happy if one of your children/close relatives continue the farm tradition? Yes No

ASSETS

Natural capital

1. Farm size:__________________, under lease____________
2. Area under crops:___________
3. Meadows, pastures: ________________
4. Other (forest, lake, unproductive, etc.):______________________
5. Is the farm land fragmented a) Yes b) No
6. Soil fertility (in general): a) Low b) Medium c) High
7. Access to irrigation water: a) No b) Yes - River/lake, Well
8. Crop yields (t/ha):

Crop	This year	Last year	Max yield
1.			
2.			
3.			
4.			
5.			

9. Agricultural practice: Monoculture Crop rotation______________________________
10. Percentage (area) of fallows ________
11. How long the fallows haven't been used _______ years
12. What is present on fallows _________________________
13. Are they used for grazing? ___________________________
14. Reason why under fallow ____________________________

Physical capital

1. Access to drinking water: Yes No
1. Access to electricity: Yes No
2. Road access to other areas: No Yes, road quality (1- lowest – 5 highest)

1	2	3	4	5

3. Ownership of the house: Yes No
4. Other available and owned objects (e.g. barn, storage…): ______________________________
5. Agricultural mechanization (and age):____
6. Irrigation system: No Yes (which one):____
7. Irrigated area (% of total arable land): __________________
8. Tools for other on-farm or off-farm activities (if applicable): ____

Human capital

1. Number of household members:
2. Age of the household head:
3. Age (all):
4. Gender (all):
5. Level of education of HH members (0-no education, 8-9-elementary, 11-12-skilled worker, 15-16-university, 16+ higher): 1____2___ 3____ 4___ 5____6____7____
6. Work capable HH members/incapable (low health, other): ___/___
7. Where did you/other HH members work before the war? ____ ____ ____

Financial capital

1. Main source of income: Agriculture Other:_____________
2. Area utilized for agricultural production (crops, meadows, pastures):___________
3. Number of livestock: Cattle ______; Sheep_______; Pig________; Poultry________; Other__________
4. Where does your livestock graze? a) own pastures b) own homestead c) communal pastures d) other:______________________
5. Do you receive any subsidies for your production?___________________________________ ____
6. Does any household member has a job outside agriculture?:
   If yes, it it: On farm (and what)____
   Off farm____
7. Any HH member(s) that lives in other area or abroad which contributes to the household?
   If yes, are they living: a) in other rural area b) urban area c) abroad
8. Average yearly household income (approx.): _______________

9. How would you roughly distribute your income per these categories:
   Agriculture _____%

   Job on farm outside agriculture_____%

   Job outside of farm_____%

   Remittances_____%

   Other (pension, aid, etc.)______%

Social capital

1. Access to information: TV, Internet, Phone, Radio
2. Are you a member of any social organization (political, business, cooperative, trade, religious, cultural):
   If yes, do you have any benefit from this organization (knowledge, income, friendship, spiritual,

   other):____

   ____

   ____

3. Do you have access to any agricultural extension service (public extension, NGO, cooperative, other)?

4. Are you using agricultural extension services? How often are you using their services?

5. Do you have trust in the national government? (1- lowest – 5 highest) | 1 | 2 | 3 | 4 | 5 |
6. What about the local government? (1- lowest – 5 highest) | 1 | 2 | 3 | 4 | 5 |
7. How do you get on with your neighbors? | 1 | 2 | 3 | 4 | 5 |
8. If some local problem or issue arises, do you think you and your neighbors would join your forces in order to overcome it?

9. Do you think your community could bring change and improve their lives if they all group together and try to do something?

CLIMATE CHANGE AND ADAPTATION

1. Do you believe the climate is changing? Yes No
2. Do you think climate change is mainly human induced? Yes No
3. Have you noticed any change in annual air temperatures since you started with agricultural production?

   Yes No

   If yes, is it becoming: Warmer Colder
4. Have you noticed any change in annual precipitation since you started with working in agriculture?

   Yes No

   If yes, is it: Higher Lower
5. Have you noticed the change in the seasonal rainfall patterns (during the vegetation season)

   Yes No

   Describe____
6. Have you experienced a loss of yield, income, or total crop failure caused by any of these events?

Event	Very often	often	sometimes	rarely	Never
Drought					
Waterlogging					
Flood					
Early autumn frost					
Late spring frost					
Hail					
Other_________					

7. Have you taken any changes on the farm in order to avoid damage caused by these events?
Yes No (if yes, state them)____

8. Have you considered or implemented any of these measures?

Measure	Have you heard about this measure? 1- Yes 2- No	Have you implemented this measure? 1- Yes 2- No	Source of information 1- Extension 2- Radio/TV 3- NGO 4- Neighbor 5- Relative 6- Literature 7- other	Has any neighbor or relative invested in this measure? 1- Yes 2- No	Have you invested in this measure 1- Yes 2- No	If no, why? 1- Lack of knowledge 2- Lack of finances 3- Lack of labor 4- Too risky 5- Not convinced in benefits 6- other	If yes, what are the outcomes? 1- Increased income 2- No benefit 3- Worse than before
1. Change of crop							
2. Change of crop variety							
3. Drought resistant crops							
4. Reduced tillage							
5. No-till							
6. Change in sowing/planting dates							
7. Fertilization (synthetic + manures)							
8. Incorporation of crop residues							
9. Use of cover crops							
10. Irrigation							
11. Drainage							
12. Erosion prevention							
13. Anti-hail nets							
14. Greenhouse							
15. Crop insurance							

9. Have you considered or implemented any of these measures?

Measure	1- Yes 2- No	If no, why 1- Lack of knowledge 2- Lack of finances 3- Lack of labor 4- Too risky 5- Not convinced in benefits 6- other	If yes, what are the outcomes 1- Increased income 2- No benefit 3- Worse than before
1. Reduce the number of livestock (if engaged in livestock production)			
2. Change from crop production to livestock (if not engaged in livestock production)			
3. Buy crop insurance			
4. Rent out your land			
5. Work on another farm			
6. Find off-farm job			
7. Migrate to urban area in search for job			
8. Migrate to another country			
Others			

DETERMINANTS OF LIVELIHOOD DIVERSIFICATION AND ADAPTATION

1. Are the household members engaged in their current activities because of:
   a) the necessity (did not have any other option) or
   b) by their own choice?

2. How many household members are full-time engaged in agricultural production?____________
3. Are you doing everything by yourself, or sometimes you hire someone for specific activities, like tillage, harvest, mowing, shepherds for livestock, etc.?
   ____

4. Are you paying them for their services, or have you established some different way of exchange?
   ____
5. Do you have the opportunity/have you considered to work on other farms beside yours?
   Yes No
6. Do you have the opportunity/have you considered to find another job somewhere else?
   Yes No
7. What factors decide your choice of crops/livestock? (own consumption, market, subsidies, agroecological conditions, other)?

	Very high	High	Medium	Low	Very low
Own consumption					
Market					
Subsidies					
Agroecological conditions					
Other________					

8. In the recent time, what did you accomplish with the current choices of your household:
   a) profit from the current production, increasing your wellbeing
   b) just covered your expenses
   c) lost money and become poorer

9. How do you use your eventual incomes? Have you invested in something, like

	Significant	Some	None
purchasing more land			
investment in the current or new production			
infrastructure			
education			
memberships in some organizations			
personal comfort			
leisure and hobbies			
other			

10. Have you (considered) to purchase more land to increase your production? Yes No
    Explain the reason for

    both____

11. In case you would like to purchase more land in your community, do you think it would be easy to find someone to sell it? Yes No, explain why

    ____

12. If you were faced with some event which lead you to the loss of your capital (drought, flood, loss of job, market failure, etc.), how did you cope with it?
    d) Used the savings to recover
    e) Sold the assets (land, livestock, house, other material valuables) to recover
    f) Received aid from the local/regional government
    g) Other____

13. How would you rate the subsidies you are receiving for agricultural production? | 1 | 2 | 3 | 4 | 5 |
    How would you characterize them in one sentence?

14. Do you have access to loans? Yes No
15. How well informed are you about such possibilities? | 1 | 2 | 3 | 4 | 5 |
16. Did you ever take a loan, or have you considered taking a loan in order to invest in your current production or start with the new one? Yes No
    In both cases, state

    why____

17. Do you have access to local/distant markets? How satisfied are you with them (access and prices)?

    Access | 1 | 2 | 3 | 4 | 5 |

    Prices | 1 | 2 | 3 | 4 | 5 |

18. What are your farm products and how do you use them

Products	Min price	Avg price	Max price	Consumed on farm (%)	Sold to market (%)	Sold directly(%)

19. How satisfied are you with the infrastructure in your community

1	2	3	4	5

20. Where do you buy your seeding materials, fertilizers and pesticides?

	In your community	In the nearby town	Not available nearby
Seed material			
Fertilizers			
Pesticides			

21. How satisfied are you with the services provided to you by the state/local government

1	2	3	4	5

22. What do you think is the biggest obstacle when it comes to your wellbeing and future?

	Highest	High	Medium	Low	Lowest
1. Political instability in the country					
2. Weak and inadequate agrarian policy					
3. Market access and purchase prices					
4. Weak infrastructure in your community					
5. Climate change and its effect on agriculture					
What is the main challenge (presented 1-5, 6-other, explain)					

23. What do you think might help you, in addition to what is mentioned here, to achieve your goals and increase your wellbeing?

PART TWO: Compilation of Papers

PAPER 1

Žurovec, O., Vedeld, P.O., Sitaula, B.K. (2015)

Agricultural Sector of Bosnia and Herzegovina and Climate Change – Challenges and Opportunities.

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Review

Agricultural Sector of Bosnia and Herzegovina and Climate Change—Challenges and Opportunities

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Abstract: Half of Bosnia and Herzegovina's (BH) population lives in rural areas. Agricultural production is a backbone of the rural economy and generates significant economic value for the country. BH is highly vulnerable to climate change, which poses a significant development challenge given the climate-sensitivity of the agricultural sector, the share of agriculture in the total economy, the number of people employed in the sector, and the closely related socio-economic issues of food security. BH has experienced serious incidences of extreme weather events over the past two decades, causing severe economic losses. Based on available data and currently available climate projections, exposure to threats from climate change will continue to increase. The review paper presents the current state of the BH agricultural sector and the impact of potential climate change on agricultural systems. It proposes policy options to optimize opportunities and mitigate consequences of possible climate change in the agricultural sector. Development of policy and research capacity should include harmonisation and centralisation of domestic agricultural policies, carrying out a vulnerability assessment and strengthening the public and private extension systems. Further technological development should include improvements in weather and climate information systems, crop development, irrigation and water management.

Keywords: Bosnia and Herzegovina; agriculture; climate change; adaptation

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1. Introduction

Bosnia and Herzegovina (BH) belongs to a group of countries considered highly vulnerable to climate change [1,2]. Agriculture is an important and vulnerable economic sector in BH, given the climate-sensitivity of the sector, the share of agriculture in the economy (7% of the GDP), the number of people employed in the sector, and the closely related socio-economic issues of food security [3].

Climate change leads to adaptation among farmers and their agricultural production in the affected areas. However, adaptation does not occur independently, but rather as a process influenced by socio-economic, political, cultural, geographical, ecological and institutional factors [4,5]. Adequate responses will depend on the ability of decision makers, from the farm level to the national policy level, to perceive climate change and to take relevant action. The current state of politics in Western Balkan countries (WBC), where the public sector is mostly silent and non-transparent, and where the scientific contributions on climate change analyses are scarce, has led to limited development of activities in this field. It therefore comes as no surprise that climate change policy issues are not visible at any level of the policy-making agenda in these countries. As a result, climate change is not treated seriously in current published key strategic documents. One of the main problems comes from inadequate social and human capital when it comes to the introduction and implementation of measures and policies. However, there is a gradual rise of awareness in WBC about climate change, its importance and impact on all spheres of life [3,6–8].

The general objective of this review paper is to present the current state of the agricultural sector in BH and the impact of climate change on agricultural systems in BH. The first section of this paper gives an overview of BH's agricultural sector and its significance, together with the challenges and possible opportunities. The second section assesses the impact of climate change to BH's agricultural sector based on both current conditions and future predictions. The first two sections are based on data derived from official statistical releases, national and international reports and other relevant literature. In the last section, we propose policy options based on the international literature to optimize opportunities and mitigate consequences of climate change in the agricultural sector, in order to increase productivity and adapt agriculture in BH to changing climate.

2. Overview of Agricultural Sector in Bosnia and Herzegovina

BH was considered as a raw material-energy providing region, of the former Yugoslavia throughout the major part of the last century [9]. In the constitutional order of Yugoslavia, BH was part of the federation of six autonomous republics, ruled by a strong central government under the control of the Communist Party. Therefore, the development path and policies cannot be attributed to individual republics only, but external decisions taken at higher levels were crucial in policy formulation and outcome processes [10]. The natural resources of BH are the country's great fortune and misfortune at the same time, which was historically recognised by a large number of occupier exploiting these resources throughout the course of history. Prior to the Second World War, BH was a particularly undeveloped agrarian country compared to its western neighbours. Agriculture was the main sector of the economy during post-war reconstruction. However, at the same time, the foundations of the industrial development, exclusively related to potential in raw materials, were established. Industry employed only 2% of the total population prior to this period [11].

The main characteristics of the former BH economy and national planning is economic development based on the example of post-revolutionary Soviet Russia [9,12], which preferred development of heavy industry as a prerequisite for the development of light industry, transport and agriculture [13]. The leading industries were in metallurgy and chemical industry. The industry employed 54.3% of the entire population in 1961, reached its peak in 1981 (58.4%), and was 44% in 1991, after which comes a new period of war. Industrialization was the key cause of de-agrarian processes, which left deep impacts on social structures in rural areas. The share of agricultural population has decreased 76% in a 40-year period (1948–1981) [14]. BH experienced industrialization that initiated an urban development and migration to urban areas, de-populating rural areas. Agricultural resources as a public good have not been seen in accordance with general social interest—large areas of arable land have been left abandoned and uncultivated [15]. This, among other factors, led to a situation where the country could meet barely 50% of its needs for food [16].

One of the main revolutionary convictions of the newly established socialist state was that the inherited capitalist model of ownership and property rights was seen as a cause of social injustice and inequality. The new government attempted to achieve their vision of social equality and justice through the introduction of common ownership [17]. This was accomplished through adoption of laws and regulations that abolished private properties as the predominant form. At this time, important economic and industrial facilities were converted to state property through confiscation, sequestration, agrarian reforms and nationalization. Land as a common ownership was acquired primarily by confiscation of assets from persons convicted as “enemies of the state” and then significantly increased through agrarian reforms in 1945 and 1953. Agrarian reforms abolished large private land holdings and limited them to a maximum of 10 ha per private entity [17,18]. The confiscated land was awarded to landless peasants and farmers with insufficient land. This led to the emergence of a large number of small and medium sized farms with a tendency of further fragmentation. The agrarian reforms set back agricultural production almost to a scenario of natural or subsistence economy [9]. In addition, the remaining agricultural production was plagued by weak capital equipment of family farms [19] and obsolete technologies [20]. A shift in agricultural policies was recorded in the 70s, where much attention was paid to the development of agriculture and rural areas. The plan was to increase the intensity of production through higher yields and general increased productivity. Investment in land amelioration was one of the focus areas of this master plan. In the 80s, Yugoslavia was plunged into a deep economic crisis, which has affected investments in agriculture and the effective implementation of the planned investment programs.

Like all other sectors, the agricultural sector has suffered enormous damage during the war period (1992–1995). The programs of reconstruction and restoration of international donors focused on basic rural infrastructure and housing, purchase of agricultural machinery and inputs, seeds and fertilizers for the reconstruction and rehabilitation of crop production. It was more of a social aid to local people than a serious investment in the revitalization of agriculture, with the main objective to return displaced population in rural areas [21].

Today, BH is still a predominantly rural country. It is estimated that about 61% of the population live in rural areas [22]. Although the share of agriculture in GDP is constantly decreasing (11% in 2003 to

7% in 2013), agricultural production is a backbone of the rural economy, employing 20% of workforce. The economy of BH demonstrated considerable vitality by achieving high growth rates, especially in 2009, but it was not enough to significantly approach the level of medium developed countries. Actual GDP per capita in 2011 was only 30% of the EU 27 average and reached only 80% of GDP of which it had in 1989 [23]. BH's decentralized political and administrative structure is very complex. This unique constitutional order involves two entities: Federation of BH (FBiH) and Republika Srpska (RS), as well as the Brcko District of BH (BD), as separate administrative units. In addition, FBiH is divided into 10 Cantons. This complex governance structure also has a great impact on management competence and capacity in the agricultural sector. The situation in the agricultural sector in BH is featured by different regulations at different levels, legislative overlaps, limited capacities and communication channels, as well as a lack of clear vision and failure to implement necessary reforms. The legacy of the past socio-political system, coupled with the current complex political structure, have significant consequences for agricultural development, facing many challenges.

2.1. Agricultural Productivity

The main problem of the agricultural sector is low productivity, both per unit of production, and per farm [8]. The main feature is small-scale, subsistence agriculture oriented production rather than a more commercial or market oriented agro-food system. It is a main cause of low competitiveness, particularly in the domestic market. Low agricultural productivity is often a consequence of the absence of clear specialization, primarily in crop production, low technology levels of farms and extreme dependence on weather conditions. Shifts in terms of improving productivity are apparent, however, these processes are very slow [24]. The main reasons for a slow process of improving productivity are difficult and risky market access, and insufficient capacity for storing and processing, especially vegetables. In addition, production of seed material, nurseries and seedlings is underdeveloped and the production depends on imported seeds, often with questionable quality and without adequate control [8]. The level of technological and marketing knowledge among producers is low, which certainly has a negative effect on the productivity of the sector. The main cause for low production of basic agricultural products is that in the previous years, existing agricultural capacities have not been used intensively. Agricultural land covers 2.1 million hectares, of which 46.5% is arable (Table 1) and as much as half of arable land remains unused (Figure 1).

Table 1. Structure of agricultural land in Bosnia and Herzegovina. Source: [25].

Category	Area (000 ha)	%
Arable land	1004.9	19.6
Orchards	99.4	1.9
Vineyards	5.6	0.1
Meadows	460.2	9.0
Pastures	588.2	11.5
Total Agricultural Land	**2158.3**	**42.2**
Forests	2,795.1	54.6
Other	166.3	3.2
Total	**5119.7**	**100.0**

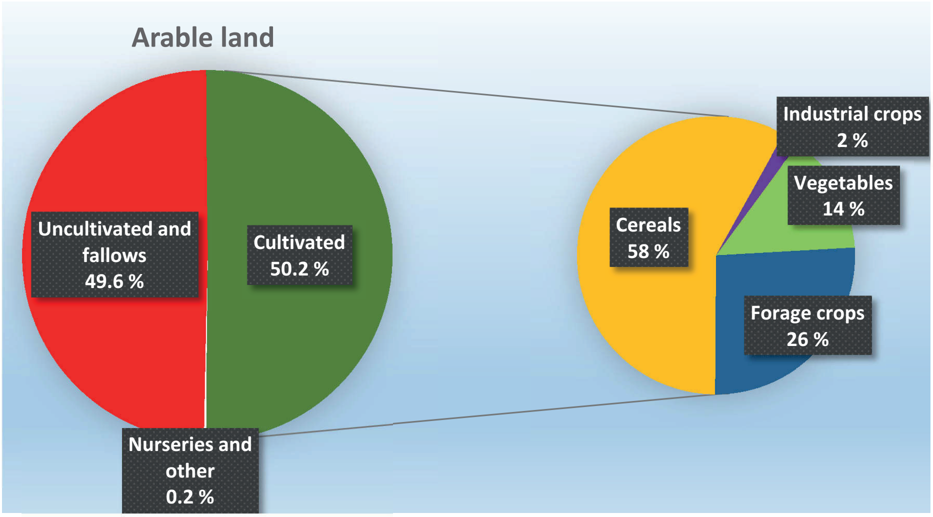

Figure 1. Structure of arable and cultivated arable land. Source: [26].

2.2. Livestock Production

Livestock production has a great significance for BH agriculture considering the available natural resources and the number of people engaged in this production. The key products from livestock involve milk and dairy products, meat and meat products. Since the number of livestock stagnated or declined in recent years, except in the case of poultry (Figure 2), growth in production of meat and milk is explained by improvements in yields and breed composition, but productivity is still low compared with countries in the region [22]. Low productivity is certainly partly due to still inadequate breed structure, inefficient breeding and selection work, but mostly because of the duality in production [8]. Extensive production on small farms is prevailing in livestock production, while on the other hand a small part of the production is organized on the modern, technologically well-equipped farms. While there has been some progress in exports and productivity in recent years, the overall competitiveness of livestock production in the international markets is still weak. BH currently achieves only a small share of imports in its major export destinations, mainly the Western Balkan countries [27]. One of the largest problems in livestock production is the banned on export of Products of Animal Origin to EU. For many years, EU has been requesting the establishment and reorganisation of control system for food and animal stock feed, based on the principle "From Farm to Fork". However, this issue has not been resolved, due to disagreements and lack of coordination and cooperation between the state and entity level institutions in the food safety system and it remains unclear when it will be addressed [28].

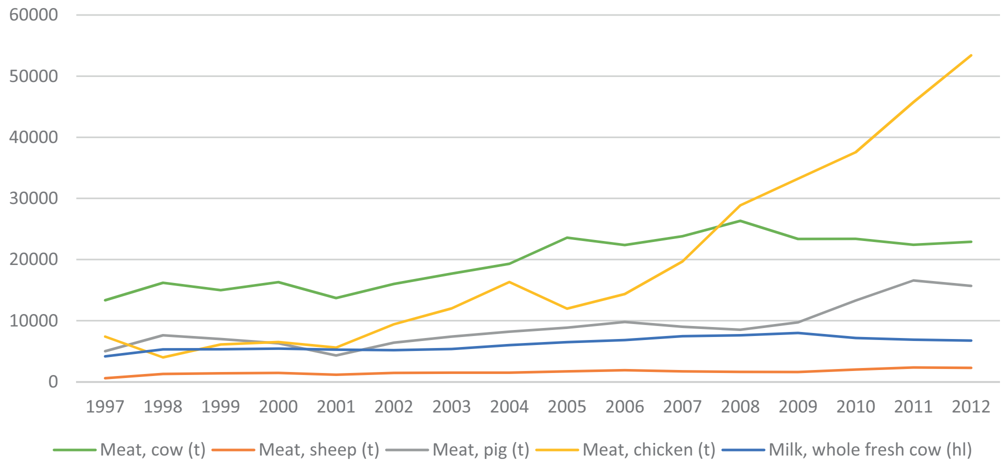

Figure 2. Meat and milk production in Bosnia and Herzegovina. Source: [29].

2.3. Crop Production

Despite relatively favourable natural conditions, crop production is facing many challenges. Frequent adverse weather conditions in key stages of crop growth (high or low temperatures, late spring or early autumn frosts, deficit or surplus rainfall) are further aggravated by lack of farm investment, high prices and poor quality of inputs (such as seeds, fertilizers, and pesticides), subsistence agriculture and traditional extensive farming practices. The result is low productivity and significantly lower yields compared with the rest of the region (Figure 3).

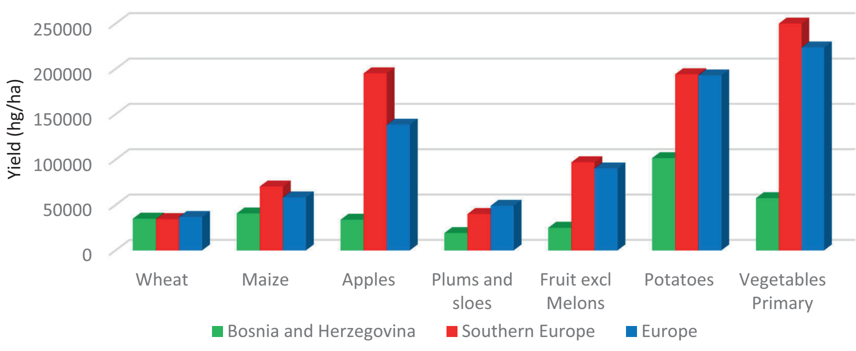

Figure 3. Yield comparison for most important crops in Bosnia and Herzegovina with the regional production. Source: [29].

Cereals dominate agricultural crop production areas (Figure 1), with maize as the main crop (more than 60% of total cereal production). Domestic production of cereals in BH is not sufficient to meet the total consumption demands [22]. The yields of forage crops are low and well below their genetic potential. Resulting feed has a low protein and high cellulose percentage, despite the usage of high quality legumes and their mixtures [30]. Hay yields on grasslands are even lower since most of them are not managed at all. Vegetable production is mainly focused on local markets and takes place in mixed farming systems, often as a supplementary source of income. Orchards and vineyards in BH suffered enormous damage during the war and are currently going through a phase of consolidation and regeneration. Plums, apples and pears dominate the production [26].

2.4. Farm Structure

The exact number of agricultural holdings, particularly family farms, is not known, since a census of agriculture that would provide a comprehensive picture of the structure of agricultural holdings has not been conducted since 1960. This includes determining and typologically categorising farms in relation to the utilized agricultural area (UAA), and determining the size of farms according to UAA. The general characteristic of the Western Balkans' agriculture is that the majority of the producers are smallholders. The main reason for this situation is the former Yugoslavian agricultural policy (farm size limit 10 hectares) [17,18]. Beside its low size (4.7 ha/farm), in most cases farms are formed from small parcels, often dislocated from each other, which makes the production more costly and less efficient., Some 250.000 farms (50%) are less than 2 hectares, and 400.000 or 80% are less than 5 hectares, while only 4% have areas beyond 10 hectares [31].

2.5. Agrarian Policy

The budget allocation to agriculture is quite low compared to developed and even developing countries amounting to about 2% of total public spending in 2007 [32]. By looking at the structure of agricultural support by groups of measures, it is noticeable that the largest amount of support during the analysed period was within the framework of direct payments to producers, which refers to payments based on output and the payment per unit area/cattle. The current BH policy resembles the EU policy in the mid-80s, which will not directly promote productivity increases in BH's agriculture. Budgetary transfers related to direct support to producers and payments based on output form more than 40% of the total agricultural budget [8]. This means that the composition of subsidies in BH is heavily oriented toward direct production rather than investments. Taking into account that most of the smallholder farmers orient their production towards subsidized crops or livestock in order to have access to an additional source of income, this form of support has the function of a social transfer rather than providing productive support to the agriculture sector [32]. The biggest difference between the agrarian policy of BH and the EU's Common Agricultural Policy (CAP) is that CAP has moved away from subsidies tied to production-unbound payments per unit area/cattle/revenue/income and is gradually moving toward investment grants (through Pillar II).

2.6. Agricultural Markets

Inadequate market access reduces the motivation of farmers to specialize and improve their performance and to increase production. Because of the fragmented agricultural production, one of the most important channels for agricultural outputs, the food industry, is not motivated to link up with agricultural producers on long-term contracts [22]. In addition, the current weak food industry is not able to take the role of being the main driver or vehicle of vertical connectivity for an efficient value chain. Consequently, the industry is not interested in improving the present value chain; it uses its negotiating powers and often does not respect agreements made. On the other hand, horizontally disjointed and disorganized producers, who since the time of socialism have expectations that the food industry has an additional social task—the purchase of produced foods—do not offer/respect contract quantities, and often do not deliver adequate quality [8]. The producers do not use the opportunity to develop its regional identity through the production of products with geographical origin, originality or traditional products. In other words, the product range is very narrow, and all companies operate within a narrow segment of the market, while the rest of the niche markets are left to import companies. That is why the food industry companies are faced with stiff competition within the domestic market, and a large number of companies are not able to independently adopt the standards required for foreign markets.

2.7. Agricultural Extension

The networks of public and private institutions, organizations and research institutions, which rely on a system of life-long education, efficient transfer of knowledge, technology and information, form a potential base for innovation and modernization, but they are not established or are severely underdeveloped. The informal sector and NGOs activities, which are implementing different, usually internationally funded, development projects, had a significant role in the transfer of technology in the previous period. These projects have launched initiatives for the establishment of private advisory services, as well as building a portal for the exchange and dissemination of various types of information, which upon completion of the project are either forgotten or unsustainable, because the system cannot become part of the technology transfer system [8]. The core of knowledge and technology transfer services is meant to go through the public extension service. The public extension services, which are located at the regional or cantonal ministries, depending on the entity, mainly perform administrative work and devote very little time to field related work. Coordination between regional extension services do not exist, nor does a systemic approach to their strengthening (especially education) and equipping. This results in a very slow technological progress in the sector compared to the agricultural sectors in neighbouring countries, which ultimately leads to a deepening of the technological and knowledge gap.

2.8. Trade Imbalance

Generally, relatively negative macroeconomic trends are the result of high foreign trade imbalance and high trade deficits, which are the main causes of the negative current account balance. Although the relative share of the negative trade balance in GDP is decreasing—from 31.9% (2006) to 28.4% (2011)—it is still unsustainably high [8]. Such a high negative trade balance is significantly affected by import of agri-food products (18.3% in 2012). Despite that BH has signed a large number of bilateral and multilateral agreements with neighbouring countries, existing inefficient trade policy mechanisms have not lead to a significant increase in exports of agriculture and food products [22]. At the same time, the agricultural sector faces many other challenges, especially in the part of the fulfilment of obligations towards the European Union, since joining inevitably requires adjustment and reform of the agricultural sector in line with EU requirements.

3. Bosnia and Herzegovina and Climate Change

BH is a mountainous country with lowlands along the banks of major rivers. Moving from north to south, the flat landscape gradually becomes wide foothills, arising from 200−600 m above sea level, and gradually turns into a mountainous region. The rest of the area is dominated by the Dinaric Alps, which extend across the whole country, from the western border with Croatia towards the southeast. The central part consist of hills among which are relatively broad river valleys and basins. Karst (barren rocky) terrains cover most of the south-western territories of BH.

As part of the general circulation of the atmosphere over the Balkans, and thus over BH, there are frequent shifts of tropical air masses during summer and the inflow of cold arctic air during winter. All these processes are largely modified by relief that occurs as a major climate modifier. For this reason, the territory of BH is split between three main types of climate: (1) Continental and moderate-continental (2) Mountain and mountain-depression; and (3) Mediterranean and modified Mediterranean climate [3,33]. Continental climate occurs in the north, the Mediterranean to the south, and the line that separates these two regions is dominated by high mountains, plateaus and cliffs which are, depending on the altitude, affected by the mountain climate.

3.1. Future Climate Change Scenarios

BH has experienced serious incidences of extreme weather events in the past two decades, causing severe economic losses. Based on available data and currently available climate projections, exposure to threats from climate change will continue to increase [33]. Observed climate changes are reflected through an increase in average temperatures in BH. For the last hundred years, the average temperature has increased by 0.8 °C (which is in line with global trends), with a tendency to accelerate—the decade of 2000–2010 is warmest in the last 120 years. According to IPCC SRES's scenarios based on SINTEX-G and ECHAM5 climate models (Figure 4), the mean seasonal temperature changes for the period 2001–2030 are expected to range from +0.8 °C to +1.0 °C above previous average temperatures [3]. Winters are predicted to become warmer (from 0.5 °C–0.8 °C), while the biggest changes will be during the months of June, July and August, with predicted changes of +1.4 °C in the north and +1.1 °C in southern areas. Precipitation is predicted to decrease by 10% in the west of the country and increase by 5% in the east. The autumn and winter seasons are expected to have the highest reduction in precipitation. Further significant temperature increases are expected during the period 2071–2100, with a predicted average rise in temperature up to 4 °C and precipitation decrease up to 50%.

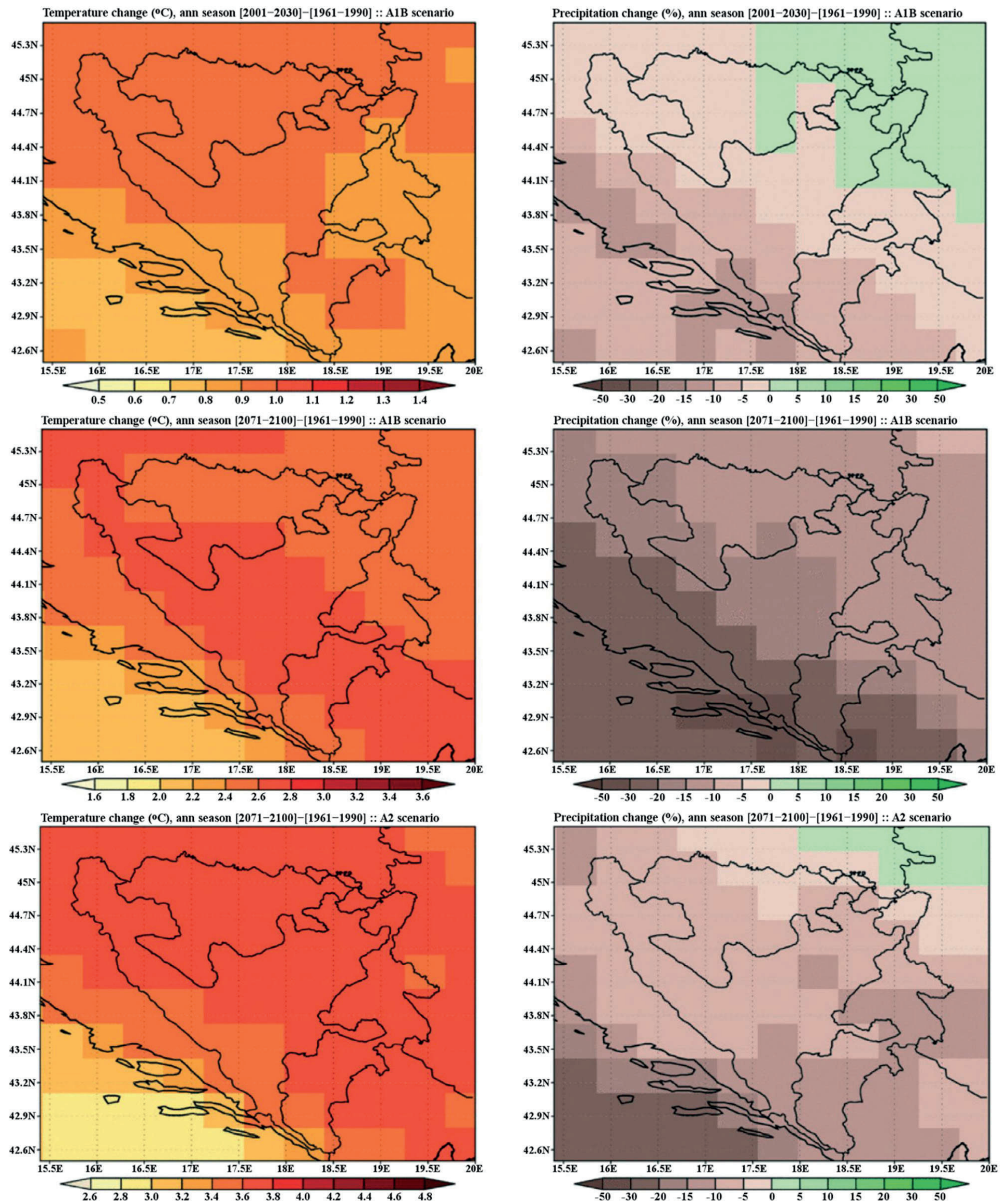

Figure 4. Temperature and precipitation projections for Bosnia and Herzegovina. Source: [3].

3.2. Recent Extreme Climate Events

Drought is a frequent adverse climatic event over the last decade in the Western Balkan and BH. Six drought periods were registered in past 14 years, resulting in enormous economic losses in agriculture. The extreme drought in 2012 was the culmination of a longer dry period, which resulted in a water supply crisis due to lowered water levels of rivers and groundwater. It is estimated that only in

2012, the drought periods caused losses of over USD 1 billion in agricultural production and yield reduction up to 70% [34]. The most affected was maize production, which is the main raw material in production of animal feed. Similar losses were found in production of barley, soybeans, alfalfa, clover, beans, meadows and pastures, which led to a lack of fodder. Lack of fodder influenced the reduction in the number of livestock and livestock production, production of milk and meat supply to the domestic market. At the same time, the effects of the drought have affected rises in food prices, and reduced the export of products. Current projections of drought impact on crop yields remain uncertain due to lack of research in this area. However, it is certain that this issue should not be ignored, taking into account the existing research. Research conducted in northeast Bosnia indicates the severity of the problems facing the country when it comes to the extension of drought periods and changes in precipitation distribution. Using climate, soil and crop data, the estimated average yield reduction in rain-fed agriculture for the six most common crops in the region for past five decades was 3.8%–20.6% and 9.3%–27.7% on loamy and heavy soil, respectively [35]. There is a big difference when the yield reduction from the last decade is compared to the rest of the research period, due to increased air temperature, precipitation, wind speed and lower relative air humidity. Most notably, the maize yield reduction in the past decade was 184% higher compared to the earlier period.

Flood is the other frequent major natural hazard related to weather and climate change in BH. In 2004, flooding affected over 300,000 people in 48 municipalities, destroyed 20,000 ha of farmland, washed away several bridges, and contaminated drinking water. In 2010, BH experienced the largest amount of precipitation recorded to that moment, which resulted in massive floods on the entire territory [36]. The flooding situation culminated with an extraordinary rainfall in May 2014, surpassing even the flood levels from 2010, affecting BH and the surrounding countries. The whole watershed of river Sava, the largest watershed in BH (67% of the total territory) was overflooded with the accumulated downstream flow of water, mud and debris, causing widespread floods in the plain. Breaches of embankments resulted in flash floods and the rivers carrying debris downstream created a path of destruction and desolation [37]. Early estimates indicate that 81 local government units suffered damages, losses, as well as social or environmental impacts to varying degrees. Around 90,000 people were temporarily displaced from their homes and more than 40,000 took extended refuge in public or private shelters. The floods in 2014 caused the damage equivalent to nearly 15% of GDP (cca 2.6 billion USD).

3.3. Impact of Climate Change on Agricultural Systems

There exist no detailed information concerning impact of climate change in BH. However, it is well documented that climate change and increased variability will lead to changes in land and water regimes, and thus have a direct impact on agriculture in the region [38] (Table 2). The impacts of climate change on agriculture are primarily reflected in changes in mean temperatures and precipitation, which subsequently lead to yield reduction and the emergence of new pathogens and diseases, crop failures long-term production declines [39]. Climate change will have different effects on agricultural systems in Europe, with likely increases in crop yields and ranges of grown crops in the north, while a significant decrease in yields are expected in the South [40]. The actual impacts of climate change depend greatly on the adaptive capacity of an affected system, region, or community to cope with the impacts and risks of climate change, which is again determined by its socioeconomic characteristics [41]. The response of crop yields to climate change varies widely, depending on agro climatic zones, species, cultivar, soil conditions, CO_2 level and other location factors [42]. Vulnerability of the agricultural sector in BH is characterised through appearance and frequency of droughts and floods, which can cause a significant yield loss or reduction.

It is expected that the duration of dry periods, the incidence of torrential flooding and intensity of soil erosion will increase during this century. In addition, a higher incidence of hail, storms and increased maximum wind speed may pose a threat to all forms of human activity [7]. This will significantly affect the water balance in soil and underground, as the increased intensity of rainfall and frequent episodes of rapid melting of snow increases the amount of water flowing over the surface and steep slopes of the mountains [3]. The result of this will be yield reductions due to reduced precipitation and increased evaporation, potentially reducing the productivity of livestock and increased incidence of pests and diseases of agricultural crops [43]. However, due to the extended vegetation period, growing seasons will be extended, with increasing potential for growing a wider range of crops.

3.4. Climate Institutions

As a signatory to UNFCCC and the Kyoto Protocol, BH is obliged to develop strategies for climate change mitigation and adaptation to changing climatic conditions, to cooperate in climate observations, research and technology transfers and to raise public awareness. It was quiet on the climate change front up until 2009, when the Initial National Communication of BH (INCBiH) under UNFCCC were published. The main objective of the INCBiH was to make an inventory of greenhouse gas emissions in line with UNFCCC reporting guidelines, which were available only for 1990 at the time. Besides the GHG inventory, the document also proposed some preliminary findings on climate change scenarios and their impact on different sectors [33]. The Second National Communication (SNCBiH) followed in 2012, which updated GHG inventory period (1991–2001), as well as vulnerability of main sectors and estimated potentials for mitigating climate change [3]. What is more important, the Climate Change Adaptation and Low-Emission Development Strategy for BH has been developed alongside SNCBiH. Although defined as the initial strategy, requiring more reliable data and additional development during the course of its implementation, it shows the political will towards building necessary capacities and policies towards low-emission and climate resilient development [44]. The strategy regards water resources and agriculture as the major priorities, which affect the other sectors to a greater or lesser extent and present some concrete activities and outputs, together with indicators, indicative budget and timeframe. Defining agriculture as a priority sector, along with the future integration of adaptation and mitigation measures in the agricultural strategic documents and the adequate funding, creates fertile ground for the realization of activities related to adaptation to climate change in agriculture proposed in the next section.

Table 2. Climate change impacts on agriculture in Western Balkan.

Nr.	Climate Change Variable	Impact	Country/Region	Source
1	Change in temperature and rainfall according to IPCC A1B and A2 scenarios	A1B (2001–2030) change in yields: winter wheat (−16% to 21%); maize (−6% to 71%); maize, irrigated (−5% to 6%); soybeans, irrigated (21%–67%) A2 (2071–2100): winter wheat (−10% to 6%); maize (−52% to −22%); maize, irrigated (−7% to 4%); soybeans, irrigated (−9% to 43%)	Serbia	[45]
2	Mean relative changes in water-limited crop yield simulated by the ClimateCrop model for the 2050s compared with 1961–1990 for 12 different climate models projections under the A1B scenario.	Projected changes in water-limited crop yield from 5% to −25%	Western Balkan	[46]
3	Rain-fed yield reduction in vulnerable areas calculated with FAO Crop Yield Response to Water Deficit using different IPCC SRES scenarios (2025–2100)	Yield reduction Vinegrape 46%–59% Tomato 72%–84% Winter wheat 8%–25% Alfalfa 58%–70% Apple 46%–59%	FYR Macedonia	[47]
	Cost of decreased production (million EUR—current prices)	Winter wheat 4.1 (2025)–8.6 (2100) Vinegrape 18.2 (2025)–23.4 (2100) Alfalfa 7.0 (2025)–8.5 (2100)		
4	Impact of a 2 °C global temperature rise on Mediterranean region according to HadCM3 simulation and CROPSYST crop simulation model	Significant yield decrease for all researched crops (legumes, C3 summer crops, tuber crops, cereals) except C4 summer crops	Mediterranean region (Serbia grid cell)	[48]

4. Policy Implications of Climate Change

The global challenges of adaptation to climate change in agriculture are many. The core challenge is to produce more food by using less resources, under changing production conditions and with net reduction in greenhouse gas emissions [49]. The extent of sustainable adaptation depends on the adaptive capacity, knowledge, skills, robustness of livelihoods and alternatives, resources and institutions accessible to enable undertaking effective adaptation [50]. Extreme weather events, such as increased intensity of droughts, frequency of heat waves, heavy precipitation events resulting in the floods and landslides, are becoming increasingly more frequent [51]. These events have significant impacts on both human lives and national economies and are expected to continue to increase in the future if we do not take sufficient actions. Extreme weather events have the potential to reverse development progress and entrench poverty, especially in developing countries like BH, characterized by limited social safety nets, lack of access to markets, capital, assets, or insurance mechanisms [52]. Below, we highlight relevant socio-political and technological processes that should be the basis for further strategic planning and development of necessary institutions in BH. These processes should address adequately the problem of climate change in agriculture.

4.1. Policy and Research Capacity

Significant difficulties for the agricultural sector in BH arise from the state's constitutional order, according to which all established levels of government—from national to municipal—have the authority for planning and management in agriculture. This sort of organization on the one hand does not allow for the establishment of functional coordinated networks of institutions, and on the other hand it leads to unnecessary and costly multiplications of institutions of the same or similar domains [8]. The unanimous attitude of most sectoral interest groups and non-governmental organizations is that BH needs a national Ministry of Agriculture, formation of which would represent a possible way to better coordinate agricultural policies and consistent articulation of the interests of the sector in international relations (especially in the process of joining with EU), as well as easier establishing the necessary information systems and registers [28]. The agricultural sector is already facing many challenges, which will be further exacerbated by increased frequency and severity of extreme weather events, eventually leading to increased vulnerability. Climate change is a global challenge whose environmental impacts knows no boundaries or borders. Only the unified stance and common policy will lead to effective coordination and harmonisation in terms of implementation of adaptation and mitigation measures in agriculture and all other vulnerable sectors.

Assessment of vulnerability to climate change is an important tool for the analysis and presentation of data at a national level, where the current and potential consequences of climate change are presented to stakeholders in a convenient way and serve as a base for further adaptation policy decisions [53]. The process of adaptation begins with an assessment of the different dimensions of vulnerability and the range of potential options for action, including their justification. A top-down approach is derived from global climate projections, which is further downscaled and applied to assess regional impacts of climate change, while the bottom-up approaches include the involvement of the population and stakeholders of the system in identifying climate-change stresses, impacts and adaptive strategies [54]. In terms of agriculture, assessment of agricultural vulnerability to climate change should lead to identification of particularly vulnerable regions and agricultural production systems, which should further lead to choice of specific adaptation measures and resource allocation for adaptation.

BH needs to have the political and scientific knowledge and public support to adapt to climate change. Investment in agricultural research and development has been declining, or stagnating at best, thus creating a knowledge gap between low and high-income countries [55]. It is crucial to take a long-term, strategic view and to conduct research in order to meet future climate challenges and to develop approaches to facilitate transfer of new knowledge and technologies into practical application. Extension services have played a key role in promoting agricultural productivity and dissemination of knowledge and their role in promoting adaptation measures to climate change will certainly have the same importance [56,57]. Therefore, it is necessary to strengthen the capacity of underdeveloped public agricultural extension services, enabling them to take leading role in terms of strengthening innovation process, building linkages between farmers and other agencies, and institutional development. Research institutes and agricultural universities as a country's leaders in knowledge generation need to create linkages and provide direct transfer of information by educating extension workers regarding the advantages and potential technologies and practices. This can be accomplished on different ways, such as demonstration fields, joint research projects, field trials, training seminars *etc.* [58].

4.2. Technological Development

Efforts to reduce vulnerability to climate change must include strengthening of adaptive capacity and resilience of rural communities. Such strategies will enable farmers to achieve food security and increased well-being under current climatic conditions and will directly contribute to increasing their ability to cope with future uncertainty. More productive and resilient agriculture requires a major shift in the way land, water, soil nutrients and genetic resources are managed to ensure that these resources are used more efficiently and sustainably [59]. Making this shift will require considerable changes in national and local governance, legislation, policies and financial mechanisms. The elements of this categorization include mechanical, biological, chemical, agronomic, biotechnological, and informational innovations [60]. Production that is more efficient and creates more opportunities and access to broader markets can boost smallholders' resilience and create sustainable livelihoods while helping to meet growing demand for food.

Development of new high yielding, input use-efficient, abiotic and biotic stress-resistant varieties with enhanced traits better suited to adapt to climate change is crucial for agricultural adaptation to climate change. Activities and research on plant genetic resources in BH started during eighties of last century, within a project called the "Gene Bank of Yugoslavia". Unfortunately, most of the documents from that period went missing or were destroyed during the last war. Activities such as *ex situ* and *in situ* inventory and conservation of plant genetic resources for agriculture have been restarted during the beginning of this century with the help of international donors [61]. After the inventory and identification of local genotypes, the next step should be linking the selection process with the other stakeholders by employing participatory techniques in order to improve the effectiveness and impact of agricultural research. Having farmers and other stakeholders involved in the development of varieties through participatory plant breeding [62,63] may lead quick and cost-effective production of new breeds and varieties of crops adapted to local needs.

Weather and climate information systems, including early warning systems, aim to reduce vulnerability and improve response capacities of those at risk by increasing their preparedness [64]. Prompt identification of a risk and communication can enable timely responses and assist in farm level adaptation. Farmers should use present and future climate-related information to plan and manage weather risks, maximize productivity, and minimize the environmental impacts of farming practices. Information from the network of agro-monitoring stations combined with remotely sensed information, enable the development of biophysical models used to estimate weather conditions, soil and nutrient status, crop water needs, soil erosion, pest and disease emergence, choice of crop variety best suited for local conditions, *etc.* [65]. Therefore, strengthening of technologies, human resources and development of monitoring, warning and forecasting networks related to hydrological, meteorological, climatic and environmental risks should be considered as one of the priorities.

Global climate change will continue to lead towards significant changes in annual precipitation patterns in south-eastern Europe. In such circumstances, irrigation can certainly be one of the key mechanisms of adaptation in agriculture. There exists no available data on irrigated areas or crops in BH. The total irrigated area according to unofficial data is only 0.4% of arable land, which is considerably less than in neighbouring countries, especially EU [66]. In this situation, irrigation is a measure that can reduce the problems of critical drought periods by improving and stabilizing yields. Due to the documented water deficits and the growing incidences of drought, irrigation should settle around 33% annual water needs for plants in south, 14% in north and 8% in central BH [67]. These needs will increase further according to future climate projections for BH, which include extension of vegetation period, increased frequency of extreme temperatures and longer frost-free periods, leading to additional increase in evapotranspiration and reduced soil moisture content [43,68]. The agricultural sector needs the support and cooperation of other sectors in order to operate in a sustainable manner and follow the principles of integrated water management. Public and private investments in irrigation would enable the expansion of irrigated areas and irrigation use as a supplement to rain-fed agriculture in order to stabilize and increase yields.

5. Conclusions

We have reviewed the agricultural sector in Bosnia and Herzegovina and the likely impacts of climate change upon it. We have also proposed policy options to optimize opportunities and mitigate consequences of climate change. We conclude that BH is a country rich in natural resources and biodiversity, and large parts of the country possess a favourable climate for agricultural production. However, despite such endowments, the agricultural sector is hampered by low productivity, extensive farming practices and technologies, carried out on small and fragmented farms. This is further exacerbated by a weak and inefficient agrarian policy and legislation, low budget allocations for agriculture, inadequate market access and a general lack of information and knowledge.

The legacy of the past socio-political system and the current complex political structure have significant consequences for the agricultural development. Agriculture is highly vulnerable to climate change. Higher temperatures and changes in precipitation are reducing crop yields and increasing the likelihood of short-term crop failures and long-term production declines. Bosnia and Herzegovina, as well as other Mediterranean countries in southern and south-eastern Europe, are expected to experience significant agricultural production losses. As a country that is a potential candidate for the EU-membership, BH needs to implement reforms in the agricultural and rural development sectors in order to reduce the significant policy gap compared to other European countries. In order to cope with the challenges of climate change and climate variability, it is imperative to raise the political awareness and increase recognition on all governmental levels about the impeding threats of climate change on the agricultural sector. The literature on climate change impacts and vulnerability in the agricultural sector stresses the importance of adaptation and urgency to implement adaptation and mitigation measures. The recently published Climate Change Adaptation and Low-Emission Development Strategy for BH shows that there is a political will to build necessary capacities and policies towards low-emission and climate resilient development. We addressed some of the relevant socio-political and technological processes that should be the basis for further strategic planning and institutions that are needed to create the capacity to address climate change in agriculture, agricultural development, knowledge transfer and implementation. Most of them require significant funds and time for their implementation. However, it is unlikely that the agricultural sector alone will be able to cope with the process of adaptation. Only the development of a favorable environment together with political, institutional, economic, social and other actors will lead to a successful agricultural adaptation to climate change.

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Conflicts of Interest

The authors declare no conflict of interest.

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PAPER 2

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Quantitative Assessment of Vulnerability to Climate Change in Rural Municipalities of Bosnia and Herzegovina

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Abstract: The rural population in Bosnia and Herzegovina (BH), which constitutes more than half of the total population, experienced serious incidences of extreme weather events in the past two decades. This part of the population is vulnerable to climate change due to significant dependence on agriculture as a climate-sensitive livelihood option. However, the source of their vulnerability is due not only to the extent and magnitude of these extreme climate events, but also to the internal status within the vulnerable systems before the occurrence of such events. In order to explore the different dimensions of vulnerability, we used a set of 20 indicators to quantitatively assess the vulnerability of the rural population to climate change at the local level in BH. Two summarizing and two weighting methods were applied to assess vulnerability—Equal weights (EW) and principal component analysis (PCA). Based on the results obtained, we concluded that the current socio-economic conditions and the increased environmental pressure as a result of the present human-environment interactions are the main determinants of vulnerability in most vulnerable municipalities, rather than the degree to which these municipalities are exposed to significant climatic variations. Most vulnerable municipalities are located across the north, with a gradual decrease in vulnerability towards the central, north, and east of the country. Vulnerability increases again from here towards the south of the country. The number of municipalities classified as the highest and highly vulnerable increased when the second summarizing method and weighted indicators were used. However, the general geographic distribution of vulnerability did not change substantially compared to the first method. The approaches used in this study provide some valuable results at the local level, and are presented in a way that is practical for decision-making processes and may serve as a base for further research when designing effective adaptation and mitigation strategies, especially in the regions with similar climatic and socio-economic conditions.

Keywords: vulnerability; climate change; rural areas; agriculture; Bosnia and Herzegovina

1. Introduction

Bosnia and Herzegovina (BH) has experienced serious incidences of extreme weather events in the past two decades, causing severe economic losses. Based on available data and current, available climate projections, exposure to threats from climate change will continue to increase [1,2]. BH is a predominantly rural country. It is estimated that nearly two thirds of the population live in rural areas [2]. The rural population in these regions is vulnerable to climate change due to heavy dependence on climate sensitive livelihood options (agriculture in particular) and limited adaptive capacity to cope with changes, similar to what is described in the case of the developing countries [3,4].

Understanding climate change, and its effects and interactions with other global challenges, is a crucial step in designing effective adaptation and mitigation measures. Therefore, vulnerability assessment is one of the key tools used to learn more about the degree of impact of climate hazards within human and ecological systems and how these systems respond and cope with this potential threat [5]. In order to provide the best possible outcome in terms of adaptation and mitigation strategies, vulnerability assessment has to be holistic, at the appropriate scale, and must integrate a wide range of relevant factors [6].

In the last decade, there has been a gradual rise of awareness about climate change, and its importance and impact in BH and the Western Balkan region in general. This is primarily reflected in the growing number of national reports and strategic documents in which climate change is increasingly recognized as an issue of key strategic importance [7,8]. Preliminary findings are based on the existing climate change scenarios and their impact on different sectors, as well as identification of the most vulnerable sectors and estimated potentials for mitigating climate change. Although the basic foundations for building the necessary capacities and policies towards more climate resilient development have been set on the national level, more detailed studies and scientific contribution regarding climate change impacts and vulnerability, especially at the local level, are still modest and insufficient. Local governments and communities have a critical role in adaptation to climate change by structuring responses to local impacts, mediating between individual and collective responses to vulnerability, and governing the delivery of resources to facilitate adaptation [9]. Spatial vulnerability assessment carried out at a local level can thus be a useful tool, which allows for engagement between researchers and local stakeholders through the visualization of climate vulnerability and the integration of its biophysical and socio-economic determinants [10]. Therefore, the objective of our study was to quantitatively assess the current state of vulnerability of the rural population to climate change at the local level in BH and to present it in a way that will facilitate further discussion between researchers, local governments, and stakeholders, ultimately leading to more detailed assessments and adaptation strategies.

2. Choice of Framework and Indicators

2.1. Choice of Framework

Many different methods and approaches have been developed and applied to quantitatively assess vulnerability on different scales [11]. While not without their constraints, these approaches are practical for decision-making processes, since they give a clear picture about the geographical location of the most vulnerable populations and allows the implementation of measures for their protection and adaptation policies [12].

Approaches to conceptualizing vulnerability in the literature concerning climate change tend to fall into three categories. The first one, the end point approach, views vulnerability in terms of the amount of (potential) damage caused to a system by a particular climate-related event or hazard [13,14]. This approach is based on assessments of hazards and their impact, in which the role of human systems in mediating the outcomes of hazard events is downplayed or neglected and, as such, may be referred to as a physical or biophysical vulnerability [13]. This approach is focused on indicators of outcome rather than indicators of the state of a system prior to the occurrence of a hazard event. The second one, the starting point approach, views vulnerability as a state determined by the internal properties of a system that exist within a system before the occurrence of a hazard event. Vulnerability viewed as an inherent property of a system arising from its internal social and economic characteristics is known as social vulnerability [13,15]. Lastly, the third approach is based on the IPCC Third Assessment Report (TAR), in which vulnerability to climate change is defined as: "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" [16]

(p. 21). Such an integrated approach includes an external biophysical dimension, represented through exposure to climate variations, as well as an internal social dimension of a system, which comprises its sensitivity and adaptive capacity [17].

Acknowledging that vulnerability of a certain area or system has an exogenous, biophysical dimension, as well as an internal, socio-economic dimension, we opted to construct a vulnerability index based on the IPCC definition of vulnerability using the indicators approach to assess socio-economic and biophysical factors contributing to vulnerability. According to the IPCC definition of vulnerability, vulnerability to climate change and variability is represented by three elements: exposure, sensitivity, and adaptive capacity [16]. According to the framework proposed by Füssel and Klein [17], exposure and sensitivity together compose the potential impact, while adaptive capacity is the potential of a system to cope with these impacts. Thus, vulnerability can be expressed with the following mathematical equation (Equation (1)):

$$V = f(PI, AC) \tag{1}$$

where V is vulnerability, PI is potential impact, and AC is adaptive capacity. Therefore, vulnerability can be defined as a function of biophysical and social indicators, which constitute the three components of vulnerability.

2.2. Choice of Indicators

A commonly used quantitative approach to assess vulnerability is the construction of a vulnerability index based on specific sets or combinations of indicators, which serve as proxies [18]. Our study views population in rural municipalities as a vulnerable system and climate change and variability as a stressor. It is based on the assumption that the large number of rural households in BH are dependent on agriculture either as a main source of income or as a significant part of their livelihoods [19]. Agriculture is highly sensitive to variations in climate, which will be further increased with the ongoing climate change. Therefore, the chosen indicators should capture the biophysical aspects of climate change, the current state of the environment exposed to climate change, and the socio-economic situation which defines adaptive capacity in rural areas. In order to accomplish greater validity and cross-comparison, we picked most of our indicators based on past peer-reviewed studies, which dealt with quantitative assessment of agricultural vulnerability on a sub-national level, e.g., [12,20–23]. However, some of the indicators, most notably financial indicators in the case of adaptive capacity, were not available at the time of writing this study. In order to address the absence of such indicators, we chose some alternative, existing indicators, which were used as the same or similar proxies in previous peer-reviewed studies. Finally, the indicators were integrated into the sub-indices, in accordance with their belonging to particular components of vulnerability, together with the rationale why certain indicators were used, as shown in Table 1.

Table 1. Indicators used for the three components of vulnerability.

Component	Indicator	Functional Relationship *	Source
Exposure	Changes in average annual temperatures between reference periods 1960–1990 and 1981–2010 [1]	+	[8]
	Changes in average annual precipitation between reference periods 1960–1990 and 1981–2010 [1]	+	[8]
	Frequency of extreme months in the vegetation period (both dry and wet) in the analyzed period (1961–2010) according to the Palmer moisture anomaly index (Z Index) [24]	+	Authors *
	Flood risk assessment for the housing sector [1,a]	+	[25]

Table 1. *Cont.*

Component	Indicator	Functional Relationship *	Source
Sensitivity	Soil depth [2]	-	[26]
	Percentage of agricultural land [4]	+	[27]
	Percentage of households engaged in agricultural production [2,a]	+	[28]
	Percentage of rural population [b]	+	[29,30]
	Arable land per capita [c]	-	[27,28]
	Population density [1,3]	+	[28]
Adaptive capacity	Unemployment rate [1]	+	[29,30]
	GDP per capita [5]	-	[29,30]
	Dependency ratio [4]	-	[28]
	Literacy rate [1]	-	[28]
	Percentage of population with higher education [d]	-	[28]
	Schools per 1000 population [1]	-	[29,30]
	Doctors per 1000 population [1]	-	[29,30]
	Road length per sq. km [2]		[29,30]
	Social capital (derived from total number of associations, NGOs, and foundations) [1,a]	-	[31,32]
	Average yield for major crops (based on the yields of wheat, maize, potato, and main fruits) [3,4]	-	[29,30]

* We calculated the frequency of extreme dry and wet months of the vegetation period for every weather station in BH which has measured the required data from 1961 to 2010. The extreme months were considered as those that had the index value lower than −3 (severe and extreme drought) and higher than 3 (very and extremely wet), based on the classification according to Wells and Goddard [33]. Positive relationship with vulnerability is assumed, since the higher frequency of extreme months increases vulnerability. [1] Indicator used in [12]; [2] Indicator used in [21]; [3] Indicator used in [22]; [4] Indicator used in [23]; [5] Indicator used in [20]; [a] Not identical to indicator used in the cited source; [b] Population in rural areas is more dependent on natural resources, has less developed infrastructure and services, as well as limited income sources compared to population in urban areas. Therefore, highly rural regions are more vulnerable [34,35]. [c] Used as a proxy for population pressure on available agroecosystems in the absence of any more reliable indicator. A negative correlation with vulnerability is assumed, since higher area per capita reduces the population pressure on arable land and therefore reduces vulnerability [34]. [d] Proxy for human capital. It is assumed that the higher percentage of the population with higher education reduces vulnerability, therefore a negative correlation with vulnerability is assumed [36].

3. Study Area

Bosnia and Herzegovina is a country in south-eastern Europe, located in the Western Balkan region, with a total surface area of 51,209.2 km^2, composed of 51,197 km^2 of land and 12.2 km^2 of sea. According to the most recent census in 2013, the population number is 3.53 million [28]. It is estimated that 61% of the total population lives in rural areas, which makes it one of the most rural countries in Europe [37]. The land is mainly hilly to mountainous, with an average altitude of 500 m. Of the total land area, 5% is lowlands, 24% hills, 42% mountains, and 29% karst region. The topography of the country and the location of the major cities are shown in Figure 1. Fertile flatlands comprise about 20% of agricultural land in BH, most of it in the northern lowlands and river valleys across the country. These areas are suitable for intensive agricultural production of a wide range of crops. Moderately to less fertile hilly and mountainous areas comprise 80% of the agricultural land, of which more than a half is relatively suitable for agricultural production, especially livestock production with its complementary grasslands and fodder production. The harsh Alpine environment (mountainous areas), steep slopes, or aridity in the vegetation period (especially in southern BH) usually limit agricultural production in the remaining areas.

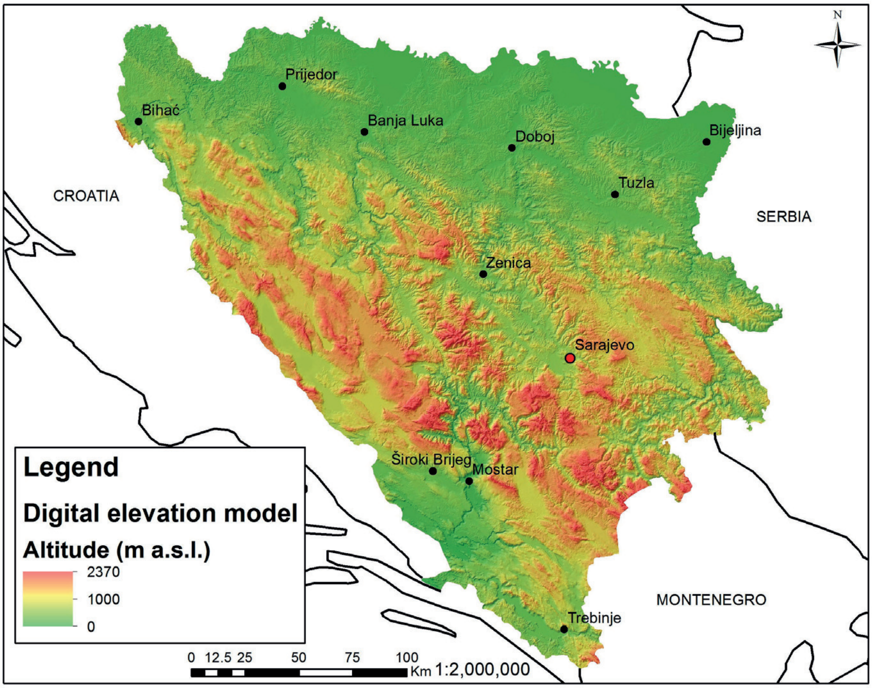

Figure 1. Geographical location, cities, and a digital elevation map of Bosnia and Herzegovina.

The general atmospheric circulation and air mass flow, the dynamic topography, the orientation of mountain ranges, the hydrographical network, and the vicinity of the Adriatic Sea have all created conditions for a wide spectrum of climate types in BH [38], as shown in Supplementary Figure S2. These include a humid continental climate, represented mostly in the northern and lowland central parts of the territory; the sub-alpine and alpine climate of the mountainous region of central, eastern and western BH; and the Mediterranean climate represented in the coastal area and the lowlands of southern BH. This means that the effects of climate change and variability will depend on geographical location, and each region is facing specific challenges. For example, the Mediterranean region, characterized by scarce and shallow soils and significant areas under karst, and northern BH, which has the same climate as most of central Europe, are faced with the negative effects of increased temperatures and unfavorable rainfall distribution [39]. At the same time, the hilly and mountainous regions of central BH might even benefit from increased temperatures due to the increased vegetation season, allowing a wider range of crops and a higher productivity of grasslands.

BH, as a country in transition, is faced with numerous political, social, economic, and other problems in the post-war period. At the same time, it has been experiencing serious incidences of extreme weather events in the past two decades, causing severe economic consequences. Six extreme drought periods and three excessive floods in BH have been registered in the past 15 years, which have affected hundreds of thousands of people and resulted in enormous economic damage in agriculture and other sectors [2].

4. Methods

This study is focused on rural municipalities. Therefore, six municipalities, which are classified as urban based on the OECD criteria [40], were excluded from this study. These urban municipalities were excluded due to insignificant agricultural production and, secondly, because demographic and socio-economic indicators in these areas are substantially higher compared to the remaining 136 municipalities of BH. Therefore, their inclusion in this study may potentially have a negative effect on the normalization of indicators and the derived results, as they would act as outliers. According to the same typology, some municipalities are classified as intermediate, i.e., the share of the rural population is between 15% and 50%. In such cases, one might still expect some variation in adaptive capacity and even sensitivity based on proximity to urban centers. While there exists no specific indicator which would emphasize higher possibility of diversification of income sources or non-agricultural livelihood opportunities in such regions, many of the chosen indicators (e.g., population density, percent of the rural population, and most of the indicators used for adaptive capacity) act as proxies in this case.

4.1. Normalization of Indicators and Their Functional Relationships with Vulnerability

Each indicator used is measured in different scales and units. Therefore, they need to be normalized to ensure that they are comparable. This was carried out using the methodology developed for the calculation of the Human Development Index (HDI) [41]. All indicators were normalized to values between 0 and 1. Before the values are normalized, it was important to identify the two possible types of functional relationship between the indicators and vulnerability. This way it is ensured that the index values are always in positive correlation with vulnerability and that higher value means higher vulnerability and vice versa. Functional relationships with vulnerability for indicators were determined from the previous studies or based on the theoretical assumptions from Table 1. If vulnerability increases with an increase in the value of the indicator (positive correlation), and therefore has a positive functional relationship with vulnerability, normalization was carried out by using the following equation (Equation (2)),

$$X_{ij} = \frac{X_i - MinX_j}{MaxX_j - MinX_j} \tag{2}$$

where X_{ij} is the normalized value of indicator (j) with respect to municipality (i), X_i is the actual value of the indicator with respect to municipality (i), and $MinX_j$ and $MaxX_j$ are the minimum and maximum values, respectively, of indicator (j) among all the municipalities.

If the functional relationship with vulnerability was negative, i.e., if vulnerability decreases with an increase in the value of the indicator (negative correlation), the following equation was used (Equation (3)):

$$X_{ij} = \frac{MaxX_j - X_i}{MaxX_j - MinX_j} \tag{3}$$

4.2. Summarizing and Weighting Methods

The next step after normalization of indicators was to summarize indicators into composite indices and assign weights based on their degree of influence on vulnerability. For the purposes of our study, given that there are many different approaches used in the international literature, e.g., [21,42–44], we decided to use two different summarizing and weighting methods in order to demonstrate the differences between them.

Using equal weights (EW), normalized indicators were integrated in two calculated composite sub-indices in accordance with their belonging to particular components of vulnerability, as defined in Table 1. Sub-index for potential impact (PI) represents the arithmetic sum of indicators for exposure and sensitivity, whose arithmetic means were calculated separately based on the chosen set of indicators, while the arithmetic mean of indicators which represent adaptive capacity makes sub-index for adaptive capacity (AC). The final value of the vulnerability index for every municipality was obtained from the arithmetic sum of these two sub-indices. The same approach was used by O'Brien et al. [21], except that the sub-index for PI was labelled as the "index of climate sensitivity under exposure". For the descriptive purposes of our discussion, we also calculated separate indices for exposure and sensitivity using the arithmetic mean of the indices which represent exposure/sensitivity, as shown in Table 1.

Principal components analysis (PCA) is a statistical method used to extract the linear combinations that best capture the information from a large group of variables. One of the methods is to use PCA to generate composite indices is by using the "eigenvalue-greater-than-one" rule proposed by Kaiser [45], which states that there are as many reliable factors as there are eigenvalues greater than one. This approach is found in Cutter et al. [46] and Wiréhn et al. [23]. After retaining all the components with eigenvalues greater than one, factor analysis in SPSS was used to generate factor loadings for all indicators, which were used as weights. Finally, we used the following equation to summarize all weighted indicators into the single composite index, as explained by [12] (Equation (4))

$$V_j = \sum_{i=1}^{n} w_i(x_{ij} - \overline{x_i})/s_i \; i = 1, \ldots, n; \; j = 1, \ldots, J \tag{4}$$

where V is a vulnerability index, w is the weight, i is the indicator, x is the indicator value, j is a specific municipality, $\overline{x}$ is the mean indicator value, and s is the standard deviation.

4.3. Data Processing and Representation

The data used for indicators (Table 1) came in different formats, some of which had to be processed before their usage in this study. Spatial data used as biophysical indicators, such as changes in average annual temperatures, changes in average annual precipitation, and flood risk assessment for the housing sector, were retrieved in the raster format at a national level. In order to make these datasets suitable for the purposes of our study, we applied the Zonal Statistic Tool within ESRI ArcGIS's Spatial Analyst on the output rasters to calculate the mean values for each spatially-explicit biophysical indicator within every separate municipality, after which they were normalized according to methods described in Chapter 3.1.

Frequency of extreme months in the vegetation period according to the Palmer moisture anomaly index (Z index) had to be calculated based on the available weather station data. This was carried out in four steps. In the first step, the Z index values were calculated from data retrieved from every weather station in BH, which recorded the necessary weather data for the required period (1961–2010). The second step was to calculate the frequency of extreme months, as described in the notes from Table 1. In the third step, the locations of weather stations were used as points for interpolation in order to generate prediction maps for the frequency of extreme months at a national level. The chosen interpolation method was cokriging, where the results from the weather stations were integrated with digital elevation data in order to provide more accurate results. Finally, in the fourth step, we used the same method described in the previous paragraph, where ESRI ArcGIS's Spatial Analyst was used to calculate the mean values for every municipality.

In the case of socio-economical statistical data collected for the remaining indicators (Table 1) from census data, statistical yearbooks, and other public archives, this was a straightforward process, since the obtained data were already on the municipal level.

The resulting vulnerability scores represent current vulnerability of rural municipalities to changes in climate variability recorded so far. The value ranges for final vulnerability scores for both used weighting methods are divided into categories using equal intervals. This method sets the value ranges in each category equal in size. The entire range of data values is divided equally into five categories and each is assigned a qualitative indicator of vulnerability (from lowest to highest). The results are represented cartographically using ESRI ArcGIS in order to visualize and analyze the results in a geographic context.

5. Results and Discussion

5.1. The Overall Vulnerability Index

To obtain the overall index of vulnerability using EW, we summed the composite sub-indices for PI and AC. The results are shown in Figure 2. According to this method, nine municipalities (6.6%) had the highest vulnerability index, while only four municipalities (2.9%) had the lowest vulnerability index. The largest number of municipalities had high (51) or moderate (47) vulnerability (37.5% and 34.6%, respectively). 18.4% of the total number of municipalities (25) had a low vulnerability index. Geographically, the most vulnerable municipalities are located across the north, with a gradual decrease in vulnerability towards the central, eastern, and western parts of the country. In the south, most of municipalities in the lowland region of Herzegovina are classified as highly vulnerable, while municipalities in the surrounding region are mostly classified as low or moderately vulnerable.

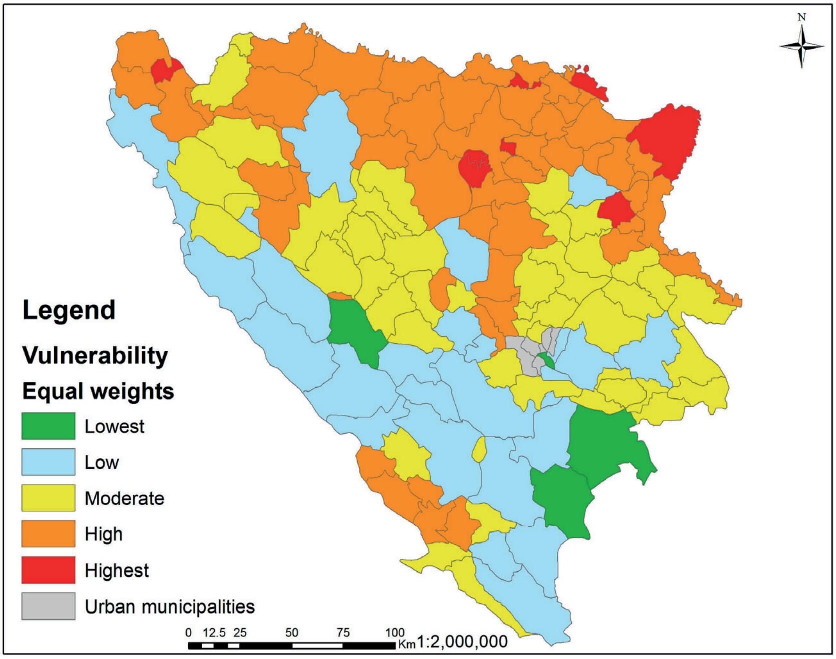

Figure 2. Vulnerability index across municipalities using equal weights.

According to Filmer and Pritchett, the absolute value of the loading of the first single component is valid for assigning weights. This method was used in Gbetibouo et al. [12] to assign weights and construct an overall vulnerability index. In the case of our study, we decided to retain all components with eigenvalues greater than one, as recommended by Kaiser [45], in order to avoid a higher degree of uncertainty in our results caused by significant dimension reduction, since the first component describes only 23% of variance. In this study, six components had an eigenvalue greater than one and together they explained 71.1% of the variance observed. Using factor analysis, we assigned weights for all variables (indicators). The value of the Kaiser-Meyer-Olkin measure of sampling adequacy was 0.719, which is acceptable for factor analysis, as well as the significance level of Bartlett's test of sphericity ($p < 0.001$). The sum of weighted variables for every municipality represents an overall vulnerability index as shown in Figure 3.

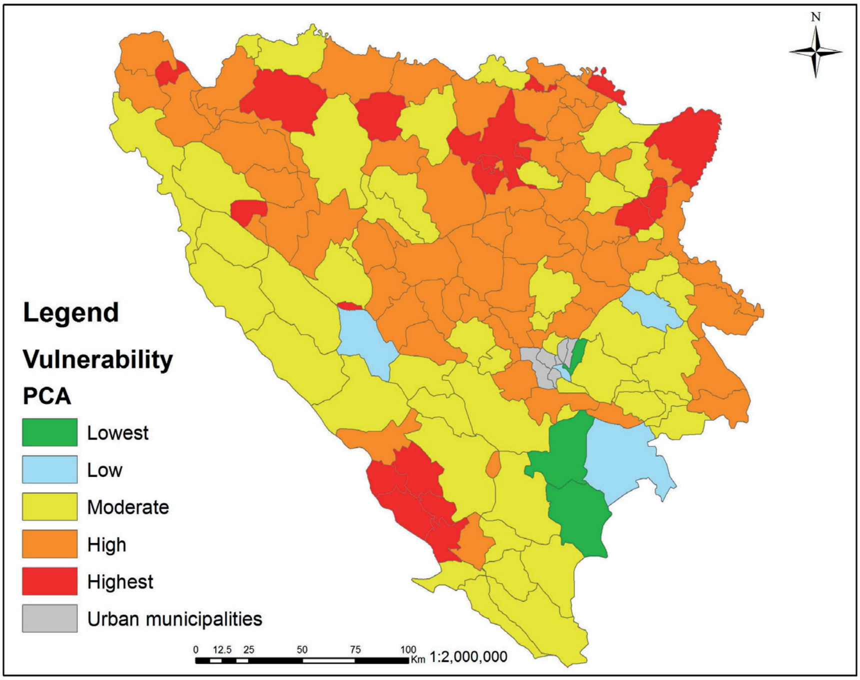

Figure 3. Vulnerability index across municipalities using PCA as weighting method.

Compared to EW, nearly half of the municipalities retained the same class of vulnerability (46.3%), while 41.9% and 8.1% of the municipalities had increased or decreased vulnerability class, respectively. More substantial changes in vulnerability class occurred in the case of five municipalities, which had their class increased by two. Although the apparent increase in the number of vulnerable municipalities is evident, the general geographic distribution of vulnerability using weighted indicators did not markedly change compared to equally weighted indicators. Most vulnerable municipalities are still located in the north, and the least vulnerable ones in the east and southeast of BH. However, there was an increase in the number of highly vulnerable municipalities in central and western BH, as well as an overall increase in vulnerability in the south. Overall, most notable is the decrease in the number of municipalities with low vulnerability indices, while there was an increase in the number of municipalities with the highest and high classes of vulnerability.

The difference in results between the two selected methods results from participation of individual indicators in the formation of the composite indices. This is conditioned by (1) summarizing method and (2) contribution of individual indicators in generation of composite indices determined by weights. The final value of the vulnerability index for our first method (EW) was obtained from the arithmetic sum of two sub-indices (PI and AC), while in the second method (PCA) a single composite index was generated from the arithmetic sum of all weighted indicators. The weighting method had a significant impact on our results. When using EW, every indicator had an equal impact on the final sub-index value, depending on whether or not it belonged to one of the three groups of indicators, while the weights used for some indicators in our study were so low they did not substantially affect the vulnerability index in the case of PCA as a weighting method. Only four indicators (average yields, road length, changes in temperature, and precipitation) had weights (loadings) above 0.3 and were therefore the main determinants of vulnerability, while nine indicators had weights below 0.1 (Supplementary Table S1). The difference in results between two weighting methods used in this study was expected, since only six components were extracted from PCA and they account for 71.1% of variance. Similar differences between these two summarizing and weighting methods were reported by Wiréhn et al. [23].

While EW and PCA are some of the common weighting methods found in the relevant literature, other methods are used, such as inverse of variance and expert opinion [44]. Each of these methods has its own constraints and the scientific debate about the optimal approach is as old as the first attempts to quantitatively assess vulnerability. The arbitrary strategy of assigning equal weights to indicators might mislead the calculations, since not all indicators can have equal influence on vulnerability or may lead to difficulties in reaching a consensus among expert panel members, similar to cases where assigning weights using expert judgment is carried out arbitrarily [12]. Assigning higher weights to indicators showing lower variance may ensure that large variations among the indicators would not unduly dominate the contribution of the rest of the indicators and distort inter regional comparisons. However, a downside to this approach is the suppression of the pronouncement of relevant indicators [43]. Using PCA, it is not guaranteed that correlations necessarily represent the real, or even statistical, influence of used sub-indicators on the phenomenon the composite indicator is measuring [47].

Representation of vulnerability with the single index might bring an insight about the degree of vulnerability on a sub-national level and identify the most vulnerable regions. However, such an approach may also be misleading and lead to simplistic policy conclusions [12,47]. In order to fully assess the "big picture", composite indicators should be used in combination with the sub-indicators. Therefore, we used the results of our first summarizing method, which was composed of sub-indictors using EW, in order to better explain the main sources of vulnerability and the influence of different components of vulnerability in the development of the overall vulnerability index in the next section.

5.2. Influence of Different Components of Vulnerability on the Overall Vulnerability Index

According to the PI index shown in Figure 4a, it is notable that the municipalities experiencing a high degree of PI from current climate variability are located in the northern part of BH, with the exception of four municipalities located on the south-western edge of the country. However, PI is composed of exposure and sensitivity [17] and therefore we have further decomposed the PI index into these two sub-indices in order to better understand the main sources contributing to PI index, as well as the degree and interaction between the components which form PI, as shown in Figure 4b,c.

Figure 4b shows the evident difference in degree of exposure between the hilly-mountainous parts of BH, which stretch from the north-west to the south-east, and the rest of the country (Figure 1). The main cause of high exposure in the northern part of BH is the highest difference in average yearly temperatures and the higher incidence of months with extreme weather conditions, while the south-western region has experienced the highest difference in the amount of precipitation. Two municipalities on the northern border of the country with the highest degree of PI are also highly vulnerable to flooding. These municipalities are in the plain region and located next to the river Sava, the biggest river in BH, which constitutes the northern border of BH and the tributaries in the territory of which BH forms the second largest sub-basin of the Danube river basin. The southern part of the country is the warmest, with a prevailing Mediterranean climate (unlike the rest of the country, which has different forms of the continental and alpine climates). The degree of exposure to climate change in these regions will continue to increase according to regional projections, with an expected average temperature increase of 4 °C in the coming decades, especially in the northern part of the country [8]. According to the same model, an additional unfavorable factor, which will affect the southern part of the country, is the further reduction in annual precipitation, especially during summer, while no significant changes in the amount of precipitation are expected in the rest of the country.

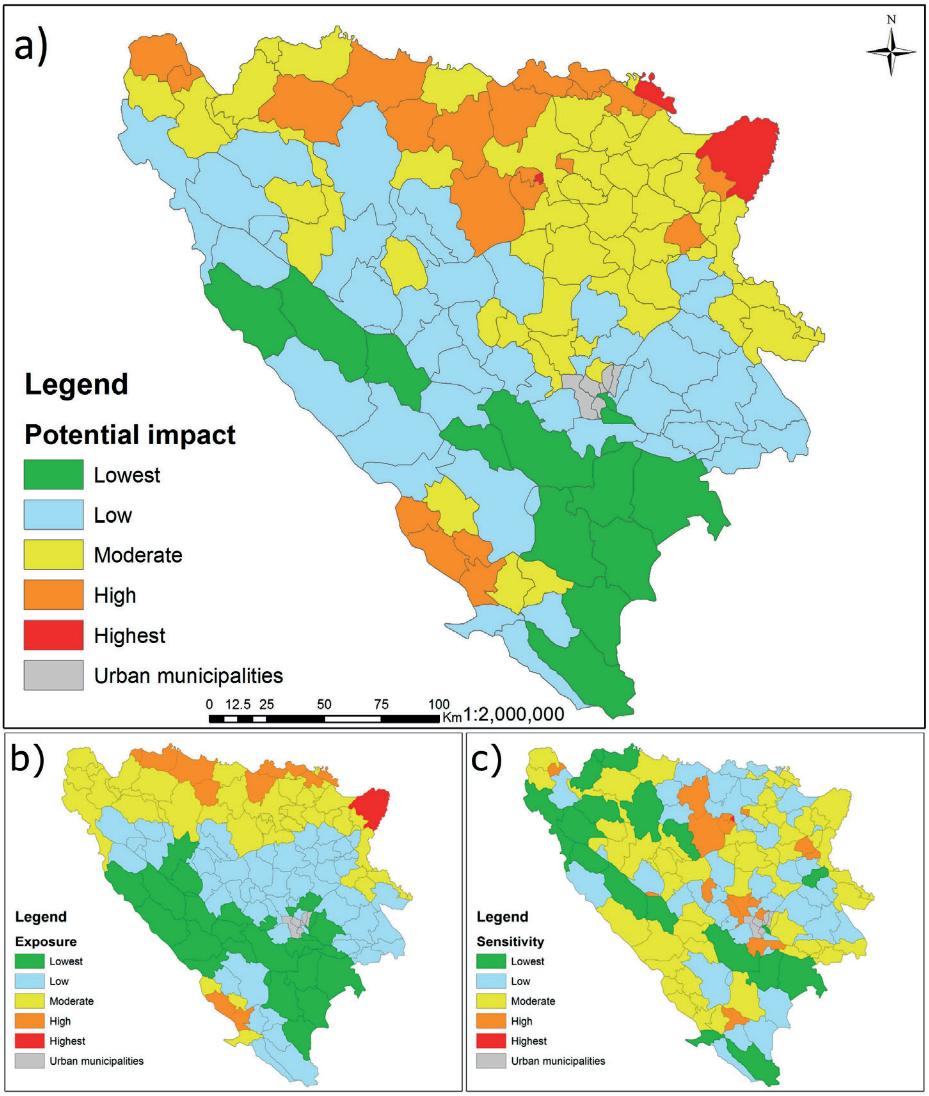

Figure 4. (**a**) Potential impact index, composed of (**b**) exposure and (**c**) sensitivity.

The observed sensitivity of municipalities in this study is quite heterogeneous geographically, as shown in Figure 4c. Similarly, the main indicators found to have the largest influence on sensitivity were variable. Municipalities from the central, mountainous part, or those found in the karst areas of the south, are limited by shallow and less fertile soils. The rest of the municipalities located mostly towards the north consist of highly rural communities with limited sources of income aside from agriculture. Other main characteristics identified in these areas are a high percentage of agricultural land and increased population pressure on it, which results in a low area of agricultural land per capita. It is important to note that central and eastern BH are rich in natural resources, especially water and mineral ores; therefore, they are not highly dependent on agriculture, as a large part of the industrial production in the country is based in these regions.

The situation is diverse when it comes to the adaptive capacity of municipalities, shown in Figure 5. However, some common characteristics are found between the municipalities with low and high adaptive capacity. Municipalities with the highest adaptive capacity have a larger GDP and lower unemployment rates. This is mainly due to the presence of larger towns or cities located within their borders, which likely creates more business opportunities for the local population. Some municipalities have developed into industrial and entrepreneurial centers in the past two decades, with a multitude of varying business activities varying from small to large in size and in outputs/activities [48]. On the other hand, municipalities with low adaptive capacity were found to have a high dependency ratio, underdeveloped infrastructure, public and social services, and high unemployment rates. A significant percentage of the population in these municipalities are smallholder farmers engaged in extensive, often subsistence, agriculture [2].

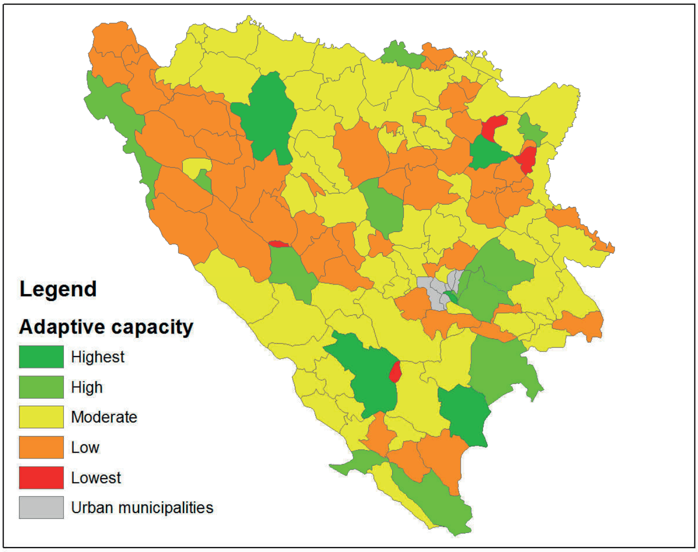

Figure 5. Adaptive capacity index.

The example from Table 2 is used to gain a more detailed insight into the main determinants of vulnerability in the nine most vulnerable municipalities in BH. Looking at the overall results based on the vulnerability index and two sub-indices from which the overall vulnerability index is composed, it is clear that the most vulnerable rural municipalities in BH are those with the high degree of PI, as well as low AC to cope with this impact. Furthermore, when the two components which generate PI (exposure and sensitivity) are analyzed separately, there is a difference as to which component determines the higher degree of PI. Apart from the most vulnerable municipality of Bijeljina, which is much more vulnerable to flooding than the rest of the municipalities of BH, it is evident that the sensitivity index is the main determinant of PI, rather than the exposure index. Therefore, it can be concluded that the current socio-economic conditions (social vulnerability) and the increased environmental pressure as a result of the present human-environment interactions are usually the main determinant of vulnerability in the most vulnerable municipalities, rather than the degree to which these municipalities are exposed to significant climatic variations (biophysical vulnerability).

Table 2. The most vulnerable municipalities in BH and their rankings according to different components of vulnerability.

Municipality	Potential impact			Adaptive Capacity
	Exposure	Sensitivity	Overall	
Bijeljina	highest	moderate	highest	moderate
Doboj-Jug	moderate	highest	highest	moderate
Doboj-Istok	moderate	high	high	low
Orašje	moderate	high	highest	moderate
Usora	moderate	high	high	low
Tešanj	moderate	high	high	moderate
Kalesija	low	high	high	low
Bužim	moderate	high	high	low
Vukosavlje	moderate	moderate	high	low

5.3. Future Considerations for Quantitative Assessment of Vulnerability to Climate Change with Special Focus on Choice of Biophysical Indicators

The results indicate variability between the chosen summarizing and weighting methods, which would certainly increase even more if additional methods from recent studies were used for further comparison, as shown by Wiréhn et al. [23]. Development of the vulnerability index involves sequential stages, including the selection of indicators, their normalization, and summation to a final value. There is a significant degree of uncertainty in vulnerability assessments and data transformation in these stages, as described in more detail by Tate [49]. Also, while a number of indicators have been used and developed for assessing vulnerability, the choice of indicators should be context and region-specific, as there is no "one size fits all" blueprint that can be used regardless of the context [50]. Based on these arguments and the experiences which we obtained during the preparation of this study, as well as reviewing literature related to vulnerability assessment in the context of agriculture and climate change, we would like to emphasize the importance of the right choice of biophysical data when doing local vulnerability assessments to climate change. We believe that the indicators used to measure exposure, such as frequency of extreme weather events (such as drought and floods) and variation of temperature and rainfall, might be misleading depending on the climate zone in which the study is conducted, as they may not fully capture the magnitude and the extent of such events.

Drought is a normal, recurring feature of climate, which occurs in all climatic regimes (in contrast to aridity, which is a permanent feature of the climate and is restricted to low rainfall areas [51]). Like vulnerability, drought has both a natural and social component, i.e., the risk associated with drought is a product of both the region's exposure to the drought, as well as the resilience of the ecosystem or adaptive capacity of that region [52]. Impacts also differ spatially and temporally, as well as depending on the type of drought. Drought has been grouped by type as follows: meteorological, hydrological, agricultural, and socioeconomic [53]. Meteorological droughts result from precipitation deficiencies, while agricultural droughts are largely the result of soil moisture deficiencies. Agriculture is usually the first economic sector to be affected by drought because soil moisture supplies are often quickly depleted, especially if the period of moisture deficiency is associated with high temperatures and windy conditions [51].

Similar to drought, waterlogging is another phenomenon which limits agricultural productivity. Unlike floods, which are in a more conventional sense defined as an overflow of water from water bodies, waterlogging occurs when the soil becomes saturated in cases when the amount of precipitation exceeds the ability of the soil to infiltrate or evaporate the excessive moisture. Like in the case of drought, the extent and duration of waterlogging is mainly related to climatic and soil water-physical properties [54]. Waterlogging causes anaerobic conditions in the crop-root zone and leads to reduced crop growth and yields; it also delays agricultural field operations, such as tillage and harvesting, and can lead to abundant surface runoff, inducing soil erosion and the loss of nutrients [55–57].

Based on the above definitions, we believe that agricultural drought should be the starting point when using drought as an indicator of agricultural vulnerability to climate change, and that the impact of drought should be based on soil moisture, not meteorological data. We also believe that waterlogging of heavy soils in humid, and in some cases sub-humid, areas, especially flatlands and valleys, can cause the same amount of damage as drought, and therefore we recommend it as an important indicator when assessing exposure to climate change in such conditions. For the purposes of this study, the approach developed by Wells and Goddard [33] was used to classify Palmer Z-index values and calculate the frequency of extreme months (both dry and wet) in the last 50 years, which was used as an indicator for exposure in our study. Most studies related to climate hazard analyses and monitoring systems have been conducted using either: (1) The Palmer Drought Severity Index (PDSI) or Palmer moisture anomaly index (Z Index) [24], based on a soil water balance equation; or (2) The Standardized Precipitation Index (SPI) [58], based on a precipitation probabilistic approach. They are called drought indices, but they have ability to measure dryness (negative values) and wetness (positive values) at the same time. The Palmer drought indices show how monthly moisture conditions differ from normal conditions for the specific area based on available soil water content, reference evapotranspiration, and precipitation, and they are sensitive to unusual dry (and wet) months even in extended dry (or wet) spells. While PDSI is used to quantify the long-term changes in soil moisture, the Z-index is usually used for detection of short-term deviations from normal moisture conditions, which are important for agriculture and were therefore included as an indicator in our study [59].

SPI can also be calculated at different time scales to monitor droughts with respect to different usable water resources. However, it might not be suitable for climate change analysis, since it does not take temperature or evapotranspiration as input parameters [60]. A new climatic drought index similar to SPI, the Standardized Precipitation Evapotranspiration Index (SPEI), has been proposed recently by Vicente-Serrano et al. [61]. SPEI is similar to SPI, but includes temperature as a parameter of calculation, which makes it closer to PDSI. As such, it has been already used in studies concerning agriculture and climate change, e.g., [62,63], and with its multiscalar character is suitable to use in drought-related vulnerability assessments.

6. Conclusions

This study was a first assessment of vulnerability to climate change at the sub-national level in BH. Quantitative assessment of vulnerability to climate change in rural municipalities was carried out for 136 rural and semi-rural municipalities in BH. The chosen conceptual framework for this research, based on the IPCC definition of vulnerability, views vulnerability as a function of biophysical and social indicators, which constitute the three components of vulnerability: exposure, sensitivity, and adaptive capacity. 20 biophysical and socio-economic indicators were used to reflect these three components. For the purposes of our study, we decided to use two different summarizing and weighting methods (EW and PCA) to assess vulnerability to demonstrate the differences between them.

Based on the results obtained for the overall vulnerability index using the first summarizing method and EW, the most vulnerable municipalities are mostly located across the north, with the gradual decrease in vulnerability towards the central, northern and eastern parts of the country. Less vulnerable municipalities are those with larger towns and cities within their territory and the ones located in hilly-mountainous central-south, central-west and south-eastern regions. From there, towards the south of BH, most of the municipalities in the Mediterranean lowland region of southern BH are classified as highly vulnerable, while municipalities in the surrounding region are mostly classified as low or moderately vulnerable. General geographic distribution of vulnerability using the second summarizing method and weighted indicators did not change substantially compared to the first method. However, there was an overall increase in the number of highly vulnerable municipalities, most notably in the central, east, and south of BH, while the number of municipalities with low vulnerability index decreased.

We used the results of our first summarizing method using EW to better explain the main sources of vulnerability and the influence of different components of vulnerability on the development of the overall vulnerability index. Based on these results, it was concluded that the current socio-economic conditions (adaptive capacity) and increased environmental pressure as a result of present human-environment interactions (sensitivity) are the usually the main determinants of vulnerability in the most vulnerable municipalities, rather than the degree to which these municipalities are exposed to significant climatic variations.

The results of this study provided valuable knowledge about the current state of vulnerability of the rural population of BH to climate change and the main determinants of vulnerability. They also establish a baseline, which can be further updated at regular intervals, and they represent the first step towards further local assessments and improvements, as new indicators become available and are discussed by the main stakeholders and the local communities. The same or similar approaches can also be applied in regions with similar climatic and socio-economic conditions, particularly the countries of the Western Balkan region and South-eastern Europe.

Supplementary Materials: The following are available online at www.mdpi.com/2071-1050/9/7/1208/s1, Figure S1: Administrative structure and municipalities of Bosnia and Herzegovina, Figure S2: Climate zones of Bosnia and Herzegovina according to Köppen-Geiger climate classification, Table S1: Factor loadings for extracted principal components.

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PAPER 3

Žurovec, O., Vedeld, P.O.

A case study of rural livelihoods and climate change adaptation in different regions of Bosnia and Herzegovina

- Manuscript -

A case study of rural livelihoods and climate change adaptation in different regions of Bosnia and Herzegovina

Ognjen Žurovec, Pål Olav Vedeld

Abstract

Nearly a third of the households in Bosnia and Herzegovina (BH) are engaged in agriculture as a livelihood strategy to cope with the effects of the multiple shocks suffered over the past three decades, resulting in economic decline and the absence of income opportunities. A significant dependence on agricultural incomes makes this part of population particularly vulnerable to climate change. Based on the data collected using a household questionnaire, this study investigates the livelihoods of rural households in three agricultural regions in BH, how they are affected by climate change and their perceptions of changes in climatic conditions, as well as household adaptation strategies and the main determinants of climate change adaptation in agriculture. The results were discussed in the context of sustainable livelihoods approach and a binary logit model was used to analyse the determinants of adoption of agricultural practices and technologies in the context of assets. The results show that rural households are relatively asset poor and dependent on agriculture irrespective of location or total income. Their access to assets is further constrained by the ongoing structures and processes. Negative effects of climate change were reported in terms of yield declines and the reduced quality of products. The studied households were found to be aware about the recent climate trends and reported to adopt a wide range of more long-term adaptation strategies. In the context of agricultural production, the level of adoption of different agricultural practices and technologies shows the signs of the overall intensification of agricultural production in BH, as well as adaptation to the perceived changes in climate. Increased access to different types of assets was shown to positively influence the likelihood of adoptions of agricultural practices and technologies, most notably social capital, access to technologies (tractors) and human capital.

1. Introduction

Bosnia and Herzegovina (BH) is predominantly rural, with 61% of the population living in rural areas (MOFTER 2012). Although the share of agriculture in GDP is decreasing, it is still a backbone of the rural economy, employing 20% of the workforce and constituting 6.4 % of total GDP. The potential for agriculture in BH is substantial. Of the total 2.1 million hectares of agricultural land, 46.5% is arable, while only 50% is currently utilised in agricultural production. Favourable climatic conditions and its geopolitical position, abundant freshwater supplies and relatively cheap labour costs gives the agricultural sector in BH a clear, comparative advantage over many other European countries and potentially gives BH an advantage in terms of labour-intensive products. Livestock production has the highest economic value in the present agricultural production system in BH, with great potential for further expansion and intensification due to the high availability of grasslands and pastures in areas less favourable for intensive crop production.

However, agriculture in BH suffers from low general productivity, with rather extensive farming practices and technologies, carried out on small and fragmented farms. This is a problem partly inherited from the past socio-political system, where agriculture was marginalized in favour of industrial development, but further exacerbated in the post-war period by poor governance in the ongoing process of transition (Žurovec et al. 2015). A large proportion of the population, most of them employed in industry, have become unemployed in the aftermath of the war in the nineties, which led to devastation, mass migration and economic decline in rural areas. In the absence of income options, a significant part of that population resorted to agriculture as a main or additional source of income. As a result, more than 31% of the total households in BH are engaged in agriculture, but only 5% of them are considered commercial farmers (AFSBH 2013). This shows the significant role that the agricultural sector in BH provides in terms of food security, mitigating a social burden of economic reforms and restructuring, as well as rural poverty reduction (Bojnec 2005). However, as agriculture remains one of the main sources of income for most rural households in BH, this means that the livelihoods of many become increasingly vulnerable to present and expected climate pressures.

BH is considered highly vulnerable to climate change (Brooks et al. 2005; Kreft and Eckstein 2013). Extreme weather events, such as increased intensity of droughts, frequency of heat waves, heavy precipitation resulting in floods and landslides and other extreme weather events, are becoming increasingly more frequent in the region and have and can cause significant economic losses (IPCC 2011; Žurovec et al. 2015). There is a limited adaptive capacity to cope with both climate and other shocks in BH, and the situation is similar to that found in developing countries. This inherently low adaptive capacity is the main determinant of vulnerability to climate change in most rural areas of BH, even more so than the degree to which these areas are de facto exposed to significant climatic variations (Žurovec et al. 2017a). Poverty in BH is mostly a rural phenomenon - close to 80 % of the total poor live in rural areas. Non-farm employment opportunities in rural areas are limited. Many rural areas have poorly developed transport, social and economic infrastructure, all of which are basic preconditions for social and economic development. These conditions preceded the massive changes through the recent war events, but were also exacerbated by the economic crisis and poor governance in the country. This is especially pronounced in remote areas, where a continuous process of desertion through migration results in the closure and degradation of the existing infrastructure including schools, shops and local clinics.

Adaptation is crucial both in order to enhance the resilience of the agricultural sector and for individuals to secure their livelihoods by increasing their adaptive capacity. Adequate responses in terms of adaptation to climate change depend on; the adaptive capacity, knowledge and skills, robustness of livelihoods and alternatives, resources and access to institutions in order to undertake effective adaptation (IPCC 2007). While technological development, government programs and insurance schemes require greater investments from the public sector and industry to be subsequently adopted by farmers (Smit and Skinner 2002), adaptation to climate change at the farm level includes many possible responses. This could encompass changes in crop management practices, livestock management practices, land use and land management and a variety of both on-farm and off-/non-farm livelihood strategies (Bryan et al. 2013). While climate change has yet to be mainstreamed into national and regional development policies in BH, individuals and communities are already adapting to changing climatic conditions. Such adaptation strategies are mostly reactive and carried out privately by individuals or communities in response to perceived and experienced adverse impacts of climate change and variability (Smit et al. 2000). Perceptions are key components in the on-farm decision-making process. Observations and experiences over time shape farmers' climate change perceptions and influence their choices of appropriate adaptation strategies. However, adaptations in agriculture are not only carried out with respect to climatic stimuli alone, but rather as a "joint effects of multiple forces" (Smit and Skinner 2002). People adapt to changes in their external frame conditions in different ways and it can be difficult to assess complex changes in institutional arrangements and explore what can be reasonably linked to climate change in addition to how other frame conditions can interact with climate change in relation to how people adapt in both the short- and long-term.

Rural households with access to agricultural means of production have the choice between both agriculture and non-agricultural economic activities. Different adaptation strategies within agriculture can also be considered, such as extensification versus intensification, as well as “exit options” such as off- and non-farm activities, migration and remittance strategies. In as much as climate change is one driver for particular courses of action, other frame conditions such as agricultural policies and market conditions, alternative economic options and other factors situate households with different asset access in different positions concerning such choices. There is no single profitable or desired option for all households or individuals; but diversification patterns in terms of adaptation must be understood as a broad spectre of opportunities. It is also useful to see this as a combination of (“free”) choice versus necessity (Ellis 2000) and or as a structure-agency dichotomy. Choices are made but under such strong preconditions or bearings that the choice is “given”.

Another feature of BH as a country is its pronounced heterogeneity in terms of geographical, agro-ecological and climatic conditions, as well as a unique, and rather asymmetric constitutional, political and institutional arrangements and governance. This means that households under different socioeconomic and agro-ecological conditions will obviously have different realities to relate to and also different perceptions of climate change and accompanying consequences for agricultural and other income generating potential. Such perceptions are both individual and social, where kinship and the existing social environment often play important roles in the evolution of perceptions and understandings of various issues.

The objectives of this study were to: i) assess the livelihoods of rural households, their access to assets and livelihood diversification strategies; ii) investigate how the households are affected by climate change and how they perceive these ongoing changes and iii) to analyse household adaptation strategies in different regions of BH and the main determinants of climate change adaptation. The results were analysed and discussed in the context of three different agricultural regions and three wealth groups according to total income level of the households.

2. Study area

BH is a country in South-eastern Europe, located in the Western Balkan region, with a total surface area of 51,209.2 km^2, composed of 51,197 km^2 of land and 12.2 km^2 of sea. The land is mainly hilly to mountainous, with an average altitude of 500 meters. Of the total land area, 5% is lowlands, 24% hills, 42% mountains, and 29% is the karst region. The general atmospheric circulation and air mass flow, the dynamic relief, the orientation of mountain ranges, the hydrographical network and the vicinity of the Adriatic Sea have all created conditions for a wide spectrum of climate types and subtypes in BH (Bajić and Trbić 2016). Generally, these include a humid continental climate, represented mostly in the northern and lowland central parts of the territory; a sub-alpine and alpine climate in the mountainous region of central, east and western BH, and a semi-arid mediterranean climate represented in the coastal areas and in lowlands of Herzegovina (southern BH). Areas above 800 m asl are mostly unsuitable for crop production due to harsh climatic conditions.

The country is divided into six agricultural regions, differing by altitude, share of certain types of crops and livestock and the degree of economic development. These can be roughly grouped into three main agricultural regions: lowlands, hilly-mountainous and Mediterranean region (FMAWF 2013). The sites used in this study are situated in these three regions (Figure 1), referred to as the northern (lowland), central (hilly-mountainous) and southern region (meditteranean).

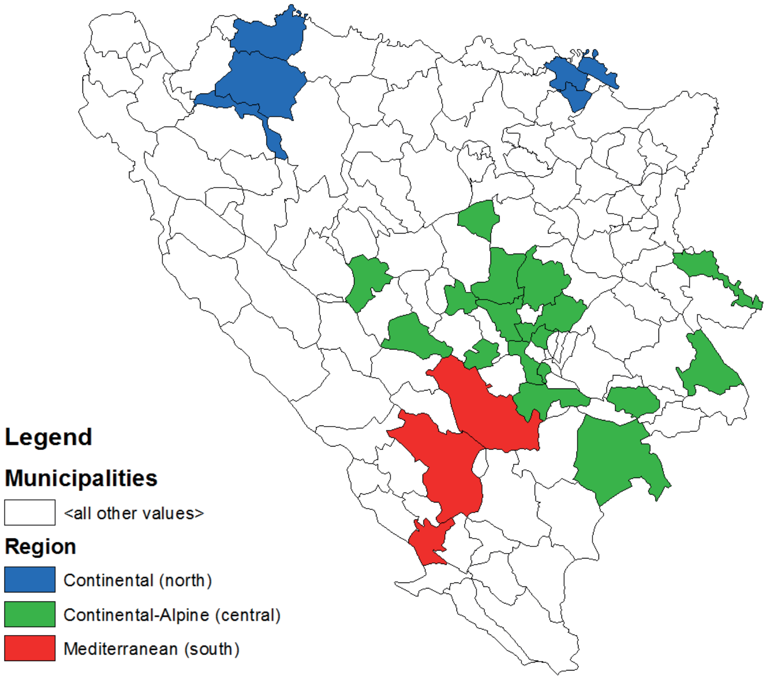

Figure 1. Surveyed Municipalities in BH

3. Methodological framework

3.1. Sustainable Livelihoods approach

We applied the Sustainable Livelihoods Approach (Chambers and Conway 1992; DFID 1999; Scoones 1998) to assess the livelihood assets, activities and outcomes and the contextual factors that influence them. This approach is based on mapping people's access to assets (natural, human, social, physical and financial capital) and the way people use and access their assets. This is mediated by institutions, social relations and policies (transforming structures and processes), as well as shocks, trends and seasonality (vulnerability context) (DFID 1999). Under such circumstances, poor people undertake a range of activities and choices (livelihood strategies) in order to achieve different livelihood outcomes (Ellis 2000).

We also utilize insights from the micro-economic agricultural adaptation studies to investigate agricultural adaptations using household livelihoods assets as socio-economic determinants of adaptation.

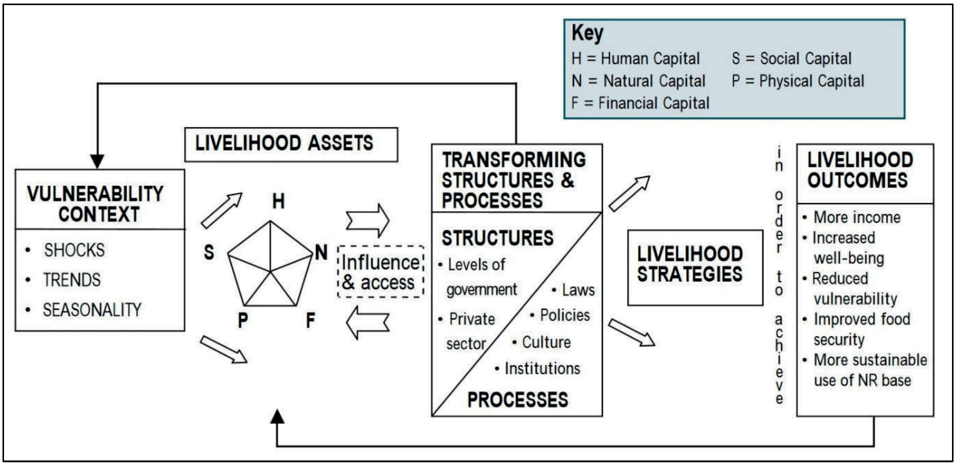

Figure 2. Sustainable livelihoods framework, Source: DFID (1999)

3.2. Data collection and methods

Primary data was collected using a household questionnaire with both closed and open-ended questions, carried out from January-February 2015. The collected data was analysed through descriptive statistics and by using analytical models. In total, we surveyed 104 rural households engaged in agriculture in three different agricultural regions in BH. The first section of the questionnaire mapped assets of the surveyed households, structured as natural, physical, human, financial and social capital. The second section was divided in two parts – the first one contained questions related to perceptions and personal observations of climate change and its nature and extent, as well as questions about the damage caused by the selected extreme weather events in the past. The second part focused on the awareness and implementation of the selected adaptation strategies. The third section encompassed the questions related to various determinants of livelihood diversification and adaptation strategies, activities and perceived challenges and obstacles for survival and livelihoods.

Total incomes were defined as the household sum of cash and subsistence incomes as reported by respondents. Income diversification of annual household income sources were also based on the estimations of the respondents. Clearly, there is uncertainty in the reliability of such results partly due to the possibility of respondents to underestimate or exaggerate their incomes. In order to avoid larger inconsistencies, the results were checked individually, using the reported quantities and market prices of the products sold.

Due to the dichotomous outcome of the variables regarding the adoption of various agricultural practices (adopted or not), we opted for the binary logit model to statistically analyse the determinants of adoption. This model considers the relationship between a binary dependent variable and a set of independent variables, whether binary or continuous. The model in its simple form can be presented as:

$$Y_i = \alpha + \beta_i \sum_{i=1}^{n} X_i + \varepsilon_i$$

Where, Y_i is the dichotomous dependent variable for individual agricultural practices (1 = adopted; 0 = not adopted), α is the Y-intercept, β_i are a set of regression coefficients, X_i denotes the set of explanatory independent variables and ε_i is an error term.

4. Results and discussion

4.1 Livelihood assets

Five main categories of capital contribute to livelihood assets: natural, physical, human, financial and social capital (Ellis 2000; Scoones 1998). Generally, people were found to be relatively asset poor. This is most notable in the limited access to natural and financial capital. The average farm size in our survey was 5 ha, which is small but still larger than the estimated farm size in BH (80% farms are smaller than 5 ha (World Bank 2010)). The average annual income per capita was 7,576.8 BAM (= USD 4,536.80), meaning that the average person lives on USD 12.43 a day. Access to basic infrastructure is satisfactory and most of the households had access to electricity, drinking water and a decent road access. The average dependency ratio inside the household was relatively high (34.2%) due to the fact that he majority households in BH that were surveyed had a three generation family household structure. Most of the people had basic access to information and physical access to public and financial services, but the level of their development was low, which constrains their wider use (e.g. underdeveloped extension services, unfavourable credit lines for rural population). In the next subsections, we present the general asset access for the sample and the differences by location and by income of households.

The access to natural capital in terms of arable land is larger the northern region of BH than in the two other regions. The size of land under lease and areas used to cultivate crops are significantly bigger. Rural households have higher and easier access to land. By comparison, agriculture in the central and southern regions is limited by lack of arable land. Most of the people in these two regions live in fertile plains and valleys, creating a pressure on limited land resources, while the remaining areas are generally less suitable and accessible due to rugged terrain, slopes, forests and karst. In the northern region we find that there is a significantly larger area of leased land, as a significant amount of land in this area is owned by the state, who rents land to farmers through various concession agreements. A smaller part of the leased areas in the northern region are privately owned. Unlike in the north, private land makes the most of the leased areas in the other two regions. The number of crops produced on farms varies by region. Farmers from the northern region had the lowest range of crops grown. The most frequent crops found in the northern region were wheat, maize and tobacco. Potato, raspberries and apple were the most common crops found in the central region, while potatoes, onions and tomatoes were most frequently found in the southern region. The dominant type of farming in the northern and the central region was mixed crop and livestock production, where livestock feed and fodder is produced on grassland areas in addition to maize, wheat and barley. The main reasons stated why some parts of the land were left as fallows are frequent flooding, lack of labour, low fertility and remoteness of certain plots.

Certain differences were found related to physical capital in the researched regions. While they are less emphasized in terms of infrastructure, the differences are primarily reflected in the possession and utilization of on-farm technologies, including mechanization, irrigation systems and greenhouses. Most farmers in the north and south have their own agricultural machinery. However, the age of the tractors and other machinery is worrying, especially in the southern region. Agricultural mechanization in BH often has a long depreciation life and there is a general tendency for such assets to become obsolete (FMAWF 2015). The percentage of households that own some type of the irrigation system in this study is surprisingly high, as it is stated in the literature and in the national reports that less than 1% of agricultural areas in BH are irrigated (Čadro et al. 2017b).

The regions do not significantly differ in terms of human capital. The only significant difference was in the education of surveyed household members. Unlike in the northern region, where most households are traditional farmers, many household members in the central region and to some degree in the south were not primarily engaged in agriculture during the pre-war time, and mainly worked as skilled workers in the different state-owned enterprises and factories. These were typically in the metal, leather or the textile industries, or some other kind of formal employment. After the war period, most of these people had lost their jobs due to devastation, migration, privatization, bankruptcy and restructuring of the companies they worked in, and they started engaging in agriculture as the key source of income in the absence of other jobs. In terms of income, the wealthiest group in this study had a significantly larger household size compared to the poorest group.

Significant differences in financial capital were also found, primarily in household income, which was much higher in the southern region. This difference is explained in more detail in the next section. The northern and central regions have somewhat higher financial capital stored in livestock. The number of sheep per farm was significantly bigger in the central region compared to the north, while the number of pigs was bigger in the north. A significant percentage of the surveyed households (28%) had incomes below the last estimated general poverty line in BH (AFSBIH 2015), most of them in northern and central region.

Indicators of social capital differ significantly between regions. All surveyed households owned a TV and/or radio as a source of information. The number of households who have access to and use internet as a source of information is also high, but somewhat lower in the central region. Farmers from the southern region are more often members of agricultural associations, usually cooperatives, but are also linked to NGOs. Farmers in the northern region had better access to extension. However, the reason for this is that the company purchasing most of the produced tobacco in this region offers extension services to its producers. The public extension provides most of the knowledge and technology transfer services in BH, but is severely underdeveloped (Žurovec et al. 2015). There are few extension workers, who mostly perform administrative work and allocate very little time to field related work, because they are understaffed and lack resources for field visits.

Table 1. Asset structure in the different regions

Variables	North (n=35)	Central (n=33)	South (n=36)	Overall
1. Natural capital				
Farm size (ha)	5.6	5.1	4.4	5.0
Land under lease (ha)**	9.3[a]	0.8[b]	0.8[b]	3.6
Area under crops (ha)**	13.9[a]	2.1[b]	2.8[b]	6.3
Grasslands (ha)**	0.3[a]	2.0[b]	1.0	1.1
Other land (forest, lake, unproductive; ha)	0.6	0.9	1.3	0.9
Fallow size (ha)	0.2	0.5	0.1	0.3
Crop diversity per farm**	3.5[a]	2.8[b]	3.6[a]	3.3
2. Physical capital				
Access to drinking water (%)**	100[a]	100[a]	80.6[b]	93.5
Access to electricity (%)	100	100	100	100.0
Road quality (from 1-bad to 5-excellent)	3.3	3.6	3.4	3.4
Farm ownership (%)	97.9	97.0	86.1	93.7
Agricultural mechanization (%)**	91.4[a]	60.6[b]	97.2[a]	83.1
Age of mechanization (years)**	10.0[a]	15.3	18.0[b]	14.4
Irrigation system (%)*	74.3	60.6[a]	88.9[b]	74.6

Irrigated land (%)	59.2	46.4	59.1	54.9
Greenhouse (%)	11.4a	18.2a	47.2b	26.0
3. Human capital				
Household size	4.2	4.5	5.0	4.6
Age of the head of household	54.3	53.8	59.5	55.9
Education – head of household (years)	10.1	12.3	11.2	11.2
Education – highest in household (years)**	12.3[a]	14.0[b]	12.9[a]	13.1
Dependency ratio (%)	32.4	23.1	47.2	34.2
4. Financial capital				
Number of cows/cattle	2.8	3.6	0.5	2.3
Number of sheep*	0.5[a]	19.2[b]	2.3	7.3
Number of goats	0.0	4.0	0.1	1.4
Number of pigs**	3.4[a]	0.1[b]	0.0[b]	1.2
Number of poultry	128.3	5.1	3.4	45.6
Number of beehives	0.0	3.1	3.3	2.1
Household annual income (BAM)**	22,302.9[a]	27,381.8[a]	48,233.3[b]	32,639.3
Annual income per household member (BAM)**	5,554.3[a]	5,949.7[a]	11,226.3[b]	7,576.8
5. Social capital				
Access to information (Radio, TV)	100.0	100.0	100.0	100.0
Internet access (%)**	94.3[a]	66.6[b]	94.4[a]	85.1
Membership in associations (%)**	37.1[a]	45.4[a]	88.9[b]	57.1
Access to extension (%)**	88.6[a]	57.6[b]	58.3[b]	68.2
Access to credit (%)**	100[a]	81.8[b]	97.2[a]	93.0

* $p<0.05$
** $p<0.01$
[a,b] Tukey test; groups with different letters are significantly different from each other ($p<0.05$)

The biggest differences between income groups, apart from income, were found in access to natural capital, with the wealthiest group of households having significantly bigger farms, areas under crops and higher diversity of crops produced on farms. Wealthier households also had a bigger household size and therefore more access to family labour, and more agricultural machinery. Lastly, the poorest households had significantly lower access to social capital, with significant differences found in membership in associations and access to credit. Clearly, higher access to natural capital and farm labour enables increased on-farm production. Increased participation in farming associations of households with higher incomes indicates the importance of these associations in improving livelihood opportunities and security. They also allow farmers, especially smallholders, improved access to markets in terms of both inputs and outputs, and access to information and technologies through a wide range of services (Stockbridge et al. 2003). Based on these results, it can be concluded that the rural households who are able to specialize in agriculture have higher income levels. We return to this under a discussion of livelihood activities and outcomes.

Table 2. Asset structure in relation to total household income

Variables	Poorest (n=35)	Poor (n=34)	Less poor (n=35)	Overall
1. Natural capital				
Farm size (ha)**	2.4[a]	4.0[a]	8.8[b]	5.0
Land under lease (ha)	1.3	5.1	4.7	3.6
Area under crops (ha)*	2.8[a]	7.2	9.1[b]	6.3
Grasslands (ha)	0.5	1.3	1.5	1.1
Other land (forest, lake, unproductive; ha)*	0.3[a]	0.6	1.8[b]	0.9
Fallow size (ha)	0.1	0.2	0.5	0.3
Crop diversity per farm*	2.6[a]	3.4	3.4[b]	3.3

2. Physical capital				
Access to drinking water (%)	100.0	91.2	88.6	93.5
Access to electricity (%)	100.0	100.0	100.0	100.0
Road quality (from 1-bad to 5-excellent)	3.6	3.2	3.5	3.4
Farm ownership (%)	97.1	91.2	94.3	93.7
Agricultural mechanization (%)**	65.7[a]	94.1[b]	91.4[b]	83.1
Age of mechanization (years)	13.1	14.5	15.3	14.4
Irrigation system (%)	68.6	70.6	85.7	74.6
Irrigated land (%)	56.6	54.8	55.8	54.9
Greenhouse (%)	17.1	29.4	31.4	26.0
3. Human capital				
Household size**	3.8[a]	4.5	5.4[b]	4.6
Age of the head of household	55.3	54.3	58.1	55.9
Education – head of household (years)	11.1	11.0	12.1	11.2
Education – highest in household (years)	12.9	12.9	13.3	13.1
Dependency ratio (%)	30.1	33.9	38.0	34.2
4. Financial capital				
Number of cows/cattle	1.7	1.9	3.2	2.3
Number of sheep	1.1	5.1	14.9	7.3
Number of goats	0.0	0.1	3.9	1.4
Number of pigs	1.2	1.1	1.3	1.2
Number of poultry	121.2	6.9	7.5	45.6
Number of beehives	3.3	1.8	1.3	2.1
Household annual income (BAM)**	13405.7[a]	25535.3[a]	59520.0[b]	32,639.3
Annual income per household member (BAM)**	3957.2[a]	6203.4[a]	12727.7[b]	7,576.8
5. Social capital				
Access to information (Radio, TV)	100.0	100.0	100.0	100.0
Internet access (%)	80.0	85.3	91.4	85.1
Membership in associations (%)**	31.4[a]	67.6[b]	74.3[b]	57.1
Access to extension (%)	71.4	70.6	62.9	68.2
Access to credit (%)**	82.9[a]	97.1[b]	100.0[b]	93.0

* p<0.05
** p<0.01
[a,b] Tukey test; groups with different letters are significantly different from each other (p<0.05)

4.1.2 Activities and outcomes

A striking feature in the overall sample is the very high dependence on agricultural incomes, constituting 72.4 % of the total average income (Table 3). They come from a variety of strategies and reflect different combinations of crops and livestock, choices influenced by the trade-off balance between subsistence and market-oriented production and the prevailing agro-ecological conditions. Off-farm incomes are the second most important contributor to total household incomes (18.5%). The reported off-farm incomes come from a variety of formal and informal employment. On-farm, non-agricultural incomes do not constitute a significant percentage of overall total incomes, but still represent a significant source of income for some individual households. The most common on-farm non-agricultural incomes are services, which some household members offer with their on-farm tools, such as mechanical workshops, carpentry, welding, tractors, transport trucks, bulldozers, logging and alcohol distilleries. Remittances (2.7%) are mainly received from family members and relatives living in urban areas or abroad. Although the average incomes received from pensions and other social transfers are quite low in BH, some households may overlook their importance in total household income. While income from pensions and other social transfers accounted for only 4.4 % of the total household income in this study, they are shown to be higher in some previous studies (e.g. (Berjan et al. 2014b; UNDP 2013). Here, we analyse and discuss the differences in income sources by region and income level, as well as diversification in agricultural production and on-farm products.

Table 3. Diversification of income sources by region

Income source	**North (n=35)**		**Central (n=33)**		**South (n=36)**		**Total (n=104)**	
Agriculture**++	17,877^{a}	78.1^{b}	16,356^{a}	55.9^{a}	41,198^{b}	83.2^{b}	25,467	72.8
On-farm non-agricultural*+	309^{a}	1.1	1,590^{b}	3.9^{a}	150^{a}	0.1^{b}	660	1.7
Off-farm+	3,158	15.9	7,068	28.2^{a}	5,298	12.1^{b}	5,140	18.5
Remittances	549	3.7	927	4.4	13	0.1	483	2.7
Pension, other social transfers*+	411	1.1^{a}	1,440	7.6^{b}	1,573	4.6	1,140	4.4
Total**	22,303	100	27,382^{a}	100	48,233^{b}	100	32,891	100

* significant difference between some of the three categories (Anova). * P<0.05; ** P<0.01.
+ = significant difference between some of the three relative income categories + P<0.05; ++ P<0.01.
a,b = Tukey test; groups with different letters are significantly different from each other (p<0.05).

There was a significant difference between relative agricultural income in the central region, which was lower (55.9 %), compared to the northern (78.1 %) and southern region (83.2 %). Interestingly, the total income from agriculture in the south is more than twice that of the other regions, as well as being a significantly higher contributor to total household income. This is not explained by the regional differences in asset access, since higher agricultural income in the south is achieved with access to the same, or even lower amounts of natural capital compared to the other regions. The main difference rather derives from the structure of the agricultural production unit and the on-farm products sold, which are determined by how the assets are used in agricultural production, as well as agricultural potential in the researched regions in terms of climatic conditions. We come back to this later in this section.

From Table 4 we see that the total income is more than four times higher for the less poor than for the poor household group. They have more land, livestock, labour, and general capital access. Regarding the diversification of income sources, a statistically significant difference was found in the case of total agricultural and off-farm incomes between the poor and the less poor group. Interestingly, there was no statistically significant difference in the relative contribution of different income sources to the total household income. Households in the three income groups thus have a similar structure of income sources in terms of their relative incomes, but they differ in their total amounts. The poorest group of households had lower total incomes from every source, except remittances. Less poor households had much higher total agricultural income. This is in line with the higher access to natural (most notably land), physical (agricultural machinery) and human capital (more family labour) these households have as discussed earlier. Another interesting finding is that the wealthiest households in this study (less poor group) tend to be either those who acquired their farms in the last 15 years on average (50% of the total sample) or have a long tradition of farming, spanning three or more generations (46% of the total sample).

Table 4. Diversification of income sources by wealth group

Income source	Poorest (n=35)		Poor (n=34)		Less poor (n=35)		Total (n=104)	
Agriculture**	9,266[a]	68.4	18,203[a]	71.9	48,725[b]	78.1	25,467	72.8
On-farm non-agricultural	124	0.7	706	2.5	1,152	1.8	660	1.7
Off-farm*	2,452[a]	18.9	5,144	20.1	7,822[b]	16.4	5,140	18.5
Remittances	648	5.4	473	1.7	329	0.9	483	2.7
Pension, other social transfers	915	6.6	1,009	3.8	1,491	2.8	1,140	4.4
Total**	13,405[a]	100	25,535[b]	100	59,519[c]	100	32,891	100

* significant difference between some of the three categories (Anova). * P<0.05; ** P<0.01.
\+ = significant difference between some of the three relative income categories + P<0.05; ++ P<0.01.
a,b = Tukey test; groups with different letters are significantly different from each other (p<0.05).

Agricultural diversification into mixed crop-livestock systems was the most dominant type of production, adopted by more than a half of the studied households (59 %). The production systems are shaped by agro-ecological conditions, which strongly influence the agricultural potential in the researched regions and domination of certain production types over others.

The structure of agricultural production by region (Table 5) shows that the large majority of households in the north are engaged in the production of cereals, tobacco and soybean. A significant part of the cereals and soybeans produced on the farm is used for subsistence as livestock feed. Tobacco was the main cash crop in the region and together with livestock-derived products accounts for the majority of household incomes from agriculture. By comparison, none of the surveyed households in the southern region produced cereals and soybean on their farms. Two thirds of the total households in the south produced different types of vegetables (mostly potato, onion and cabbage), while nearly half of the households also produced vegetables in greenhouses (mainly tomato, peppers and lettuce). Fruit production, both soft (mostly strawberry) and top fruit (peach, nectarine, cherry, vineyards), was also a significant source of income for about a third of the households in the south. The favourable climatic conditions in this region provide an advantage on the local and regional markets for agricultural products due to earlier ripening of crops, as well as the cultivation of some early and late-season fruits and vegetables that are in demand by consumers and therefore can command a high price. Households in the central region were more livestock-focused, with a significantly higher percentage of dairy and cattle farmers. The main cash crops in this region were different types of fruit (both soft and top fruit) and vegetables (potato). Raspberry plantations and greenhouse vegetable production were dominant types of production on smaller farms, achieving highest economic returns per acreage.

Table 5. Diversification of agricultural production by region and income

Production	Percentage of households						
Crops	North (n=35)	Central (n=33)	South (n=36)	Poorest (n=35)	Poor (n=34)	Less poor (n=35)	Average (n=104)
Cereals**	97.1[a]	27.3[b]	0.0[c]	42.9	47.1	34.3	41.3
Soybean**	54.3[a]	0.0[b]	0.0[b]	22.9	14.7	17.1	18.3
Tobacco**	77.1[a]	0.0[b]	0.0[b]	31.4	29.4	20.0	26.9
Vegetables**++	0.0[a]	39.4[b]	66.7[c]	17.1[a]	41.2	48.6[b]	35.6
Vegetables (greenhouse)**	11.4[a]	18.2[a]	47.2[b]	17.1	29.4	31.4	26.0
Top fruit**	0.0[a]	33.3[b]	30.6[b]	14.3	23.5	25.7	21.2
Soft fruit**	8.6[a]	33.3[b]	38.9[b]	31.4	20.6	28.6	26.9
Livestock							
Cattle**	37.1	57.6[a]	27.8[b]	40.0	38.2	42.9	40.4
Small ruminants and pigs**	68.6[a]	51.5	8.3[b]	48.6	44.1	34.3	42.3
Poultry**+	74.3[a]	39.4[b]	8.3[c]	51.4	41.2	28.6	40.4
Other	0.0	9.1	11.1	5.7	5.9	8.6	6.7

* significant difference between some of the three categories (Anova). * P<0.05; ** P<0.01.
\+ = significant difference between some of the three relative income categories + P<0.05; ++ P<0.01.
a,b = Tukey test; groups with different letters are significantly different from each other (p<0.05).

Unlike the regional comparison, the structure of agricultural production in terms of income did not yield a notable number of statistically significant differences. There is less cereal production and more vegetable and fruit production with increases in income. While the ownership of the different types of livestock is relatively similar in all income groups, they tend to differ in terms of the number of livestock owned (although this difference was not statistically significant (Table 2). The only exception is the percentage in possession and the total number of poultry, which is highest for the poorest income group. However, these are mostly small flocks, with usually less than 30 units and rudimentary egg production used largely for subsistence, with the direct sale of surpluses.

While most of the production is market oriented, a significant percentage of crops in the average sample was used for subsistence (17 %), like cereals for livestock feed and potato for household consumption. The subsistence use of crops by region was 4.7, 20.8 and 27 % for the southern, northern and central region, respectively. The use of meat and livestock-derived products for subsistence is higher than for crops (32%). More than 30% of the total produced eggs, pork, lamb meat and dairy products were consumed on the farm. Subsistence is also found within every income group, but it was higher in the poorest group in terms of both crops (25%) and livestock-derived products (35%).

There was a notable difference by region regarding how crops were sold. While the households in the northern region prefer to sell most of their crops at local or regional markets (75 %), those in the central and southern region sell a significant percentage of their crops directly to consumers (42 and 50 % in the central and south region, respectively). Market sales are roughly the same in percentage values depending on the income group, while the percentage of direct sales increases with the increase in total income. Market outlets vary and include direct sales to consumers via marketplaces, orders and delivery, on-farm sales, sales by the road-sides, or direct sales to large consumers. Milk and chicken meat are the two commodities mostly sold in the market, while eggs, honey and other types of meat are mostly sold directly to the consumers. Most of the farm products are sold as fresh, while a small number of households use added-value processing as a strategy to increase the net profitability of their products. The common value-added products found in this study were apple and pear juice, jam, cheese and other dairy products.

The results show a very high relative dependence on agriculture, especially in the north and south, and irrespective of income group. Higher incomes from agriculture is driving the wealthiest group, most of them from the southern region. Low agricultural incomes and a significant degree of subsistence, coupled with low incomes from off-farm activities constrain the livelihoods and income from the poorest group – most of them from the northern region. The situation in the central region resembles that found in the north, with one difference; that low incomes from agriculture are partly mitigated by income from non-agricultural on- and off-farm activities. Wealthier households also show a higher degree of entrepreneurship, reflected in more variable market outlet choices.

Higher agricultural incomes in the southern region can be mainly attributed to more favourable climatic conditions in this region, which enables the farmers to time their production in order to exploit the opportunities on the market and also to produce more lucrative crops. In addition, households in the southern region have better access technologies (e.g. irrigation, greenhouses) and are more often part of agricultural associations. Access to technologies enables a higher degree of agricultural intensification, while participation in associations allows for increased and improved access to markets, information and technologies.

This difference in livelihood outcomes however, can not only be attributed to asset structure and activities. Rural households are situated within institutional and organisational conditions partly beyond their direct control. These institutional processes and organisational structures influence both access to livelihood assets and the composition of livelihood portfolios and therefore have an impact on peoples' ability to secure livelihood outcomes (Ellis 2000).

4.1.3 Institutional constraints to improved livelihoods

In the context of rural households in BH, main constraints found to hinder improved livelihoods result from the shocks brought about by war devastation and post-conflict transition from the centrally planned to market economy, which resulted in the creation of fundamentally different governmental institutions. Such conditions led to a rise in unemployment and informal economy, inflation, high rates of migration and other longer-term constraints on development which are often found in all transition economies (Davis 2006). These reforms have affected rural households in BH in many ways. High dependence on agriculture in rural areas is mainly driven by a lack of alternative income sources. The dependence on agriculture for both subsistence and as a source of income can be seen as an effective strategy to cope with risks and uncertainty. However, simple technologies, lack of entrepreneurship, absence of specialisation and capital farm investments keep agricultural and labour productivity low. We focus on some key constraints identified by the rural households in our study.

The decentralized political and administrative structure of BH is both very complex and quite unique. A tripartite government structure, established to ensure that the interests of the three major ethnic groups are represented, resulted in an asymmetrical and complex governance structure. BH comprises two state entities - Federation of BH (FBiH) and Republika Srpska (RS), as well as the municipality of Brčko District of BH (BD), which are all politically autonomous to an extent. In addition, FBiH is divided into 10 Cantons, each with its own government. The lowest administrative units are municipalities. There are 143 of them and each one has its own government and public services, which are under the jurisdiction of the cantons (in FBiH) or the entity (in RS). This has led to different policies at different levels, legislative overlaps, limited capacities and communication channels, as well as lack of a clear vision and failure to implement necessary reforms. Consequently, this affects every aspect of development, implementation and enforcement of policies and results in an unsustainable level of government spending, a staggering amount of corruption, economic stagnation and economic inefficiency. The difficult and complicated political situation is one of the main obstacles for foreign investments, without which there is no significant economic progress (Borensztein et al. 1998). According to the most recent official survey in 2017, the unemployment rate in BH was 20.5 % (AFSBIH 2017), which is among the highest in the world (WB 2017). This creates a pessimistic environment and leads to both migration to urban areas and abroad, leaving the ever aging population in rural areas.

The main feature of agricultural policies in BH is a low budget allocation for agriculture. The public spending for agriculture accounted for about 3 % of the total public spending in 2015 (MOFTER 2016). The largest amount of support (90 %) was classified as direct payments to farmers, which refers to payments based on output and the payment per unit area/cattle. This means that the composition of subsidies in BH is heavily oriented toward direct production rather than investments, thus having a social safety net function rather than providing productive support to the agricultural sector. Of the total number of surveyed households, 65.4 % were subsidized for different types of production. Not only are the budget allocations low, but the payments are usually not paid within the allocated budget year. Some of the surveyed households reported not having been paid the agreed subsidies since 2014. In the absence of investment grants, the farm function is on the level of simple reproduction, using outdated and obsolete fixed assets under the lack of financial resources to invest in expanded production (Bernstein 2010).

Domestic agricultural production suffers from low competitiveness caused by poor governance and a lack of public investments. The problem partly lies in an insufficiently developed food industry, discrepancy with quality standards and legislation, low levels of market-oriented production to create the critical mass needed for export, as well as the problems of inconsistent product quality and increased transport costs due to fragmentation of smallholders and supply chains (Bajramović et al. 2008). In addition, the disconnected smallholders and the lack of association in cooperatives with the aim of improving production and joint appearance on the market has, to date, deprived smallholder farmers of better negotiating opportunities and favourable purchases of both their products and the necessary inputs. The lack of competitiveness in the agricultural sector makes it difficult to enter export markets, and to compete with imported products in the domestic market. A general unsustainably high negative trade balance in BH and low domestic competitiveness is significantly affected by import of agricultural products. The most recent ratio of import coverage by export for agricultural products was only 31.7% (MOFTER 2017).

Although there is a large number of banks and credit organizations in BH, which enables sufficient physical access to loans, the conditions posed to obtain the credit for agricultural producers are highly demanding and discouraging for farmers, especially smallholders. An unstable political situation in the country and a dysfunctional market further create a large degree of uncertainty and discourage investments in agriculture, which is consequently stagnating (see Berjan et al. (2014a)).

Furthermore, important obstacles to development of the agricultural sector in BH include the large fragmentation of agricultural land and an inefficient land market. Regulated maximum private farm size in a former socialist state (10 ha), coupled with the still existing inheritance law, demanding the subdivision of farm holdings into equal parts among all heirs, resulted in severe fragmentation of private holdings and farms. A staggering 88.5% of households in our total sample had farms formed from small parcels, often dislocated from each other, which makes agricultural production less efficient and hampers investment in technologies. Those who are interested in investing in expansion or consolidation of their farms are often faced with an incomplete land registry and rigid land transaction processes, making land registration and land transactions costly and time consuming (World Bank 2010).

4.2 Impact of climate change on livelihoods and adaptation strategies

4.2.1 Reported damage from adverse weather effects

The reported damages in terms of adverse weather effects were almost exclusively related to agricultural production and the associated damage to crops in terms of yield declines and the reduced quality of products. Negative effects of drought were seen as the most serious and the most frequent cause leading to production declines and were more frequent in the northern and central region. In the same regions, occasional waterlogging is associated with reduced crop growth and consequently yields, as well as delays in agricultural field operations. More significant damage to crops and infrastructure due to floods was reported only in the northern region. Damage to crops caused by hail is found in every region, but it was more frequent in the north. Similarly, damage caused by frost is found in all regions. Negative effects of early spring frost are similar in all regions, while the increased presence of late crops (most notably fruits) in the central and southern region is the main reason for the damage caused by late autumn frosts.

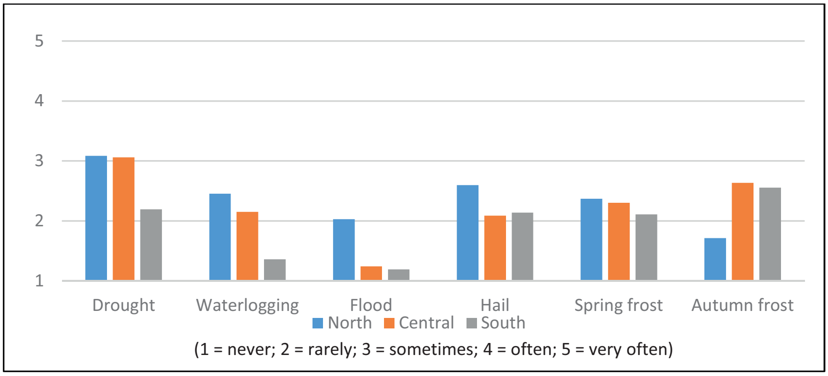

Figure 3. Reported frequency of damage caused by adverse weather conditions

The reported negative impacts of adverse weather conditions correspond well with the prevalent climatic conditions in the studied regions, as well as with previous scientific findings. The southern region is semi-arid while the other two regions are humid. The agricultural systems in the semi-arid south are traditionally and inherently more drought resilient in design and function. Thus, drought in the south is perceived as something which occurs regularly, unlike in the other regions that have been recently exposed to the increasing frequency of droughts (Čadro et al. 2017a). The mostly plain landscape and the dominant heavy soils with limited infiltration capacity makes the northern region more vulnerable to negative effects caused by heavy precipitation events, such as waterlogging and floods (Žurovec et al. 2017a). Increased incidences of hail have also been recorded (UNFCCC 2013). Frosts occur regularly in the studied climate zones, further modified by topography of the studied regions and therefore cannot be attributed to climate change. However, it is not known if the ongoing climate trends have any influence on the occurrence of frosts in the region.

4.2.2 Perceptions of climate change

Rural households report awareness of recent trends in climate change. The overwhelming majority of the respondents in our study perceive an increase in average temperature (92 %). This in line with the actual climate data for the period from 1961 to 2015, where, an increase in temperatures was recorded in every region (Figure 4a). Average annual temperature has increased by 1.6 ºC in all regions for the observed 55-year period. The increase was even bigger if only the months of the cropping season are observed (March-September) and range from 1.7 ºC in the north, 1.8 ºC in the central to 2.1 ºC in the southern region. The average temperature in BH has increased by 0.8°C in the last 100 years, while the last two decades are the warmest ever recorded (UNFCCC 2013).

The perception of long-term precipitation change varied by region in this study. While most of the respondents in the northern region perceive a decrease in the total amount of precipitation, most of the respondents in the southern and central region report different distribution of the precipitation over the year. However, there has been a slight factual increasing trend in the total annual precipitation in the northern and central region, while a significant decrease has been observed only in the south, where the total annual precipitation has decreased 120 mm in the last 55 years (Figure 4b). Minimum changes in precipitation were recorded within the cropping season (March-September) in all regions, with a very low increase in precipitation trends in the observed period.

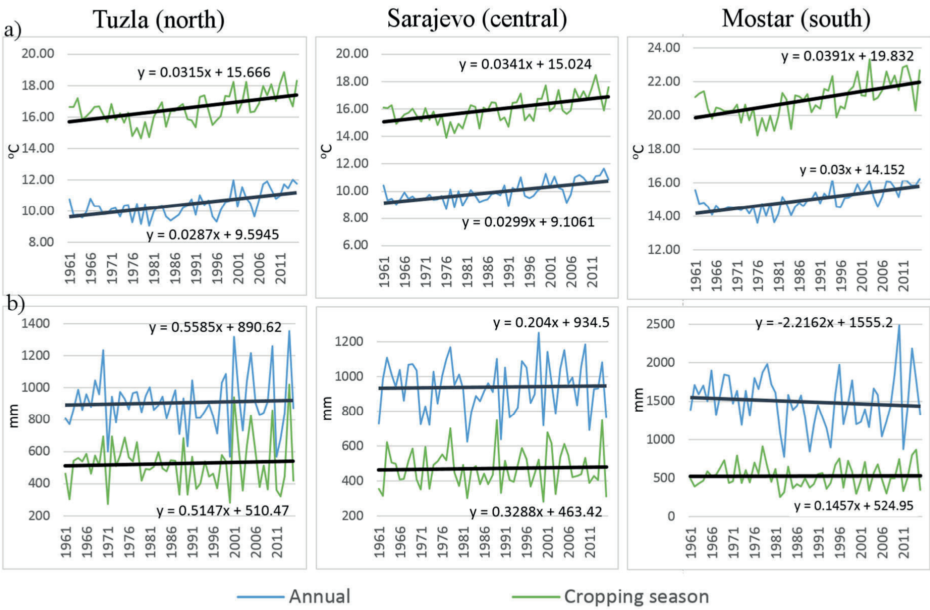

Figure 4. a Temperature trends and **b** precipitation trends from the weather stations in the studied regions

One reason why some respondents perceive a decreased amount of precipitation, even though it is not in line with the actual long-term climate observations, may be based on a measured decrease in water availability under the prolonged and severe droughts and higher temperatures experienced in recent years, as previously reported by Bryan et al. (2013). While the level of annual precipitation did not significantly change, a decrease in number of days with precipitation and an increase in number of days with more intense precipitation resulted in the increased frequency of droughts (UNFCCC 2013).

We found little differences between perceptions of climate changes by income groups. The only notable difference was that part of the respondents (18 %) from the wealthiest group did not attribute the increased incidence of extreme weather events to climate change.

4.2.3 Adaptation strategies

Respondents reported different adaptation strategies, in terms of both non-agricultural activities and the adoption of agricultural practices and technologies (Table 5). Overall, off-farm employment was the most common non-agricultural strategy and 57.7% of the total researched households had one or more family members employed off the farm. The central region had the highest level of off-farm activities. Other non-agricultural activities were adopted to a lesser extent, and with some variation by region and by income levels. A third of the households in the north decided to lease out parts of their land, partly due to lack of labour access and partly due to remoteness of some of the parcels of land relative to their farm. Household members in the central region, especially the younger and educated ones, tend to migrate more to urban areas. Migration to urban areas was also significantly more expressed in the poorest group of households.

Table 5. Reported adaptation strategies by region and income.

Adaptation strategies	Percentage of households						
	North (n=35)	Central (n=33)	South (n=36)	Poorest (n=35)	Poor (n=34)	Less poor (n=35)	Average (n=104)
Non-agricultural							
Lease out land**	31.4[a]	3.1[b]	0.0[b]	11.4	12.1	11.1	11.8
Work on other farm	17.1	3.1	19.4	20.0	14.7	5.6	13.6
Finding employment*	62.9	72.7[a]	38.9[b]	60.0	55.9	54.1	57.7
Moving to urban area*+	14.3	21.2[a]	0.0[b]	22.9[a]	5.9	5.4[b]	11.5
Moving abroad	5.7	6.1	5.6	8.6	2.9	5.4	5.8
Agricultural							
Change of crop**	88.6[a]	43.3[b]	70.6[a]	61.8	84.4	58.8	68.7
Change of crop variety**	91.4[a]	54.8[b]	85.3[a]	70.6	81.3	85.7	78.0
Drought resistant crops*	2.9[a]	26.7[b]	14.7	5.9	21.9	14.7	14.1
Reduced tillage	5.7	16.1	8.8	5.9	12.5	11.4	10.0
No-till	0.0	3.2	5.9	2.9	3.1	2.9	3.0
Change in sowing/planting dates	54.3	46.7	58.8	52.9	53.1	58.8	53.5
Fertilization (synthetic + manures)	94.3	90.0	100.0	88.2	100.0	100.0	94.9
Incorporation of crop residues**	88.6[a]	50.0[b]	15.2[c]	47.1	61.3	47.1	52.0
Use of cover crops*	5.7[a]	26.7[b]	8.8	14.7	15.6	8.8	13.1
Irrigation**	85.7[a]	60.0[b]	97.1[a]	82.4	75.0	91.2	81.8
Drainage**	54.3[a]	20.0[b]	0.0[b]	26.5	28.1	20.6	25.3
Erosion prevention**	2.9[a]	23.3[b]	0.0[a]	8.8	6.3	8.8	8.1
Anti-hail nets	0.0	10.0	5.9	5.9	6.3	2.9	5.1
Greenhouse**	11.4[a]	18.2[a]	47.2[b]	17.1	29.4	32.4	26.0
Crop insurance**	51.4[a]	0.0[b]	0.0[b]	14.3	18.2	19.4	17.3
Agricultural adaptations (average per household)	6.4a	4.5b	4.9	4.9	5.6	5.3	5.3

* significant difference between some of the three categories (Anova). * $P<0.05$; ** $P<0.01$.
\+ = significant difference between some of the three relative income categories + $P<0.05$; ++ $P<0.01$.
a,b = Tukey test; groups with different letters are significantly different from each other ($p<0.05$).

We also looked into the adoption of various agricultural practices and technologies. There are indications in our material for an overall intensification strategy for agricultural production in BH, as well as adaptation to the perceived changes in climatic conditions. Most notable is the application of both organic and mineral fertilizers, adopted by 94.9 % of the households in this study. While we did not measure the total amounts applied, increased fertilization is likely one of the main reasons for an overall increase in yields of the main crops, such as maize, wheat and potato (Vaško and Mirjanić 2013). However, the yields of most crops are still significantly lower compared to the more developed parts of Europe (Žurovec et al. 2015).

We also found a high degree of adoption of irrigation, where 82.7% of the surveyed households reported investing in some type of irrigation system, irrigating an average of 55.7% of their utilized arable land. Drip irrigation is mainly used for cash crops and greenhouses, although the irrigation of cereals and other crops using typhons was also found in the northern region. Public investments in irrigation and related agricultural and water management projects in the post-war period in BH has been low, thus the adoption of irrigation is carried out privately by individual households. Therefore, the adoption of irrigation can be seen as a reactive adaptation to intensify production and as a response to the perceived increased incidence of droughts. Most of the irrigation systems are simple, not requiring significant investments. They are usually drip-irrigation systems using water from private wells or adjacent watercourses, mostly manually operated and without much regard to water consumption. Most of those who irrigate generally avoid paying water usage fees due to the lack of farm registers and other means of water monitoring. This makes irrigation cost-effective from the individual farmers point of view, but less so from a social profitability point of view.

While subsistence needs still are an important determinant in the selection of crops and livestock, an increasing number of cash crops on farms and more market-oriented production are noticeable. A significant number of households report to change their crops according to market demands (68.7 %), or report to use more productive crop varieties (78 %), in order to achieve higher yields. Some households, most notably in the central region, have adopted crops that are more drought tolerant.

Other agricultural adaptation strategies include those requiring low implementation investments. Most notable adopted agricultural practices are changes in sowing/planting dates (53.5 %) and incorporation of crop residues (52%). The degree of adoption of certain agricultural practices varied significantly by region, while no significant differences were observed in terms of different income groups. Some adoptions are more suited for particular regions, such as drainage (northern region) or erosion prevention (central region). Conservation agriculture practices were found to be less common, such as use of cover crops (13.3%), reduced tillage (10.1%) and no-till (3.0%). Only a small part of the respondents were familiar with the existence and implementation of such measures, most notably no-till (23.2%), and reduced tillage (35.4%). There is a general lack of knowledge in the Western Balkan region regarding the effects of conservation tillage practices. However, recent short-term results show that reduced tillage is potentially more climate resilient in central BH (Žurovec et al. 2017b). The reported 17.3% of households who insured their crops might lead to the conclusion that a significant number of households opted for crop insurance as a strategy to protect themselves against the risk of crop failure. However, crop insurance is an isolated phenomenon related to tobacco producers in the northern region, who are offered crop insurance by the company purchasing the majority of produced tobacco in the region. Although some insurance companies in BH offer crop insurance services, the wider application of these services were not reported.

Fifteen different agronomic practices were reported in this study. Households adopted 5.3 on average. The results varied by researched region, while no statistical difference was found in terms of income. Households in the northern region adopted 6.4 of them on average, compared to 4.9 and 4.5 in the southern and central region, respectively. A large majority of respondents reported both agronomic and economic benefits upon adoption of the reported practices. The main reported constraints for altered adoption were lack of financial capital, knowledge and labour.

The differences in adopted agricultural practices further demonstrate that location plays an important role in climate change adaptation in BH, both in the number and type of adoptions. Furthermore, adoption of agricultural practices was less dependent on income group, despite the significant differences in total income among them. In the context of the livelihoods approach, adaptations are seen as the outcome of different livelihood strategies, which are not necessarily seen as a way to only maximize profits, but rather as development and diversification of a portfolio of assets pursuing different motives, such as increased well-being, reduced vulnerability, improved food security and a more sustainable use of natural resources (DFID 1999; Ellis 2000). Climate change can directly affect livelihoods and the capacity to adapt to shocks will be determined how assets are accessed and used in different ways. Furthermore, it has been reported by a significant body of literature that access to capital assets has an important role in facilitating adaptation and adoption of technologies in agriculture. Below we analyse the agricultural practices as a function of access to various assets at the individual household level.

4.2.4 Determinants of agricultural practices and technology adoption

We used bivariate logistics regression to assess the important determinants of the various adopted agricultural practices and technologies in terms of access to different types of assets. In total, 10 out of 15 agricultural practices were found to have an adequate sample size for the analysis. Based on the overall results (Table 6), it is evident that the factors influencing the decision to adopt a particular agricultural practice vary and it is difficult to draw generalized conclusions. However, it is notable that increased access to different types of assets in most cases influence the likelihood of adoption. Factors influencing adoption in our study correspond well to empirical research findings in relation to farmers' general adaptation to climate change. Social capital was found to be the most significant determinant of adoption. Membership in agricultural associations, internet access, access and utilisation of public extension and the frequency of extension visits increase the likelihood for adoption of most practices. Participation in different social groups provides one means for exposure to knowledge, innovations and technologies that can be used to adapt to changes in climatic conditions (Bryan et al. 2013; Deressa et al. 2009).

Access to physical capital, which includes farm machinery, buildings, other facilities and equipment, is a primary factor of production in agriculture. We could not draw conclusions related to infrastructure because most of the households in this study owned their farms and nearly all of them had access to basic infrastructure, such as electricity and water. However, possession of tractors and its highly positive influence on adoption in our study shows the importance of access to technologies in terms of different management options and labour they provide (Nhemachena et al. 2014). Investment in physical capital can be also seen as a more long term adaptation strategy, like investments in greenhouses or irrigation systems.

Human capital also had a positive impact on adoption. While an increase in household size can be seen as an increase in total labour available, which increases the likelihood to adopt certain agricultural practices, education can also influence adaptation through increased awareness and knowledge, better access to social networks, off-farm work and a general increased adaptive capacity (Wamsler 2011; Yohe and Tol 2002). Younger farmers are also more innovative and less risk-averse compared to their older counterparts (Ali and Erenstein 2017).

Natural capital, viewed through farm size, had a mixed effect on long term adaptation in our study. While an increase in the farm size was shown to increase the likelihood of adoption of some agricultural practices (e.g. incorporation of crop residues, crop insurance), the opposite effect was found in case of larger on-farm investments, such as irrigation, drainage or greenhouse. This may be due to the fact that farmers on larger farms prefer to adapt by diversifying their crops and/or grasslands and pastures (if they have livestock), rather than to invest in infrastructure or technologies.

Increase in total household income generally had an overall positive effect on adoption. Interestingly, however, non-agricultural income is mostly negatively associated with adoption. This could be explained by the household motives for diversification of their income generating activities, described as “push” and “pull” factors (Haggblade et al. 2007). Households may be pushed into agriculture by necessity and may be pulled by non–agricultural opportunities. Such households would be less likely to invest in agriculture and focus more on non-agricultural opportunities.

Table 3. Determinants of adaptation, odd ratios, BH 201xx (<1 means negative association, >1 positive)

Capital assets	Change of crop	Change of crop variety	Drought resistant crops	Change in sowing/planting dates	Incorporation of crop residues	Cover crops	Irrigation	Drainage	Greenhouse	Crop insurance
Farm size	1.07	1.09	0.95	1.06	1.00	0.99	0.98	0.87^{*}	1.09	0.98
Farm size (incl. leased land)	1.00	1.02	1.07	0.99	1.27^{**}	1.01	0.91^{**}	1.24	0.90^{**}	1.33^{**}
Possession of tractor	3.89^{*}	5.13^{*}	105.51	3.55^{*}	4.16^{*}	0.07	7.98^{*}	2.32	6.53^{*}	662.84
Farming experience	1.01	1.02	1.00	1.04^{*}	0.99	0.92	1.00	0.98	0.98	1.10
Age (head of HH)	0.96	0.91^{***}	0.96	0.99	0.98	0.98	0.99	1.00	0.99	0.99
Education (head of HH)	1.09	0.87	1.89^{*}	1.17^{*}	1.04	0.68	0.93	0.97	0.91	0.95
Education (highest in HH)	0.60	1.20	1.29	0.87	1.16	1.54	1.34	1.69^{**}	0.81	0.77
Household size	1.01	0.83	0.28	1.47^{*}	0.84	0.66	1.71	0.40	1.47^{**}	1.12
Association membership	2.19	4.03^{*}	23.10^{*}	1.44	0.30	9.32^{**}	0.26	0.39	2.09	1.36
Extension visits	2.91	1.07	0.00	0.35	5.33^{*}	0.23	1.41	6.73^{**}	0.89	2585.99
Frequency of extension visits	0.79	0.79	4.57^{**}	1.09	1.02	2.06^{**}	2.74^{*}	1.01	1.10	0.26
Internet access	1.97	2.13	0.47	2.40^{*}	0.57	0.69	10.42^{***}	3.88	0.36	1161.70
Total income	1.00	1.00	1.00^{**}	1.00	1.00	1.00	1.00	1.00^{*}	1.00	1.00
Income per capita	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Agricultural income	0.15	0.28	0.00^{*}	0.10	4.32	4.04	0.09	0.01	2.07	46.29
Non-agricultural income	0.78	0.66^{*}	0.60	0.70^{*}	1.52	3.30	0.86	0.83^{*}	0.88	1.94^{*}

* p<0.1
** p<0.05
*** p<0.01

5. Conclusions

The studied rural households in BH are exposed to multiple stressors that increase vulnerability and constrain their livelihood options. Many stressors are typical for economies in transition, and include factors such as inefficient institutions and policies, inadequate infrastructure, services and imperfect markets and access. Under such conditions, continued high dependence on agriculture in rural areas is more driven by a lack of alternative income sources.

The results of this study indicate a very high relative dependence on agriculture in the study areas (72.8%). There are some variations by location (56-83%) and by income level (68-78%). The total income from agriculture is around 25000 USD per year for the whole sample, while the difference in total income is 2-3 times larger for the southern region than the other two and more than 5 times higher agricultural income for the least poor group than for the poorest group. The substantial difference in incomes observed mainly depends on how the available assets are used in agriculture. The less poor own more land and are able to produce more. However, the example of the southern region shows that significantly higher agricultural incomes can be achieved also with significantly lower access to land. This is mainly attributed to more favourable climatic conditions in this region, which enables the farmers to time their production in order to exploit the opportunities on the market and to produce more lucrative crops. Furthermore, households in the southern region have better access to technology (e.g. irrigation, greenhouses) and are more often part of agricultural associations. Lastly, less poor households show a higher degree of entrepreneurship, reflected in more variable market outlet choices.

Combing these insights, we see a group of less poor households with higher incomes and more specialised in agriculture, while we observe a group of low-income households depending somewhat more on off-farm activities. Half of the less poor income group was composed of the households from the southern region, while the poorest group was mainly composed from the households from the northern region. The households in the central region are more similar to those in the north in terms of income, with the difference that low incomes from agriculture are partly mitigated by income from non-agricultural on- and off-farm activities.

The observed high dependence on agriculture makes rural households more vulnerable to negative effects of climate change, some of them already affecting the studied households. The negative effect of droughts were most common and more stressed in the humid continental climate of the northern and central region than in the south, which is traditionally more resilient due to the prevalent semi-arid climatic conditions that present production systems are designed for. The northern region experienced occasional incidences of heavy precipitation events, leading to waterlogging and floods. Damage from hail is found all regions, but was more frequent in the north. It is not known if the ongoing climate trends have any influence on the occurrence of early spring and late autumn frosts, which occur regularly in the studied climate zones and cause significant damage to crops.

Studied households express their awareness of the recent climate trends. Most respondents in our study perceive an increase in average temperature in line with the actual climate data. The way changes in precipitation are perceived, both in terms of amount and distribution, varied depending on the region. However, actual climate data showed a significant decrease in precipitation only in the south (-120 mm). We attribute this inconsistency between perceived and actual precipitation to a decrease in water availability under the increased frequency and intensity of droughts and higher temperatures.

While it is hard to differentiate whether it is climate change, agricultural intensification, or some other factor that are the main motives behind certain adaptation options, especially within agriculture, the number of adopted measures shows that there are signs of an overall intensification strategy of agricultural production in BH, as well as marked adaptations to (perceived) climate changes. Most notable were the application of both organic and mineral fertilizers, changes in crops and crop varieties, and a surprisingly high degree of irrigation. Other common agricultural practices were those that require no or little investments. The main reported constraints for further adoption and long-term adaptation within agriculture were lack of funds, knowledge and labour. Certain agricultural practices carried out were in some cases more region-specific, but overall were similar in relation to income level.

The results indicate that increased access to different types of assets in most cases influence the likelihood of adaptations in agriculture. Higher access to social capital was found to have a positive influence on adoption of significant number of agricultural practices, along with higher access to technologies (tractors) and human capital. Higher access to natural capital (land) had a mixed effect, increasing the likelihood of adoption of some practices, but the opposite effect was found in the case of larger on-farm investments, such as irrigation, drainage or greenhouses. Similar results were found in the case of financial capital - the increase in total household income generally had an overall positive effect on adaptation, while non-agricultural income is mostly negatively associated with adaptation. This is likely because many household members in rural households are looking to exit agriculture and allocate more labour to non-farm activities.

Climate change in BH enters a scene of economic recession and lack of income generating possibilities, especially outside agriculture. Nevertheless, the main resource at hand for the rural dwellers in the sample is still land and agriculture for both cash and subsistence incomes. Climate change does not change the heavy dependence on agriculture, but has created additional hardship for most households. The increased incidence of adverse weather events leads to lower incomes from agriculture due to production declines, and as the alternative employment options are limited, climate change may lead to increased poverty for those who lack the capacity to adapt.

It is difficult to predict what has and what will happen over time based on the results of this survey alone. It may seem reasonable to assume more migration of rural people, especially younger and more educated. On the other hand, it does also seem as if there are groups of people looking to increase investment and specialise in agriculture. Some of them are established farmers and have a long tradition of farming in their family, while there are also some groups of new farmers moving into the rural landscape, bringing their investments. Given the current conditions, agriculture may be the main driver of rural development in BH. Potential increased incomes from agriculture can lead to investments also in other sectors in rural areas. However, there are constraints for such developments, in terms of production, markets and institutional constraints. Therefore, future rural development policies should be focused on rural infrastructure, availability and accessibility to technologies and inputs, easier purchases of land, accessibility to markets, farming associations, better extension and accessible and favourable credits. In general, more investments in rural and agricultural development to support the ability of households to make strategic long-term decisions are necessary, in order to secure and improve their livelihoods.

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PAPER 4

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Effects of tillage practice on soil structure, N_2O emissions and economics in cereal production under current socio-economic conditions in central Bosnia and Herzegovina.

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RESEARCH ARTICLE

Effects of tillage practice on soil structure, N_2O emissions and economics in cereal production under current socio-economic conditions in central Bosnia and Herzegovina

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Abstract

Conservation tillage is expected to have a positive effect on soil physical properties, soil Carbon (C) storage, while reducing fuel, labour and machinery costs. However, reduced tillage could increase soil nitrous oxide (N_2O) emissions and offset the expected gains from increased C sequestration. To date, conservation tillage is barely practiced or studied in Bosnia and Herzegovina (BH). Here, we report a field study on the short-term effects of reduced (RT) and no tillage (NT) on N_2O emission dynamics, yield-scaled N_2O emissions, soil structure and the economics of cereal production, as compared with conventional tillage (CT). The field experiment was conducted in the Sarajevo region on a clayey loam under typical climatic conditions for humid, continental BH. N_2O emissions were monitored in a Maize-Barley rotation over two cropping seasons. Soil structure was studied at the end of the second season. In the much wetter 2014, N_2O emission were in the order of CT > RT > NT, while in the drier 2015, the order was RT > CT > NT. The emission factors were within or slightly above the uncertainty range of the IPCC Tier 1 factor, if taking account for the N input from the cover crop (alfalfa) preceding the first experimental year. Saturated soils in spring, formation of soil crusts and occasional droughts adversely affected yields, particularly in the second year (barley). In 2014, yield-scaled N_2O emissions ranged from 83.2 to 161.7 g N Mg^{-1} grain (corn) but were much greater in the second year due to crop failure (barley). RT had the smallest yield-scaled N_2O emission in both years. NT resulted in economically inacceptable returns, due to the increased costs of weed control and low yields in both years. The reduced number of operations in RT reduced production costs and generated positive net returns. Therefore, RT could potentially provide agronomic and environmental benefits in crop production in BH.

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Introduction

It is widely believed that conservation tillage practices such as no-till (NT), minimum or reduced tillage (RT) have beneficial effects on cropping systems relative to conventional tillage (CT). Typically, conservation tillage is associated with improved water infiltration and conservation, reduced erosion and improved soil structure [1, 2] and is perceived as an environmentally sound and sustainable management practice [3]. Recently, conservation tillage practices have been advocated as a measure to mitigate climate change through enhanced soil carbon (C) sequestration [4]. However, C accumulation in soils is finite and the question whether or not agricultural soils lend themselves to sequester relevant amounts of C is currently under debate [5, 6]. One drawback of increased C sequestration into soils may be increased nitrous oxide (N_2O) emissions, offsetting the "cooling effect" of CO_2 draw down [7]. Variable effects of NT/RT on N_2O emissions have been reported [8], varying from decreased to increased N_2O emissions, especially shortly after shifting from CT to NT [9, 10]. Nevertheless, the benefits of increased soil organic C (SOC) on soil structure, water-nutrient relationships and soil biota are well established [11].

Nitrous oxide (N_2O) is a greenhouse gas (GHG) with a radiative forcing 298 times that of CO_2 in a 100-year perspective [12] and currently the most important agent for stratospheric ozone destruction [13]. Agricultural soils are the largest anthropogenic source of N_2O, associated with the ever-increasing use of synthetic nitrogen (N) and manures [14]. It is estimated that soil-borne N_2O emissions contribute around 60% to the total anthropogenic climate footprint of agriculture [15]. N_2O is a product of the microbial N transformations denitrification and nitrifier denitrification in soil, but it is also produced as a by-product during nitrification and during dissimilatory reduction of NO_3^- to NH_4^+ [16]. Soil denitrification produces both N_2O and N_2, hence this process may serve either as a source or a sink for N_2O [17]. The rate and product ratio (N_2O/N_2) of denitrification in soil depends on various factors such as the amount and availability of mineral N, the C:N ratio of the soil organic matter, the pH as well as temperature and soil moisture content [18]. According to Seitzinger et al. [19], approximately 40% of the 270 Tg N yr $^{-1}$ globally added to terrestrial ecosystems are removed by soil denitrification.

Soil management can lead to degradation of soil structure [20]. Increase in bulk density due to compaction leads to decreased porosity and changes in pore size distribution, which may give rise to decreased soil aeration, reduced water infiltration, formation of crusts, reduced plant root growth, changes in biological processes and delayed germination and emergence of seedlings [21–23]. Conservation tillage, combined with permanent soil cover, has been shown to result in a build-up of SOC in soil surface layers and has a potential to improve soil structure and to increase infiltration of water, thus reducing water runoff and erosion [20, 24].

Minimum soil disturbance is one of its three main pillars of conservation agriculture [3]. So far, conservation agriculture has been adopted mainly in countries in which highly mechanized and high-input agricultural production prevails [25]. The reason for this is CA's documented ability to reduce land degradation, soil erosion and to reduce fuel costs [26]. Implementing CA in a country with prevailing low-input smallholder agriculture, such as Bosnia and Herzegovina (BH), could thus have a potential to stabilise crop yields and improve soil conditions, while being less labour intensive and more cost-efficient, especially in rain-fed agriculture. However, a number of obstacles challenges implementation of CA in BH. Agriculture in BH today is characterized by smallholder farmers with low financial capital and high risk aversion, pursuing subsistence farming in mixed crop/livestock systems on limited land resources [27]. This has resulted in decreased productivity due to inadequate technical equipment and mechanisation and lack of education, similar to what has been described for developing countries [28]. Smallholders have become risk averse in applying costly inputs, such as fertilizers and pesticides, which has resulted in significant yield reductions. In addition, the existence of counterfeits and low quality products, such as seed material, fertilizers and pesticides, reduces trust in the effectiveness of agricultural inputs [29]. Due to the lack of investment in modern agricultural machinery, smallholder farmers in BH and Western Balkan are forced to apply conventional tilling methods using existing machinery with small working width, which increases the production costs due to the increased number of passages and increased fuel consumption [30].

First attempts to investigate the benefits of conservation tillage in the Western Balkan region were made in former Yugoslavia in the 1960ies and 70ies [31]. Yet, conservation tillage is very little applied to date. Despite a renewed interest in tillage research in BH and the neighbouring countries in the past decade [32, 33], long-term effects of alternative tillage methods on soil structure, crop yields and N_2O emissions under the current agro-ecological conditions are largely unknown. In fact, while much is known about the impact of fertilizer N on different agricultural crops, N_2O emissions and its underlying variables have never been studied in BH or the western Balkan region.

The objectives of the present study were i) to examine the effects of CT, RT and NT on soil structure, crop yields and N_2O emissions, ii) to compare yield-scaled emissions in the three tillage systems and iii) to evaluate the economics of RT and NT with respect to the likelihood of its adoption by small-scale farmers under the current socio-economic conditions. For this, we set up a field experiment under typical pedo- climatic conditions of continental BH and conducted weekly N_2O measurements in a Maize-Barley rotation over two growing seasons. Soil structure was measured at the end of the second year.

Materials and methods

Experimental site

This study was carried out on the research farm Butmir of the Faculty of Agricultural and Food Sciences in Sarajevo, Bosnia and Herzegovina (43˚49'N, 18˚19'E, 547 m a.s.l.) from December 2013 to December 2015. The study site has a continental humid climate with a mean annual temperature of 9.6 °C and a mean annual precipitation of 899 mm. The soil is classified as a Fluvisol, with a pH of 6.40 and a total C and N content of 1.34% and 0.14%, respectively. The texture class is a clayey loam, with 41.5, 24.6 and 33.9% of sand, silt and clay, respectively. The experiment included three tillage treatments laid out in a strip design with four subplots per treatment.

- Conventional tillage (CT): autumn ploughing to 30 cm depth and secondary tillage with a roto-tiller in spring to 15 cm depth before seedbed preparation
- Reduced tillage (RT): no autumn ploughing but disking to 15 cm depth in spring before seedbed preparation
- No tillage (NT): direct sowing into the untilled soil. Since no specialised NT seed drill was available, we used a traditional mechanical drill with an added ballast for increased penetration strength

The treatments were established in three 50 m long and 5 m wide stripes. Each strip was divided in four 50 m^2 subplots for GHG exchange and yield measurements. The crop rotation consisted of Corn (*Zea mays L.*) in 2014 and spring Barley (*Hordeum vulgare L.*) in 2015. At the time establishing the experiment in autumn 2013, the field was uniformly grown to Alfalfa, which was either autumn ploughed (CT) in 2013 and tilled in spring 2014, chemically mulched and partly incorporated by disking (RT) in spring 2014, or mulched entirely chemically in spring 2014 (NT). Crop residues in 2014 (corn) were milled with a silo combine and fully (CT) or partially (RT) incorporated into soil during autumn ploughing (CT) and disking (RT), or used as a mulch (NT). The same fertilizer rate was used for all treatments. We used N fertilizers which are common and accessible on the local market and chose fertilization rates which resemble those commonly used by smallholder farmers in BH. N fertilization was carried out by mechanical spreading of 250 kg ha^{-1} CAN (Calcium-Ammonium-Nitrate) in July 2014, one month after sowing, and 450 kg ha^{-1} NPK 15:15:15 applied in April 2015, during seedbed preparation. Both rates of fertilizer applied are equivalent to a fertilization rate of 67.5 kg N ha^{-1}.

Weed control was carried out with glyphosate in NT and RT (before seedbed preparation) in both years. Broad leaf and grass-weed control in the first year was carried out using 2,4-Dichlorophenoxyacetic acid after sowing and pre-emergence, and the combination of Nicosulfuron and Prosulfuron in post-emergence. Broad leaf weeds in barley were controlled with 2,4-Dichlorophenoxyacetic acid in post-emergence in the second year. The experiment was carried out under rain-fed conditions (only 0.4% of BH's arable land is irrigated [27]).

Monthly and yearly meteorological data for the period 1961–2010 and the daily data for the study period were obtained from the meteorological station at Sarajevo International Airport (43˚49'N, 18˚20'E) situated close to experimental site and provided by the Federal Hydrometeorological Institute of Bosnia and Herzegovina.

Field fluxes of N_2O and the derived emission factor and intensity

Weekly to bi-weekly measurements of N_2O emissions were carried out from December 2013 to December 2014 and from March 2015 to December 2015. On each sampling date, fluxes were measured between 4 and 6 pm in the afternoon, in an attempt to circumvent the bias arising from randomly sampling diurnal variation in N_2O emission. Both midday and night-time maxima have been reported [34]. It is noteworthy, however, that fluxes were measured within one hour in all treatments, so that differences between treatments should not be due to diurnal variation. The fluxes were measured following the methodology described by Nadeem et al. [35], using static aluminium chambers. Aluminium frames (60×60×15 cm) were permanently installed in the field and only removed for field operations and placed back at the same location in the plot. A total of 12 frames were installed on the experimental field, giving four replicates plots for each treatment (CT, RT, NT). Gas sampling was carried out by deploying the chambers (62×62×30 cm) on the frames for 45 min and withdrawing 15-ml gas samples from the chamber headspace using a 20-ml polypropylene syringe with stopcock at regular intervals of 15 min (0, 15, 30 and 45 min). The samples (15 ml) were transferred to pre-evacuated 12-ml glass vials crimped with butyl rubber septa resulting in an overpressure in the vials to avoid contamination during sample storage. Flux measurements were carried out every 7–10 days throughout the entire research period and every 3–5 days in the month after fertilization in 2015. The gas samples were analysed at the Norwegian University of Life Sciences, using a gas chromatograph (GC, Model 7890 A, Agilant, Santa Clara, CA, USA) equipped with a 30-m-wide bore Poraplot Q (0.53 mm) column run at 38˚C with back flushing and helium (He) as a carrier gas. The electron capture detector (ECD) was run at 375˚C with 17 ml min^{-1} ArCH4 (90/10 Vol %) as makeup gas. The GC was connected to an autosampler via a peristaltic pump (Gilson minipuls 3, Middleton, W1, USA) pumping approximately 2.5 ml gas through a 250-μl sampling loop maintained at 1 Atm pressure. The injection system was back-flushed by helium (6.0) before each sampling to minimize memory effects. Temperatures inside the chamber and above the soil surface were used to calculate an average temperature during flux sampling.

Rates of N_2O emission were estimated by fitting either a linear ($R^2 \geq 0.85$) or a quadratic function to the observed N_2O accumulation over time. For this, all fluxes were inspected graphically and fluxes with a $R^2 < 0.85$ and a flux density of < 5 mg N m^{-2} h^{-1} were set to zero. N_2O flux was calculated according to Eq 1:

$$F_{N2O} = \frac{d_{N2O}}{dt} \times \frac{V_c}{A} \times \frac{M_N}{V_m} \times 60 \quad (1)$$

where F_{N2O} is the N_2O emission flux (μg N_2O-N m^{-2} h^{-1}), d_{N2O}/dt is the relative change in N_2O concentration in the chamber headspace (ppmv min^{-1}), Vc is the chamber volume (L), A is the area covered by the chamber (m^2), M_N is the molecular mass of N in N_2O (g mol^{-1}) and Vm is the molecular volume of gas at chamber temperature (L mol^{-1}).

Cumulative fluxes were calculated by plotting daily average N_2O fluxes against time, interpolating linearly between them, and integrating the area under the curve [36]. Cumulative flux in 2014 represents area-scaled emissions for the entire year, while in 2015 it represents the cumulative flux for 226 days of the year (flux measurements started on 20th of March) plus linearly interpolated values for the missing period, assuming small off-season emissions like observed in the previous year. Emission factors were calculated as the fraction of applied fertilizer N emitted as N_2O-N, assuming background N_2O emission of 1 kg N ha^{-1} year^{-1} [37]. Yield-scaled N_2O emission was calculated as emission intensity, which is a function of N fertilization rate and expressed as N_2O-N (g) emitted per ton of grain yield [38]. To account for the N-input by preceding alfalfa in the first cropping year, we estimated the N returned to soil with the crowns and roots based in literature values. According to Kelner et al. [39], this amount is 107 kg N ha^{-1} for a 1-year stand of alfalfa. However, when the yields of the first cut from that study are compared with results reported by Junuzović [40] for our field, we reduced the N yield by roughly 50% to a more realistic N input of 53.5 kg N ha^{-1}.

Soil measurements

Soil moisture and temperature at 5 cm depth were measured daily using data loggers (Decagon EM50, Pullman, WA, USA) together with ECH2O sensors (Decagon) for volumetric soil water content (VSWC) and temperature in three replicates per treatment. No measurements are available for the period between 2 April and 24 June 2014, due to equipment failure.

Soil physical properties were analysed in undisturbed soil cores (100 cm^3 stainless steel cylinders) collected in July 2015 in four replicates per treatment. Particle density (PD) was determined using an air pycnometer according to Langer. Bulk density (PD) was determined gravimetrically. BD and PD were used to calculate total porosity, which was used to convert VSWC to water filled pore space (WFPS) by Eq 2:

$$WFPS = \frac{VSWC}{1 - \frac{BD}{PD}} \quad (2)$$

Soil water retention curves between pF 1.8 and 4.2 were determined using ceramic pressure plate extractors [41]. These results were then used to determine soil pore size distributions in different tillage treatments.

In 2015, soil samples were taken from 0 to 15 cm depth at each gas sampling date. Multiple cores from each treatment (4 per subplot) were homogenized, bulked and frozen. Immediately after thawing, 45 g fresh weight soil was extracted by 30 minutes of horizontal shaking in a 50 ml 2M KCl solution. The extracts were filtered and soil mineral N (NH_4^+, NO_3^-) was analysed by colorimetry as described by Keeney [42].

Yield and economic parameters

Yields were measured on each subplot as dry grain corn in 2014 and barley in 2015 standardized to 14% moisture content. Production costs were estimated for each of the three tillage systems. Input items such as seed, fertilizer and chemicals applied were purchased from local retailers and the exact prices were recorded. Average purchase market prices for the crops used in the experiment are taken from Agency for Statistics of Bosnia and Herzegovina [43, 44] for the respective years. For an approximation of labour and tillage operation costs, we used data from the local agricultural extension service, which were cross-validated with farmers in the same area. The results were calculated and discussed as the difference in net return per hectare in the three tillage systems, which was calculated from net income for crop after deducting all variable costs. We refrained to estimate fixed costs for production systems in this study due to high variability in possession of tractors and other necessary mechanisation and assets, which often have a long depreciation life and the general tendency to become obsolete [45].

Statistical analysis

N_2O emission rates were log-transformed to approach normal Gaussian distribution. To test the effects of treatment and year, repeated measures two-way ANOVA followed by Bonferroni post-test was performed for N_2O flux data, soil temperature and WFPS. One-way ANOVA followed by a Tukey's multiple comparison post test was performed for soil NH_4^+ and NO_3^-, cumulative N_2O emissions and yield-scaled N_2O emissions. All data were analysed using SPSS ver. 24 (IBM Corp, USA).

Results

Weather conditions

The average temperature in 2014 and 2015 was 11.2 and 10.2 °C, respectively, which is warmer than the long-term reference temperature (9.6 °C). The year 2014 had an exceptionally warm winter (Jan-March, 2015, Fig 1), while monthly temperatures for the rest of the year were similar to the long-term average values. Monthly average temperatures in summer 2015 were clearly higher than the reference temperatures. (Fig 1).

Both the amount of annual precipitation and the seasonal distribution varied greatly between the two years. Cumulative precipitation was larger (1020 mm) in 2014, while it was smaller in 2015 (719 mm) compared with the reference precipitation (899 mm). The annual rain distribution in 2014 showed excessive amounts of precipitation in April, May and September and the amount of precipitation was larger than the monthly reference precipitation throughout most of the cropping season. By contrast, 2015 was a dry year, with extremely low precipitation in the cropping season, especially May and July, with monthly precipitation sums of only 24 and 6 mm, respectively.

N_2O emission dynamics and ancillary variables

All treatments had similar N_2O emission dynamics, although peak values differed during certain periods, most notably after fertilization (Figs 2A and 3A). Two-way repeated measures ANOVA showed that tillage and experimental year had a significant effect on N_2O flux ($P < 0.05$), while the interaction between tillage and experimental year was not significant. According to Bonferroni pairwise comparison, the difference in N_2O emissions between CT and NT was significant only for the 90% confidence interval in the first year, while there was a significant difference between RT and NT ($P < 0.05$) in the second year. All peak emissions coincided with high WFPS values and elevated soil temperatures (Figs 2B and 3B). In contrast,

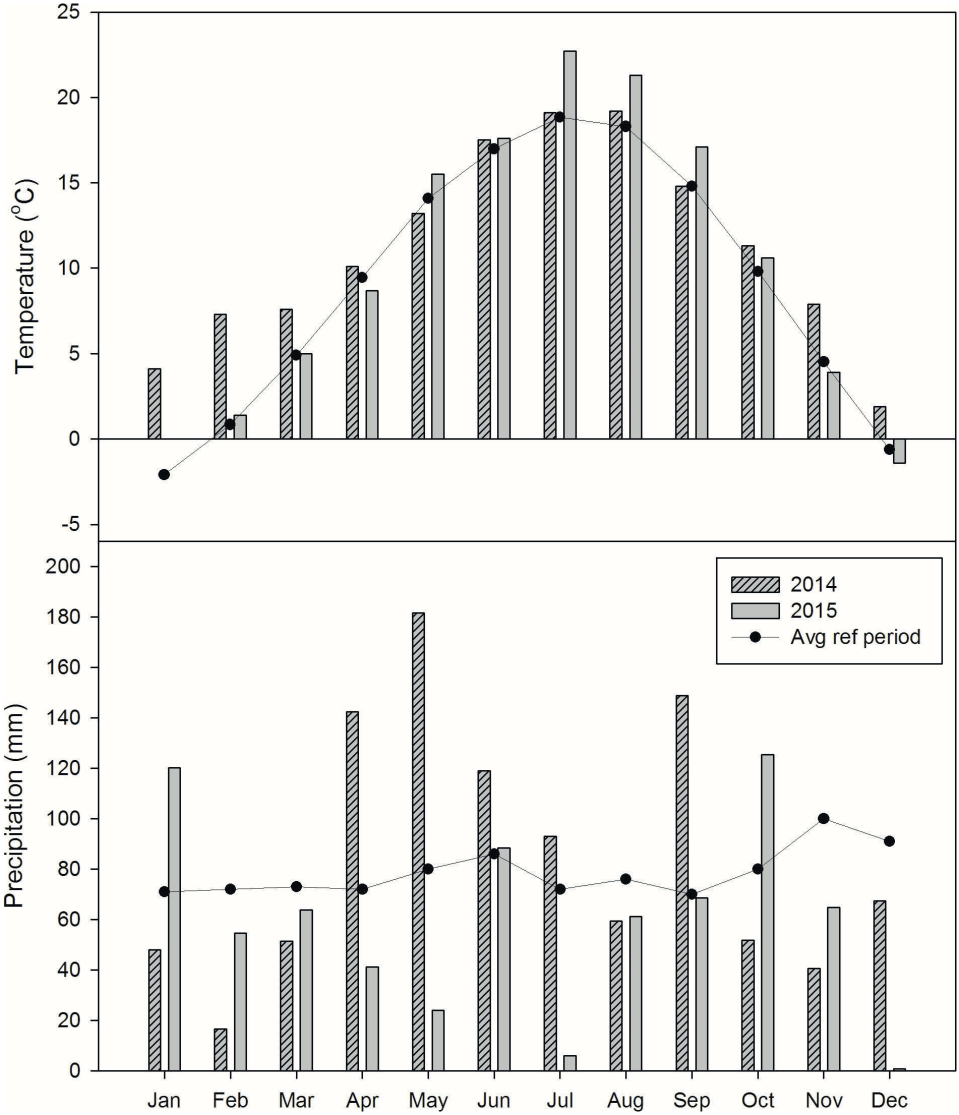

Fig 1. Average monthly temperatures and precipitation close to the sampling site.

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winter emissions in 2014 (January–April) were small, despite large WFPS values in non-tilled soil. The first N_2O emission peak occurred at the beginning of April, at the time of rototillage in CT; Emission rates in CT and RT increased, whereas they remained small in NT. The largest N_2O emission rates were recorded, regardless of treatment, in August 2014, one month after fertilization, when soil moisture started to fluctuate (Fig 2A and 2B). Maximum observed

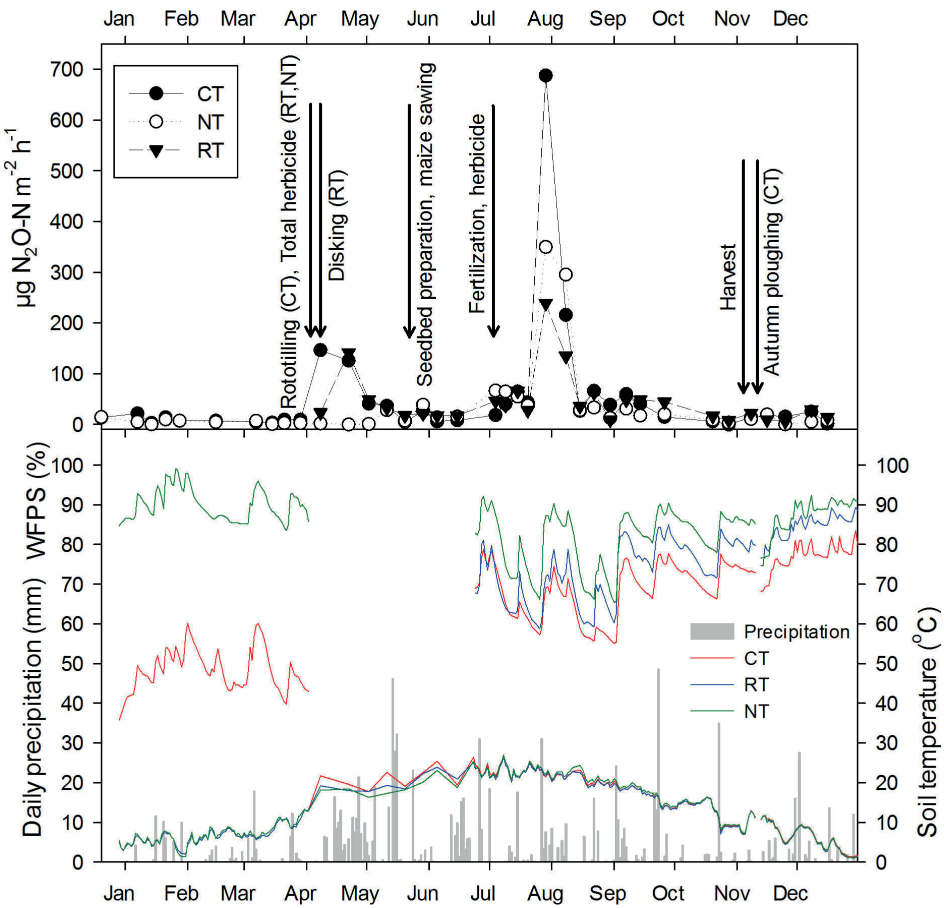

Fig 2. **a** Mean N_2O emissions per treatment (n = 4) and **b** daily precipitation, and mean soil temperature and moisture in 5 cm depth in CT, NT and RT treatments in 2014. Error bars are omitted to maintain readability.

https://doi.org/10.1371/journal.pone.0187681.g002

fluxes (treatment means per date) were 587.1 μg N_2O-N m^{-2} h^{-1} for CT, 373.7 for NT and 301.0 for RT. Emission rates remained slightly elevated for the remainder of the cropping period in all treatments, before decreasing gradually with decreasing soil temperature to low background values one month before harvest (first week of November).

In 2015, N_2O measurements started right before tillage operations in March (Fig 3A). Emission rates remained small during seedbed preparation and herbicide treatment until fertilization and sowing of barley in the beginning of April. N_2O emission rates increased strongly in all treatments immediately after fertilization and remained large throughout April, while the soil was still wet (>60% WFPS; Fig 3B). Maximum emission rates were measured three weeks after fertilization, with treatment means of 434.4 μg N_2O-N m^{-2} h^{-1} for RT, 306.2 for NT and 234.0 μg N_2O-N m^{-2} h^{-1} for CT. When WFPS values dropped below 60% in the middle of May, N_2O emission rates receded. A smaller, transient emission peak was observed in NT and

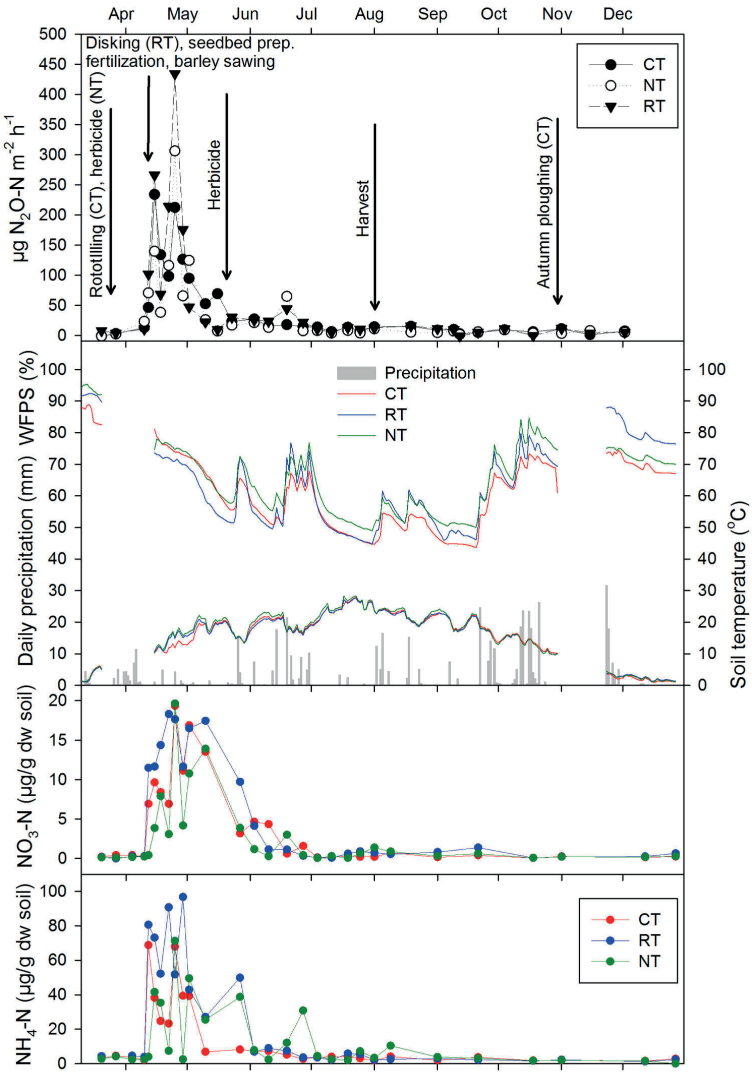

Fig 3. **a** Mean N_2O emissions (n = 4), **b** daily precipitation, mean soil temperature and moisture in 5 cm depth, **c** Soil NO_3^- and **d** soil NH_4^+ concentrations in 0–15 cm depth CT, NT and RT treatments in 2015. Error bars are omitted to maintain readability.

https://doi.org/10.1371/journal.pone.0187681.g003

RT, but not in CT plots, in the middle of June, which coincided with rewetting of dry soil by rain. Pronounced drying-rewetting later in 2015 did not induce measurable N_2O emission response, nor did harvest and ploughing, which is in line with small mineral N concentrations during this period (Fig 3C and 3D).

To find out whether tillage treatments had any effect on known drivers for N_2O emission, we tested for differences in soil temperatures and WFPS in both years and for differences in extractable NH_4^+ or NO_3^- in 2015 across treatments. Mean daily soil temperature showed little difference between treatments (Figs 2B and 3B), but annual average soil temperature was slightly higher in NT plots in both years (12.8 and 13.2 °C) than in CT (12.6 and 12.8) and RT plots (12.5 and 12.8) and statistically significant ($P < 0.001$).

In both years, CT soils had consistently smaller WFPS values than RT or NT soil. This contrast was most pronounced after ploughing (CT) and secondary tillage (CT and RT). During the wet summer of 2014, WFPS values of NT soil were almost constantly within the range of 80–90% WFPS, often exceeding 90%. On average, WFPS of NT soil exceeded that of CT and RT soil by 22.1% and 4.6%, respectively. Also in the dry summer of 2015, NT soil had the highest average WFPS values, although the difference between the treatments was less pronounced than in 2014 (6.4% and 3.7% higher than in CT and RT soils, respectively). Both tillage, experimental year and their interaction had a highly significant effect on WFPS and the difference was significant between every treatment ($P < 0.0001$).

No significant difference between treatments was found for extractable NH_4^+ or NO_3^- at 0–15 cm depth in 2015. The mineral N content increased rapidly after fertilization (Fig 3C and 3D), before levelling off to low background values by the end of June. The increase in NH_4^+ was somewhat delayed in NT soil, reflecting the difference between surface applied (NT) and incorporated (during seedbed preparation in CT and RT) fertilizer. Concentrations of NO_3^- declined to below 10 μg g^{-1} one month after fertilization and remained at very low levels for the remainder of the growing season. Similar to NO_3^-, NH_4^+ concentrations declined to values lower than 10 μg g dw $soil^{-1}$ two months after fertilization and remained low until the end of the year. The only difference was that NT showed occasionally elevated concentrations of NH_4^+, likely reflecting drying-rewetting induced mineralization pulses.

Soil properties and crop yields

By August 2015, i.e. in the second experimental year, two months after seedbed preparation, tillage regime had resulted in clear differences in soil bulk density, total porosity and pore size distribution (Table 1). CT soil had the smallest bulk density among all treatments, which was significantly different from that of NT ($P < 0.05$). Accordingly, CT soil had a larger porosity and a larger share of medium and macro pores. Increased bulk density in NT combined with reduced infiltration resulted in soil crusting and occasional waterlogging during both growing seasons.

Next to soil properties, weather conditions had a major impact on crop yields in both cropping seasons. Excessive rainfall during spring 2014 delayed most of agricultural operations, including rototilling, disking, seedbed preparation and sowing of corn for more than one

Table 1. Soil physical properties 20 months after the establishment of contrasting tillage regimes (August 2015).

Treatment	Bulk density* (g cm^{-3})	Total porosity (%)	Pore size distribution (%)		
			Micro (<0.2 μm)	Meso (0.2–10 μm)	Macro (>10 μm)
CT	1.36 (±0.03)^a	53.56^a	13.85^a	27.03^a	12.68^a
RT	1.42 (±0.04)	51.07^a	12.57^a	26.53^a	11.97^a
NT	1.55 (±0.04)^b	45.40^b	15.72^b	21.47^b	8.22^b

* SE shown in brackets

a,b Different letters indicate significant differences across treatments (Bonferroni, P < 0.05)

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Table 2. Average crop yields corrected for 14% moisture in CT, RT and NT.

Year—crop	Treatment	Average yield (kg ha^{-1}) ± SD (n = 4)
	CT	6561.9 ± 678.7[a]
2014—corn	RT	6165.8 ± 790.3[a]
	NT	4314.2 ± 1118.2[b]
	CT	1508.1 ± 139.7[a]
2015—barley	RT	2185.0 ± 254.3[b]
	NT	1571.5 ± 135.2[a]

[a,b] Different letters indicate significant differences across treatments (Bonferroni, P < 0.05)

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month, which led to late harvest and yield decrease. The same weather conditions occurred in the following year, resulting in late sowing of barley. This delay, coupled with two drought periods in May and July, led to crop failure. Average crop yields per treatment and year are shown in Table 2.

Cumulative N_2O emissions and emission factors

In 2014, cumulative N_2O emission was largest in CT and significantly different from RT and NT only at $P < 0.1$ (Table 3). Cumulative N_2O emissions in 2015 were significantly smaller ($P < 0.005$) than in 2014 for all treatments and RT had the highest emission, followed by CT and NT, with the difference between RT and NT treatments being significant ($P < 0.05$).

Annual N_2O emission factors, assuming a background emission of 1 kg N_2O-N ha^{-1} y^{-1} [37], are shown in Fig 4. Extraordinary large apparent emission factors were found in 2014 with 4.8% for CT, 2.9% for RT and 2.6% for NT, which likely reflect the extra N from alfalfa incorporated in autumn 2013 (CT) and spring 2014 (RT), or mulched in spring 2014 (RT, NT). We therefore estimated the amount of N from alfalfa residues based on N content and crown-root ratios reported in the literature as well as measured yields and added this N to the fertilizer N. Estimated N input by alfalfa crop residues was 53.5 kg N ha^{-1} for all three treatments. This resulted in more realistic emission factors of 1.5, 1.6 and 2.7% for NT, RT and CT, respectively, in the year of establishing the three tillage treatments. Irrespective of the amount of N input estimated, CT hat the largest emission factor in 2014. Emission factors in the dry year 2015 were much smaller and in the order of 0.7, 1.0 and 1.5% for NT, CT and RT, respectively.

Yield-scaled N_2O emission (Fig 5) was smallest for RT plots in both cropping seasons, ranging from 83.2 (2014) to 413.5 g N_2O-N Mg^{-1} (2015). NT had the largest yield-scaled N_2O emission in 2014 (161.7), while it was largest for CT in 2015 (736.1). Very high values in 2015 are the result of crop failure caused by drought. Analysis by one-way ANOVA followed by a

Table 3. Cumulative N_2O emissions.

Season	Cumulative N_2O emission (kg N_2O-N ha^{-1})*		
	CT	RT	NT
2014	4.3 (±0.6)[a]	3.0 (±0.2)[b]	2.8 (±0.4)[b]
2015	1.7 (±0.1)	1.9 (±0.1)[a]	1.4 (±0.05)[b]

* SE shown in brackets

[a,b] Different letters indicate significant differences across treatments (Bonferroni, P < 0.1 in 2014 and P < 0.05 in 2015)

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Tukey's multiple comparison post-test showed statistically significant differences between RT and NT ($P < 0.05$) in 2014 and between CT and RT ($P < 0.005$) in 2015

Economic comparison between tillage methods

Based on estimated net return per hectare in the different tillage systems (Table 4), it is evident that the reduced number of cultivation steps in NT decreased production costs as compared to CT. However, this reduction was zeroed by increased costs for weed control. With an overall smaller yield in NT, this resulted in markedly smaller net return in NT than in RT or CT in 2014. There was a notable difference in net return between the two years among the tillage treatments. The differences in yield between the two cropping seasons can be mainly attributed to different weather conditions, which lead to yield reduction in the first year and crop failure in the second year. Notably, RT had large net return, close to that of CT, in the first year and the least negative net return in the second year. CT had largest net return in the first year and smallest in the second year. NT achieved a small net return in the first year in comparison to CT and RT, while it had less negative net return than CT in the second year.

Discussion

Tillage effects on N_2O fluxes and soil variables

N_2O emissions showed a similar N fertilization response in all treatments and consequently similar N_2O emission rates in both years. Between 35% (NT) and 57% (CT) of the cumulative

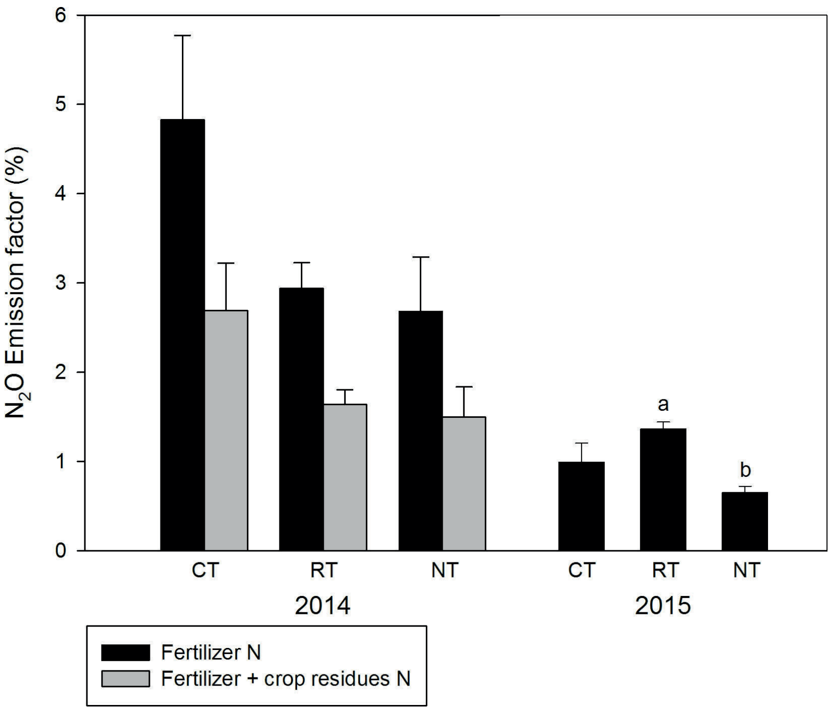

Fig 4. N_2O emission factors. Different letters indicate significant differences across treatments at $P < 0.05$.

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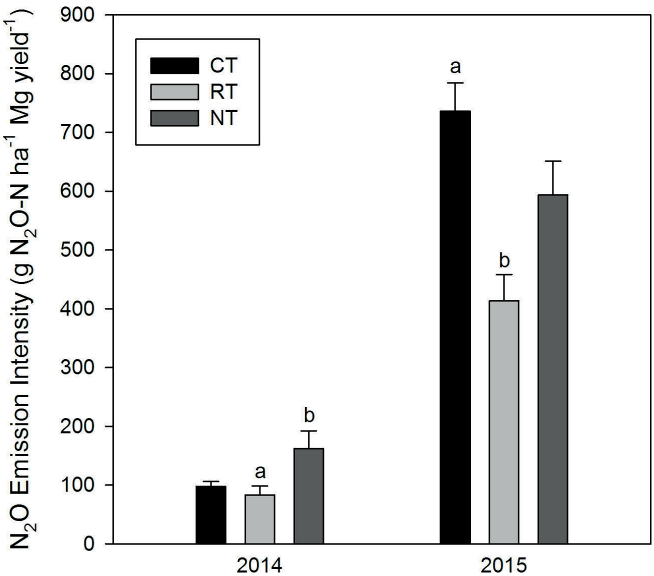

Fig 5. Yield-scaled N_2O emissions. Different letters indicate significant differences across treatments at $P < 0.05$.

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annual N_2O emission occurred during the first month after fertilization in 2014, while this share was between 54 and 57% in 2015. In each of the two growing seasons, temporal N_2O emission patterns resembled each other irrespective of treatment, with only a few notable exceptions. A clear treatment effect was noted after spring tillage operations in 2014, when N_2O emissions increased in CT and RT plots, but not in NT plots. While elevated emissions in CT and RT may be partly attributed to increased organic matter decomposition triggered by secondary tillage [46], it is important to note that N_2O emissions in CT did not respond to ploughing in autumn later the same year (Fig 1). This suggests that tillage as such does not induce elevated N_2O emissions. Increased emissions in RT and CT in April-May 2014 coincided with an extraordinary wet period and increasing soil temperatures (Fig 1B), while the main difference between treatments was that alfalfa residues had been incorporated freshly (RT) or in previous autumn (CT), whereas residues remained undisturbed in NT after chemical mulching, when the peaks in CT and RT occurred. It is likely that the incorporation of the N-rich residues into the wet soil created conditions favourable for mineralisation of C and N from the residues, fuelling N_2O emissions by nitrification and denitrification. By contrast, chemical mulching of alfalfa in NT created no distinguishable emission peak in 2014. An increase in N_2O emissions after incorporation of cover crop residues in comparison with residues left on the surface was previously reported in the meta-study by Basche et al. [47]. Alternatively, the first observed emission peak in CT was due to the release of previously produced N_2O that was trapped in deeper soil pores. However, this effect did not occur shortly after disking in RT. Transiently elevated N_2O emissions in RT and NT relative to CT were observed on one day in June 2015 (Fig 3A), shortly after abundant rain had increased WFPS values from ~50 to ~75% (Fig 3B), while there was still available NO_3^- present in the soil (Fig 3C). Enhanced N_2O emissions triggered by drying-rewetting are well documented [48, 49]

Table 4. Net income per hectare under different tillage systems based on the difference of crop net income and variable costs of production.

Season/Crop	Price (BAM)*		
2014 Corn	**CT**	**RT**	**NT**
Seed cost	240	240	240
Fertilizer and application	265	265	265
Tillage operations, fuel, maintenance, labour	272	146	80
Herbicide and application	99	188	233
Harvesting (hired machinery and labour)	300	300	300
Total variable costs	1176	1139	1118
	Yield (t)		
	6.56	6.17	4.31
		Price (BAM per t)	268.4
Net income	1761.3	1655.0	1158.0
Net return	**585.3**	**516.0**	**40.0**
2015 Barley	**CT**	**RT**	**NT**
Seed cost	200	200	200
Fertilizer and application	475	475	475
Tillage, fuel, maintenance, labour	265	142	70
Herbicide and application	54	143	188
Harvesting (hired machinery and labour)	300	300	300
Total variable costs	1294	1260	1233
	Yield (t)		
	1.51	2.18	1.57
		Price (BAM per t)	388.63
Net income	586.1	849.1	610.7
Net return	**-707.9**	**-410.9**	**-622.3**

* 1 BAM = 0.51 EUR

https://doi.org/10.1371/journal.pone.0187681.t004

and are most likely due to denitrification. Interestingly, WFPS increase in CT was smaller than in RT and NT, probably explaining the lack of N_2O emission response in this treatment. Periods of repeated drought and rewetting later in 2015 did not induce measurable N_2O emissions, apparently because small concentrations of NH_4^+ and NO_3^- limited nitrification and denitrification activity. All peak emissions outside the period directly affected by fertilization coincided with large WFPS (70–90%) and high soil temperatures (>10˚C), illustrating the importance of crop residue management (April 2014) and tillage regime (June 2015) for N_2O emissions outside the period directly affected by fertilization. The greatest differences between treatment means of N_2O emissions were seen after fertilizer application. In 2014, post-fertilization emissions were greatest in CT, followed by NT and RT (Fig 2A), despite lowest WFPS values in CT (Fig 2B). The likely reason for this is that incorporation of the preceding crop (alfalfa) in autumn 2013 had resulted in a more active microbial community in CT than in RT and NT, which was further stimulated by rototilling in spring 2014. Thus, CT plots responded stronger to N addition than RT or NT plots. In 2015, no N-rich residues were present, and RT responded strongest to N-fertilization (Fig 3A), providing the most favourable conditions for nitrification and denitrification in terms of soil structure and substrate availability.

Despite the relatively short periods of distinct N_2O flux, we found differences in annual emissions between treatments (Table 3). Since annual emissions were dominated by post-fertilization fluxes, largest annual emissions were found in CT in 2014 and in RT in 2015. NT had the smallest emission in both years, although this difference was not significant in 2014. A meta-analysis of reported N_2O emissions in 239 paired field trials with conventional tillage (CT) and NT/RT showed no consistent short-term ($\leq$10 years) tillage effect on area-scaled N_2O emissions when land was converted from CT to NT/RT [8]. Smaller N_2O emissions from NT soils in a newly established tillage experiment, like the case in our study, were previously reported by Chatskikh and Olesen [50] in a loamy sand soil with barley as a crop, while long-term reduction in N_2O emission by NT on loams are reported by Gregorich et al. [51] and Mosier et al. [38] for corn-soybean crop rotation. By contrast, larger N_2O emissions in newly established NT systems than in CT have been reported by Ball et al. [52] and Baggs et al. [53] on loamy soils in humid areas. This indicates that tillage effects on N_2O emissions are highly variable, both spatially and temporally, and influenced by a wide spectrum of biotic and abiotic factors and their interactions in the specific region. It should be also mentioned, that the sampling frequency used in our study was low and that contrasts in annual N_2O emission probably underestimated treatment effects, since the resolution was not high enough to capture every N_2O emission peak.

In our experiment, tillage regime had a clear effect on every measured soil variable. Soil temperatures in NT were on average 0.3–0.4 °C higher and had up to 22.1% larger average WPFS values as compared with CT. Lower bulk density and more medium and macro pores in CT suggested that the ploughed soil was better aerated than RT or NT. Overall, warmer, wetter and less aerated soil in NT would be expected to favour denitrification and hence increased N_2O emissions, especially in case of heavy soils in humid climates [9]. Interestingly, this effect was not found in our study, which may have a number of management-specific reasons. Firstly, while no cover crops were planned in our study, all fields were uniformly cropped to alfalfa, an N-fixing legume, in the year prior to establishing the experiment. Using alfalfa or some other legume as a cover crop is not common in BH, but is sometimes practiced by farmers who do not have access to manure (which was the case on our field) or want to decrease the production costs with the application of green manures. Even though we did not measure mineral N in the first year, it is obvious from the N_2O emissions that ploughing the cover crop in autumn prior to the first experimental year and rototilling it in spring released more C and N than in RT and NT, likely because alfalfa residues had a longer contact time with the soil. A similar finding was reported by [54] for a Mediterranean cover crop system. Secondly, 2014 was an extraordinary wet year (Fig 1), with WFPS values around 70–80% in CT and exceeding 90% in NT in the period after fertilization (Fig 2). It is well known that N_2O emissions from denitrification are greatest at WFPS values around 80%, (e.g. [55]), whereas larger WFPS values favour reduction of N_2O to N_2 [56]. For instance, larger N_2O emissions at 80% compared to 100% WFPS have been reported by Ciarlo et al. [57], who observed decreasing N_2O emission in saturated soil. In the wet summer of 2014, we observed several occasions of waterlogging during sampling in NT plots. RT plots had WFPS values intermediate to RT and NT, which resulted in intermediate post-fertilization N_2O emissions. In contrast, the second year was quite dry (Fig 1), and the differences in WFPS between treatments were less pronounced. Post-fertilization emissions occurred during a period with decreasing WFPS, and were largest in RT. We have no explanation for this finding other than that NH_4+ and NO_3^- values were largest in RT during this period, pointing at enhanced mineralisation and nitrification in this treatment at 60–80% WFPS.

Soil properties

Our experiment was conducted on a clayey loam low in SOC (1.34%). The soil had been under intensive arable cropping for the past decade with limited application of manure. Arable cultivation without manures decreases the SOM content over time and consequently weakens the structural stability of the soil [58]. Twenty months into our experimental trial, NT soil had the largest bulk density and may have experienced soil compaction [59], which is known to be a problem in soils with low aggregate stability [60]. Negative effects of soil compaction on crop yields are well documented [61]. In our study, NT soil had 8.2% less total porosity than CT soil and smaller proportion of meso and macro pores (Table 1). This led to reduced water infiltration and occasional waterlogging during more intense and prolonged rainfall events, especially in 2014. In both years, large rainfalls after sowing led to soil crusting, even in the presence of mulched crop residues in RT and NT, delaying the emergence of seedlings relative to CT. This effect was especially pronounced in NT, which led to significant reduction (approx. 25%) in the abundance of corn plants relative to CT and RT in 2014. Another notable observation was that both corn and barley plants in CT and RT were taller irrespective of their phenological stage and that the phenological development was 10–15 days ahead this of NT. Among the positive effects of NT and RT in 2015 was a larger proportion of soil micro- and macro-pores, respectively (Table 1), resulting in larger soil water retention during drought periods, which probably contributed to equal (NT) or larger (RT) barley yields compared with CT in 2015, despite later phenological development and general crop failure.

N_2O emission factor and intensity

Assuming a background emission of 1 kg N_2O-N ha^{-1} y^{-1} [37], we obtained mean N_2O emission factors (EF) ranging from 2.7 to 4.8% of fertilizer N applied. Since these emission factors are markedly larger than the IPCC Tier 1 EF (1% of applied fertilizer N), we tried to estimate the additional N input from alfalfa residues during the first year (Fig 4), based on the results from Kelner et al. [39] and adjusted for alfalfa yields from our study field [40]. Adding this amount of N to the fertilizer N, reduced N_2O emission factors in 2014 to 1.5, 1.6 and 2.7% for NT, RT and CT respectively, which is closer, but still above the IPCC Tier 1 EF of 1% [37]. In 2015, emission factors were 0.7, 1.0 and 1.5% for NT, CT and RT respectively, which is close to the IPCC Tier 1 EF, despite the general crop failure in this year. Given the uncertain estimate of extra N input in 2014, and the insignificant differences in the EF across tillage treatments in 2015, we conclude that tillage regime had no measurable effect on the N_2O emission factors in our experiment.

To assess the N_2O footprint of cropping methods, yield-scaled approaches are increasing employed [38, 62]. Calculated as N_2O intensity (g N_2O-N Mg $grain^{-1}$), RT had the lowest intensity in both years. We used the results from 2014 for further comparison, since the high values in 2015 essentially reflected crop failure. Yield-scaled N_2O emissions in 2014 ranged from 83.2 (RT) to 161.7 g N_2O-N Mg^{-1} (NT) and this difference was statistically significant. These results are within range of 77.1–391.8 g N_2O-N Mg^{-1} as reported by Guo et al. [63], but larger than those reported by Halvorson et al. [64] (31–67 g N_2O-N Mg^{-1}) and Venterea et al. [65] (46–100 g N_2O-N Mg^{-1}) for the same crop (corn). Our intensities are smaller than those reported by Burzaco et al. [66] for similar fertilization rates (211–285 g N_2O-N Mg^{-1}) and markedly smaller than the 1.3–2.0 kg N_2O-N Mg^{-1} reported by Gagnon et al. [67].

Environmental vs. economic benefits

It has been widely recognised that conservation tillage practices have a beneficial effect on soil properties in cropping systems compared to conventional practices [68]. However, the adoption of NT in Europe is still limited in comparison with the Americas, despite extensive research in this area [69]. The relative advantages of NT and CT depend on a number of aspects, grouped roughly into agronomic and environmental factors [70]. According to Soane et al. [69], the opinions and choices of farmers related to tillage will be dictated primarily by agronomic factors, whereas environmental factors are of a more general concern for soil and landscape protection and climate change. While the agronomic benefits of alternative tillage methods are easy to recognize, the likelihood for their adoption is constrained due to relative uncertainty about the economic benefits [71, 72].

Summarizing stipulated costs and revenues over the two cropping seasons, including one year of crop failure, it is notable that RT had smaller yield-scaled N_2O emissions than CT and NT, while generating the largest net returns per ha. These findings are in agreement with and support the current situation in Europe, where intermediate forms of tillage have been adopted much more widely than NT [69]. While only a small reduction of variable costs in NT could be achieved in our experiment due to the increased costs for weed control, the main reason for small net returns and large yield-scaled N_2O emissions in NT were lower crop yields compared to CT and RT. Conservation tillage initially leads to yield reduction of varying degree depending on crop type, tillage, soil properties, climate and crop rotation [73, 74]. However, it is expected that the yield gap between reduced and conventional tillage will level out over time, as the soil structure, water infiltration and root growth improve in the surface soil under continuous NT systems [75].

Based on our findings and the current socio-economic conditions in BH, we conclude that a wider acceptance of NT is not realistic at the moment, especially among risk-averse smallholder farmers who lack knowledge and financial capital. However, our result also show that RT could be a compromise between CT and NT, given the current conditions, because it can be both N efficient and economically acceptable. RT appeared to be more resilient to weather extremes, particularly during the dry year of 2015. Our study was conducted in "continental" BH, characteristic for the northern lowlands and river valleys of central, eastern and western BH, which is central for BH's intensive agricultural production of a wide range of crops. Yet, further research is needed in other agroclimatic zones and soil types of BH to assess tillage effects at the national level. In addition, longer-term studies are needed to make more reliable projections of yield levels and environmental savings.

Conclusion

Fertilization was found to be the main driver of N_2O emissions irrespective of tillage treatment. However, clear treatment effects outside the period directly affected by fertilization were noted, indicating the importance of crop residue management and tillage on soil structure, temperature and moisture. Annual emissions were different between tillage treatments, but this depended on the year. NT had the smallest N_2O emission in both years, while CT had the largest emission in the first year and RT the largest emission in the second year. When normalized for yield, RT had the smallest N_2O intensity in both years. The emission factors were within or slightly above the uncertainty range of the IPCC Tier 1 EF. Reduction in variable costs associated with NT was small due to the increased costs of weed control. Moreover, low yields in NT in both years resulted in economically inacceptable returns. On the other hand, the reduced number of operations in case of RT generated higher net returns due to reduced production costs. Based on our results, we conclude that RT could be a feasible way to improve N yields and net returns, while reducing yield-scaled N_2O emissions under the given agro-ecological and socio-economic conditions of BH. Future studies with the objective to mitigate N_2O and other greenhouse gas emissions, improve crop yields and N use efficiency from agricultural systems in the region are needed, including long-term observation, that can integrate over the large interannual weather variability in central BH. Studies on the effect of CA principles other than reduced tillage (e.g. cover crops, crop rotation) are needed if region-specific production system are to be designed to optimize crop production both environmentally and economically.

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