

(千葉大学審査学位論文)

Monitoring and Analysing Land Use and Land Cover
Changes in an Arid Region Based on Multi-Satellite Data:
The Kashgar Region, Northwest China

February 2019

Chiba University Graduate School of Science

Division of Geosystem and Biological Science

Department of Earth Science

AYISULITAN MAIMAITIAILI

Acknowledgment

I would like to acknowledge and thank all the people that have helped and supported me through this difficult and challenging period in my life.

My deepest and most sincere gratitude go to my supervisor Professor Akihiko Kondoh for the guidance, advice and encouragement throughout the tenure of this work. I extremely appreciate his valuable suggestions and contributions.

I also appreciate Professor Higuchi, Professor Ichi, Professor Takeuchi and Professor Kuzi Sensei, and gratefully acknowledge Chiba University for providing the facilities during the JPC and course of this study. I am grateful member of Chiba University, with whom I had interaction at various stages of my research.

Spatial thanks go to my colleagues Mr Hama, Mr Akbar, Miss Yuki, Miss Eunice and Mrs Zinnat during my research tenure at Chiba University.

Last, but most of all, my appreciations go to my husband Anvar Azat, enough words cannot be found to express his assistance and suggestions towards my progress in life, his warm love, endless hours of patience, understanding and constant encouragement and strength during the graduate study.

I would like to express my gratefulness and love to my parents and my parents in law for their support during my research and residence in Japan.

Abstract

In arid regions, oasis is one of the ecological landscapes and the primary space for human life and agricultural production. However, oases ecosystems are fragile and sensitive to changes in the environment, where water is the major limiting factor for environmental and socio-economic development. Understanding causes of Land Use and Land Cover Change (LUCC) and its effects on water resources in arid regions is important for the development of management strategies to improve or prevent environmental deterioration and loss of natural resources. Moreover, plays a significant role in the stability and economic development of the region. The Kashgar Region is the key research area in this study; it is a typical mountain-alluvial plain-oasis-desert ecosystem in an arid region, Central Asia and the area is one of the largest oases in Xinjiang Uyghur Autonomous Region, China. In addition, the Kashgar Region is an important cotton and grain production area. This study's main objectives are (1) to detect, quantify and map the spatiotemporal dynamics of LUCC, occurred during the period from 1972 to 2014; (2) to investigate the impact of LUCC on the water resources. (3) to understand the interrelationship between LUCC and its social and natural factors.

Results showed LUCCs have been significant in the Kashgar Region during the last 42 years. Cultivated land and urban/built-up lands were the most changed land cover (LC), with 3.6 % and 0.4 % from 1972 to 10.2 % and 3 % in 2014, respectively. According to the land use transfer matrix, cultivated land replaced grass- and forestland. The significant findings of this study are the spatial expansion of cultivated land occurred peripheral extension of the existing oases in 1972, after distributed mainly in middle parts of Kashgar and Yarkant River in 1990, intensification of the area under the agricultural production. From 2000 to 2014, land use change exhibited new characteristics, cultivated land expanded along the alluvial fans where the place takes advantage of using water resources. The Kashgar Region surrounded by mountains, these mountain fronts are distributed alluvial fans. Alluvial fans are important sources of groundwater in the prevailing Kashgar Region. These areas have favourable conditions for agricultural land expansions.

These findings demonstrating that at the geographical characteristics of Kashgar controlling LUCCs.

It is shown that the agricultural land area more than doubled from 1972 to 2014. This is the result of the interaction of (1) vast agricultural population growth and their basic and economic desires, increase of annual per capita production of grain (2) positive price development for cotton production and globalized markets of cotton, (3) increased construction of highway and railway network in regional telecoupling for transport agricultural production, connection of outsidies cities, (4) promote a rural economy by the diversification of agricultural production, demand of the outside and (5) implement agricultural subsidy and combined with regional geographic characteristics of Kashgar Region. Expansion of cultivated land led to increased water consumptions occupies more than 90% of the total water use and stressed fragile water systems.

Water resources originate from the mountain precipitation and snowmelt water. Snow cover investigation results revealed that high snow cover area accumulations and its seasonal process contributed to increasing runoff in the same year, this short-term change of snow cover would beneficial for irrigated agricultural land. However, the seasonal temperature of sources region has been increased, which has led to decreasing of mountain solid precipitation and will lead to increase spring runoff or shifts peak runoff discharges. If the temperature continues to rise in long run, impact on the future quantity of water resources, the decrease of water resources will seriously affect oasis. These causes will be the restricting factor of Kashgar Region oasis development in the future.

Therefore, future expansion of cultivated land in the Kashgar Region should be restricted, and the efficiency of surface water resources use should be improved. The selection of adaption strategies relating to climate change and oasis development is very important for sustainable development in the Kashgar Region.

Keywords: Arid Region; LUCC; Driving Forces; Water resources; Oasis; Kashgar Region.

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Chapter 1. Introduction

1.1 Background of the study

Arid regions occupy one-third of the global land surface area (McGinnies, 1979), where 365 million inhabitants were living in 2000 (Figure 1.1). This is an increase of 227% compared to 1950 (Global Population Datasets, 2000). Rapid population growth give stress on vulnerable ecosystems, an increase in utilization of surface water and groundwater for irrigation has taken place in the arid region, land degradation and desertification have ranked as a major environmental and social issues (Xiao et al., 2007), disappeared inland lakes as a LopNor in Xinjiang (Chen et al., 2011), Aral Sea has shrunk rapidly in Central Asia (Micklin, 2010), dried up and shrunk the Dead Sea in the Middle East (Radwan and Al-Weshah, 2000). These environmental problems are originated from the mass utilization of water resources and over-exploitation with less consideration for the ecological conservation of groundwater. Owing to scarce water resources, ecosystems and societies are vulnerable to environmental changes, especially hydrological changes under condition of global warming (Shen et al., 2010).

In China, arid and semi-arid area comprises about 26.6 % of China's land area, where is the vast area in the hinterland of the Eurasian continent. It includes the Xinjiang Uyghur Autonomous Region, the middle and west parts of the Inner Mongolia Autonomous Region, most part of the Ningxia Hui Autonomous Region, and the Hexi Corridor region in the Gansu Province (Figure 1.2). Its geographical location ranges longitude 73-125° E and latitude 30-35° N (Luo and Yang, 2003). The total area is approximately 2.02 million square kilometres, accounting more than one-fifth of China's total terrestrial area. The Kunlun-Altun-Qilian Mountains are the south boundary of the area, which combined with Qinghai-Tibet Plateau, blocks the vapour from India

Ocean. Altai Mountain is the northern boundary, blocking the vapour from the Arctic Ocean. The landscapes characteristics include alpine, inland basins, Gobi desert and widespread sandy desert. This inland region is controlled by the continental climate with little rainfall throughout the year and strong evaporative potential (Shen et al., 2013). The average annual temperature is about 8 °C, and annual rainfall is less than 300 mm on mean, gradually decreasing from east to west (Figure 1.2). These areas existed with long sunshine and solar energy resources, abundant mineral resources and agricultural productive potential (Xu et al., 2011). However, the area belongs to a typical arid eco-fragile area, due to water resources shortage, sparse vegetation and widespread desertification. Past several decades, these arid regions have been experiencing considerable environmental change, such as degradation, water shortage, glacier retreat, and desertification expansion (Hao et al., 2008), which have exacerbated the conflicts between natural ecosystems and human societies in the regions. Researchers have been investigated the environment evolution and mechanism in the arid region (Wang et al., 2010; Yang et al., 1995). Shi and Zhang (1995) analysed the climate change process and found that the climate trend in the arid region of northwest China turned to the warmer and wetter trend; Stewart et al. (2001) indicated the climate condition in the arid region was more sensitive to climate change; Ding et al. (2006) analysed glacier change trend under climate change and found glacier retreat, increasing runoff of glacial meltwater. Xu et al. (2009) showed that the effect of climate change on species distribution in the arid region; Chen and Xu studied the impact of climate change in the arid region on water resources in the typical river basin (Chen et al., 2007; Chen et al., 2008; Chen et al., 2010; Xu and Peng, 2010; Xu et al., 2011); Shen et al. (2013) estimated irrigation water demand with a combination of the remote sensing data. The results suggested that irrigation water requirement increased the remarkably arid region of Northwest China. Zhi et al. (2013) identified pan

evaporation (E_p) dynamics in the arid region of Northwest China during the period 1985-2010. The results found that E_p in the region exhibited an obvious decreasing trend at a rate -6mm yr^{-2} until 1993, then increased that was 10.7mm yr^{-2} . These many studies have been conducted to examine changes in climate, water resource, etc.

Recently, increases of social, economic activities and environmental changes of arid regions have posed big challenge to sustainable development. Particularly, an arid environmental system, featured by sensitivity and instability, may pose big challenge to a regional sustainable development strategy within the context of global change, as its ecological equilibrium can be easily damaged under the pressures of social, economic and technological developments represented by LUCC (Glasby, 2002). Land use changes have generally been considered a local environmental issue, however, it is becoming a force of global importance (Foley et al., 2005). LUCC play a major role in climate change at global, regional and local scales. At the global scale, LUCC are responsible for releasing greenhouse gases to the atmosphere, thereby driving global warming (Quaas, 2011). At the local scale, analysis of local scale LUCC, conducted over a range of timescales help to uncover general principles that provide an explanation and prediction of new LUCC (Lambin et al., 2003). Due to their interactions climate, ecosystem processes, biogeochemical cycles, biodiversity and human activities (IGBP, 1999).

LUCC and its implications to global environment change and sustainability of arid region are major research challenge in human environmental sciences (Turner et al., 2007). Human activities are the major forces in shaping LUCC of other humid and sub humid regions worldwide. However, biophysical and human factor created LUCC in arid region, due to its vulnerable environment. Therefore, an integration of biophysical and human factors investigation of LUCC dynamics remains as an important research task.

Understanding causes and consequences of LUCCs are one of the fundamental objectives of global change research (Rindfuss et al., 2004). Information of LUCCs is necessary for effective planning and management of the sustainable and food security (Anil et al., 2011). Accurate and up-to-date LUCC informations are essential to understand and assess the environmental consequences of changes. There is an ongoing demand for up-to-date LUCC information for sustainable development. Therefore, there are an increasing international concern about LUCC and its driving forces in arid regions (Braumoh and Osaki, 2010).

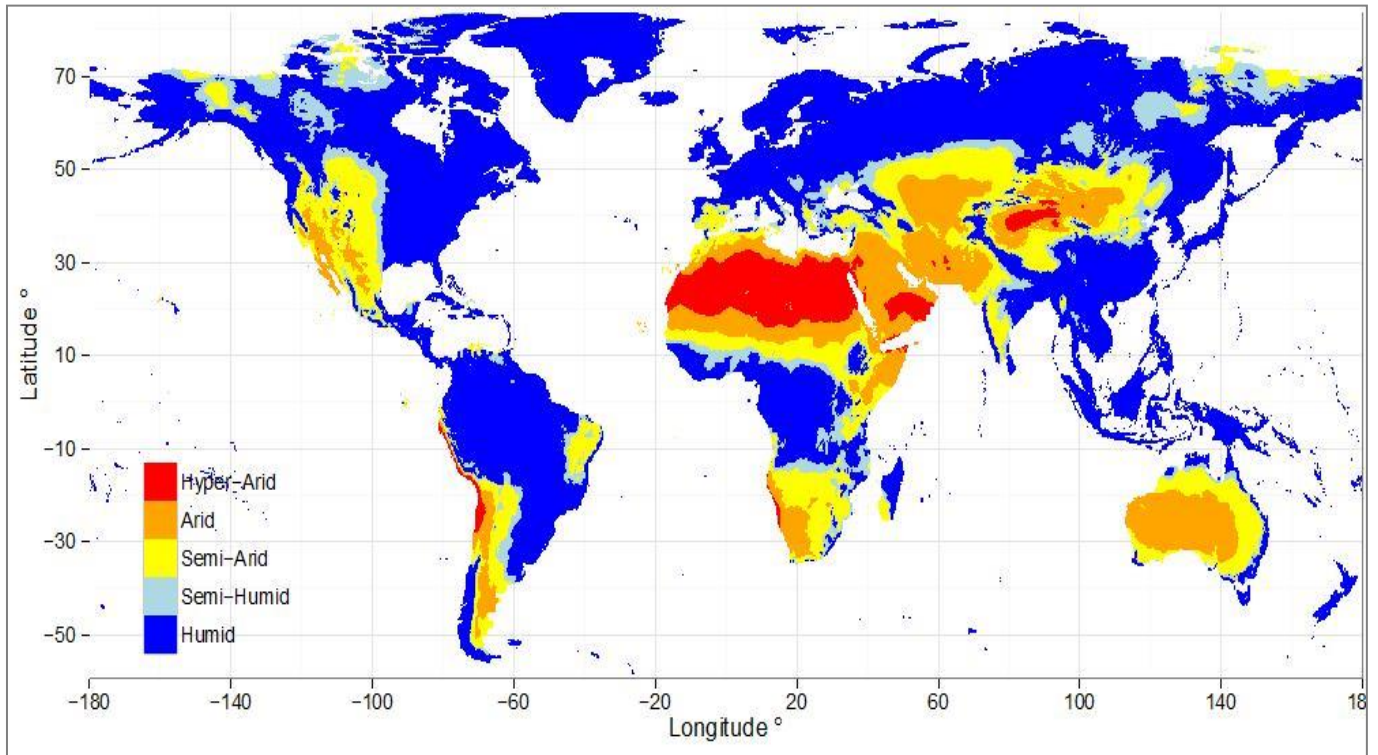


Figure 1.1 Global climatic zones distribution map

(Data from Consultative Group for International Agricultural Research- Consortium for Spatial Information)

Red is hyper-arid region, orange is arid region, yellow is semi-arid region, light blue is semi-humid region, and blue is humid region. The map showed that arid region occupies vast area of the global land surface, spanning most developing countries in the world.

The LUCC is a central component of global environmental changes, therefore, several global organization and projects have been establishing. The lasted project was Global Land Programme (GLP), which was jointly established by International Human Dimensions Program on Global Environment Change (IHDP, 1996) and International Geosphere-Biosphere Program (IGBP, 1987), are the chief international global change project promoting Land Change Science (LCS) for environmental sustainability. The orientation of land system science at the interface of physical, ecological and social systems was reflected in GLP, is a core project of both the IGBP and IHDP, commissioned by the International Council for Science (ICSU) and the International Social Science Council (ISSC). The GLP started in 2006 for a 10-year period after releasing its science plan in 2005 (GLP, 2005). GLP aims at synthesis and integration of insights, knowledge and methodologies in research across the land system science community. Place-based (region) research in case studies has always formed a key component of land system science. In order to better understand individual case studies and identify generic pattern across case studies, meta-analysis was conducted, focusing on the causes of key land change process or consequences of land change (Verburg et al., 2015). The LUCC work was the synthesis of case studies to identify common driving factors of change and causation patterns (Lambin and Geist, 2002, 2004). The research of LUCC is matured and become more integrative, mainly focusing on both drivers and impacts of land changes and including a wide range of interacting process of land use change. Research filed engaging scientists across the social, economic, geographical and natural sciences (Rindfuss et al., 2004; Turner et al., 2007). The feedbacks between drivers and impacts have been increased attention (Verburg, 2006). Over the decades, progress has been made in understanding LUCC in specific places, using frameworks such as human-natural systems (Marinna et al., 2011), coupled human-environmental systems (Moran, 2010), or social-ecological

systems (Walker et al., 2006). Although the framework for these systems is helpful in guiding the analysis of internal forces in driving LUCC, they fall short in their consideration of increasing scale, extent, and speed of existing and emerging connections between coupled systems over a large distance. However, LUCC around the world is increasingly being driven by new agents and causes with emanating from distant locations, through forces such as trade, consumption, migration, transnational land deals (Liu et al., 2014). A new conceptual framework is thus needed to account for such distant forces. This chapter applies a framework that explicitly takes distant forces into account in LUCC and builds on the concept of telecoupling (i.e., environmental and socioeconomic interactions among coupled systems over large distances). The interactions between social and ecological systems and telecoupling between world regions (Lambin and Meyfroidt, 2011; Liu et al., 2013) and between cities and their rural hinterlands (Seto et al., 2012) have motivated an integrated socio-ecological systems perspective (Verburg, 2015).

Numerous researchers improved measurement and understanding of causes of LUCC by integrating environmental, human and remote sensing/GIS science solved various questions about LUCC, its cause and impacts on humans and the environment (Lambin et al.,1999). In particular, there is increasing literature of research focusing on arid region LUCC. It is mainly because the arid region has experienced and suffering in the last few decades by LUCCs. However, studies on LUCC of arid areas in developing countries are often restricted, perhaps due to the lack of financial resources, physical accessibility and historical data (Brandt and Townsed, 2006). Therefore, the current study represents a case study on LUCC in a typical arid area in Northwest China. We selected the Kashgar Region, as a case study. Because of the place-based case study as this research has formed a key component of land system science.

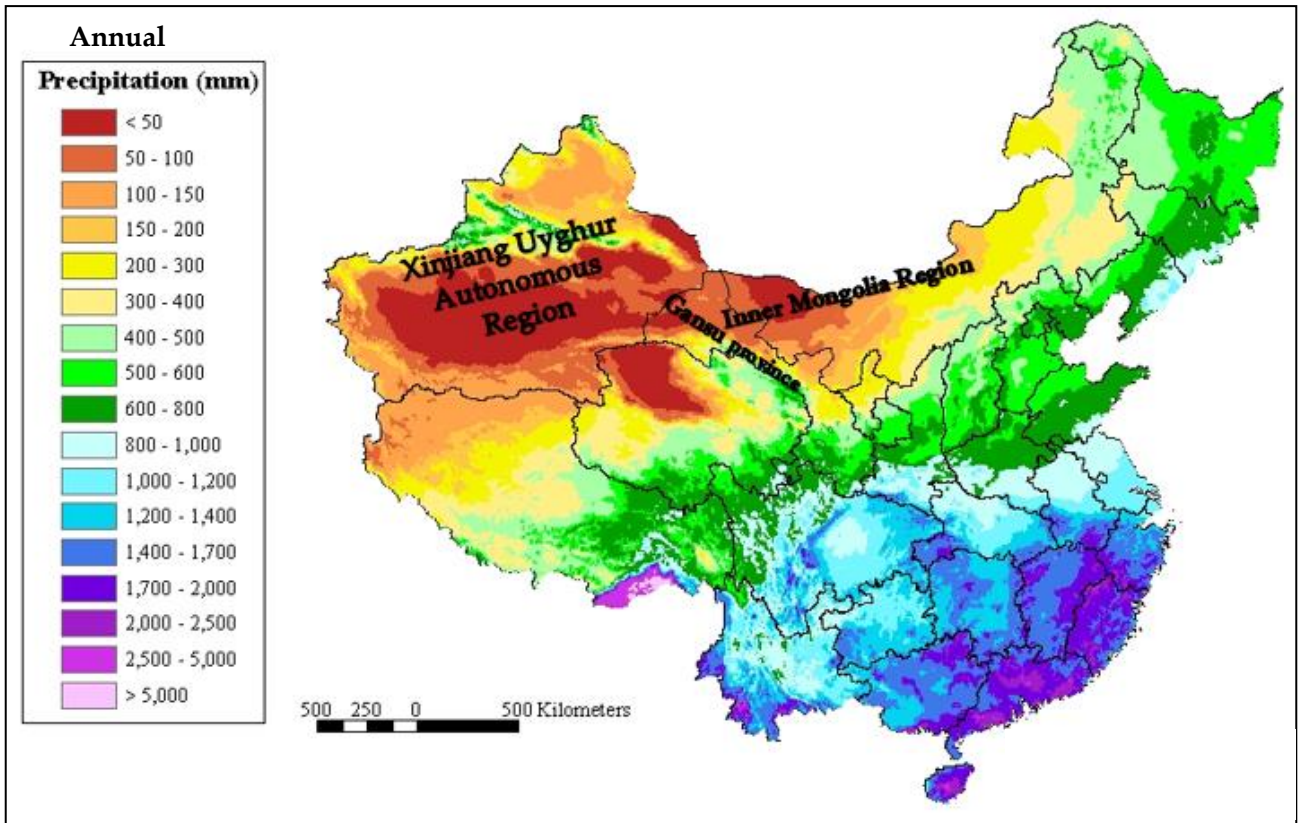


Figure 1.2 Spatial patterns in precipitation across China

Arid region of China includes the Xinjiang Uyghur Autonomous Region, the middle and west parts of the Inner Mongolia Autonomous Region, most part of the Ningxia Hui Autonomous Region, and the Hexi Corridor region in the Gansu Province. Annual precipitation is gradually decreasing from east to west.

1.2 Statement of the LUCC research problem

Our current understanding of LUCC and its driving forces of arid regions especially in the Kashgar Region, northwest China is inadequate. Kashgar Region lies in far western China in the Uyghur Autonomous Region of Xinjiang. The region is situated at the western end of the Tarim Basin in a fertile oasis of loess and alluvial soils watered by the Kashgar and Yarkant Rivers and by several springs. The fertile oasis allows corn, rice, wheat and cotton as well as melons, grapes, apricots, peaches and cherries to grow. Various handicrafts such as cotton and silk textiles, leatherwear and pottery are produced in the city and its suburbs. The historical importance of the Kashgar Region has primarily been linked to its significance as a trading centre. Located at the foot of the Pamirs Mountains between a vast desert and immense mountain range, Kashgar Region was once an isolated oasis on the long trade route across the Asian continent. It was a major hub along the great Silk Road as the northern and southern Silk Routes crossed here and caravans departed for Central Asia, India, Pakistan and ancient Persia (current Iran).

Over the last half-century, there has been rapid population growth and economic development, leading to the modification of natural ecological processes by human activities. Over-irrigation and build-up of reservoirs have decreased the water flow of the river by $1.5 \times 10^9 \text{m}^3/\text{year}$. Consequently, 240 km long along the Kashgar and Yarkant Rivers have died, due to frequent drying up of the rivers, leading to expansions of the desert area towards the north (Zhen, 1998). The overcutting of desert vegetation and tree along the rivers, resulted in activation of 80% of fixed and semi-fixed sand dunes, which are moving toward the oasis at a rate of 5-10m/year ((Nian et al.,1992), the practice of flood irrigation has salinized 59.17% of arable land ($3.38 \times 10^5 \text{ha}$) (Guo, 1991). The significant high correlation existed between urbanization and water utilization based on the urbanization and water resource data in

the Kashgar Region (Anvar et al., 2011a, b). Mansuer et al. (2011) analysed spatiotemporal dynamic changes of groundwater in Kashgar Region using groundwater measured data and found cultivated land had been increasing continually, resulted in decreased groundwater level in the midstream and downstream of Kashgar and Yarkant Rivers.

In May 2017, China 's President Xi announced his 'One Belt, One Road' (OBOR) model to the world (news of Xinhua, 2017). OBOR aims to cross the Himalaya, Pamir, and Tien Shan mountains, traverse the deserts and steppe of Central, South, and Southwest Asia (Troy et al., 2017). The Kashgar Region is one of the important hubs in the New Silk Road, OBOR economic construction as Figure 1.3 showed. Core projects to connect China by Northwest China (Kashgar Region) with other regions to connect regions outside China include the highway and railway linking (Fernando et al., 2018). New roads and other infrastructures can promote social and economic development, for example, by increasing the access to agricultural supplies and markets, facilitating the transportation of people and goods, and decreasing production costs and crop losses. Therefore should be stimulated when the goal is to connect isolated oasis as Kashgar Region. However, when planned and built through areas of arid fragile environments (Kashgar Region, Northwest China), they may have led to rapid LUCC.



Figure 1.3 Map of Central Asia with geographical features (mountains, desert, steppe) and existing major infrastructure (pipelines, railroads). Major infrastructure (pipelines, railroads) (Source: Troy et al., 2017)

In Kashgar Region, water is the major limiting resources that not only precious natural resource but also an important social factor for economic development (Jia, 1996). Formation of water from high mountain snow and glacier meltwater, mid-mountain precipitation and low mountain bedrock fissure water provided important water resources to low basins, due to the extremely arid low lands. However, climate change has led to uncertainty on the process of growth and decline of glaciers and snow cover and spatiotemporal changes of precipitation. Future water resources trend of Kashgar Region under ongoing climate change are not clearly identified yet. Besides the impact of human activities, the hydrological cycle in the Kashgar Region has also affected by climate changes. Global warming will accelerate atmospheric circulation and hydrological cycle, subsequently affecting the spatial and temporal distribution of water resources and exacerbating water shortages, especially in arid regions (Chen et al., 2016). The occurrence of surface water in the Kashgar Region has strongly related to the climatic, hydrological, and geomorphological factors. Most studies on the Kashgar Region focused on individual factors or processes, such as water stress (Anwaer et al., 2010, 2011), climate change (Abudoukerimu et al., 2012), and groundwater changes (Mansur et al., 2011).

The insufficient controls over land reclamation and converter natural vegetation to cultivated land have supported an agricultural land expansion of Kashgar Region. Loss of natural vegetation cover is often a precedent to soil erosion and deterioration of water storage of capacity. These modifications of the land system may lead to desertification continually due to long-term factors such as climate change, triggering short-term degradation of ecosystems by humans.

The study of vulnerable arid environments is important to research for sustainable development, since the ecological equilibrium of many of these arid areas as Kashgar Region and other arid regions of China, and central

Asia has deteriorated rapidly beyond the level of present social and economic development. The cultivated land has been expanded over the last decade mostly due to the concentration of crop and cotton production. The polarisation between more intensive and more extensive use of land has been described as the main trend of current land use changes (Ayisulitan et al., 2018). In Kashgar Region, however, this trend is less clear, and these processes have not been mapped and quantified at a regional scale and change trajectories among the land cover types have not been systematically evaluated and explained currently.

1.3 Objectives of the study

To address the issue of gaining a systematic understanding of magnitude of land cover change at the regional scale, the overall aims of this study are to quantify the LUCC, to depth understand relationship between LUCC and its social and natural factors, based on the integration of multiple remote sensing sensors and the applications of environmental and socio-economic data. The achievement of the main purpose is based on the following specific objectives:

The first purpose is to detect, quantify and map the spatiotemporal dynamics of LUCC over 42 years period, 1972-2014. In order to quantify LUCC, to produce land cover (LC) maps for 1972, 1990, 2000 and 2014 by Landsat MSS, TM, ETM+, and OLI. The LC maps are important for regional monitoring, resources management and the component of the planning process for local government. Moreover, they will enable policy makers objective decision making by providing a broad and synoptic perspective of land use measurements and mapping of environmental change. It will provide scientific information for One Belt, One Road (OBOR) programming processes and the planning.

The second purpose is to investigate the impact of LUCC on water resources. Due to the extremely arid climate of the Kashgar Region, water is a

precious natural resource and important for economic development. This is linked to anthropogenic activities and natural ecosystems as both compete for water. Investigate LUCCs and its impacts on water resources are extremely necessary to maintain an ecological balance.

The third purpose is to understand the interrelationship between LUCC and its social and natural factors. For social factors, we used socio-economic and government reports (population, GDP, primary industry, investment of road network developments, price and policy changes) data. Using quantify and correlation analysis methods to identify interrelationships between LUCC and its population, policy changes, road constructions and economic development act social factors. For natural factor, we mainly considered geographic locations of Kashgar Region firstly. The area is vast, including high mountain with the glacier, snow and low basins with an arid climate. The water resources originate from the mountain area located in the upper reaches of the basin and are mainly composed of mountain precipitation and ice-snow meltwater. Flow at the mountain-pass supplies water consumption of oasis. River runoff is one of the very important factors, which affects oasis development, and it is attributed to the snow-ice melting and therefore is very sensitive to climate processes. Snowmelt water is the main sources of runoff, groundwater recharges, agriculture and demographics in the Kashgar Region. LUCC of Kashgar Region have strong dependencies on this water resources, which could greatly affect the socio-economic development, disturb the fragile ecosystems and even lead to the frequent occurrence of drought/flood disasters. Therefore, the study of snow cover area changes as well as its impact on river runoff is very important for effective water resources management. We estimated snow cover area by remote sensing data. The temperature and precipitation play important role in the snow cover area and its melting process. We analysed snow cover, temperature, precipitation and runoff as the natural factor.

Chapter 2. Study area- the Kashgar Region

2.1 Location of study area

The Kashgar Region located in Northwest China, is in the southwest Xinjiang Uyghur Autonomous Region (Figure 2.1). The study area's administrative boundary lies within the range of 71° 39'–79°52' E and 35° 28'–40° 18' N. The Kashgar Region administrative divisions include one city and 11 counties within a 113,915 km² area and characterized by high mountains, desert plains and cities, counties, valleys along the major rivers. According to 2014 census statistics, the total population was 4,228,200; the non-agricultural population accounts for 22.23%, and the agricultural population accounts for 77.66%.

Three mountains surround the Kashgar Region, Tianshan Mountain to the north, the Kunlun Mountain to the south, and the Pamir peaks to the west, stretching to 4.25×10^4 km². Water vapour from the Indian Ocean and the Arctic Cold front has difficulty penetrating the area due to the high mountain barriers (Ayisulitan et al., 2018). Therefore, the Kashgar Region has a typical inner-continental climate, with annual precipitation of less than 100mm and pan evaporation of higher than 2000mm annually in the plain (Yan et al., 2010), while permanent snow and glaciers exist at higher altitudes. The Kashgar Region consists mainly of the Kashgar River and Yarkant River Plains. The average annual surface runoff of the Kashgar and Yarkant Rivers is 4.5 and 7.5×10^9 m³, respectively. Water from these rivers is used mainly for irrigation, groundwater recharge and hydropower generation.

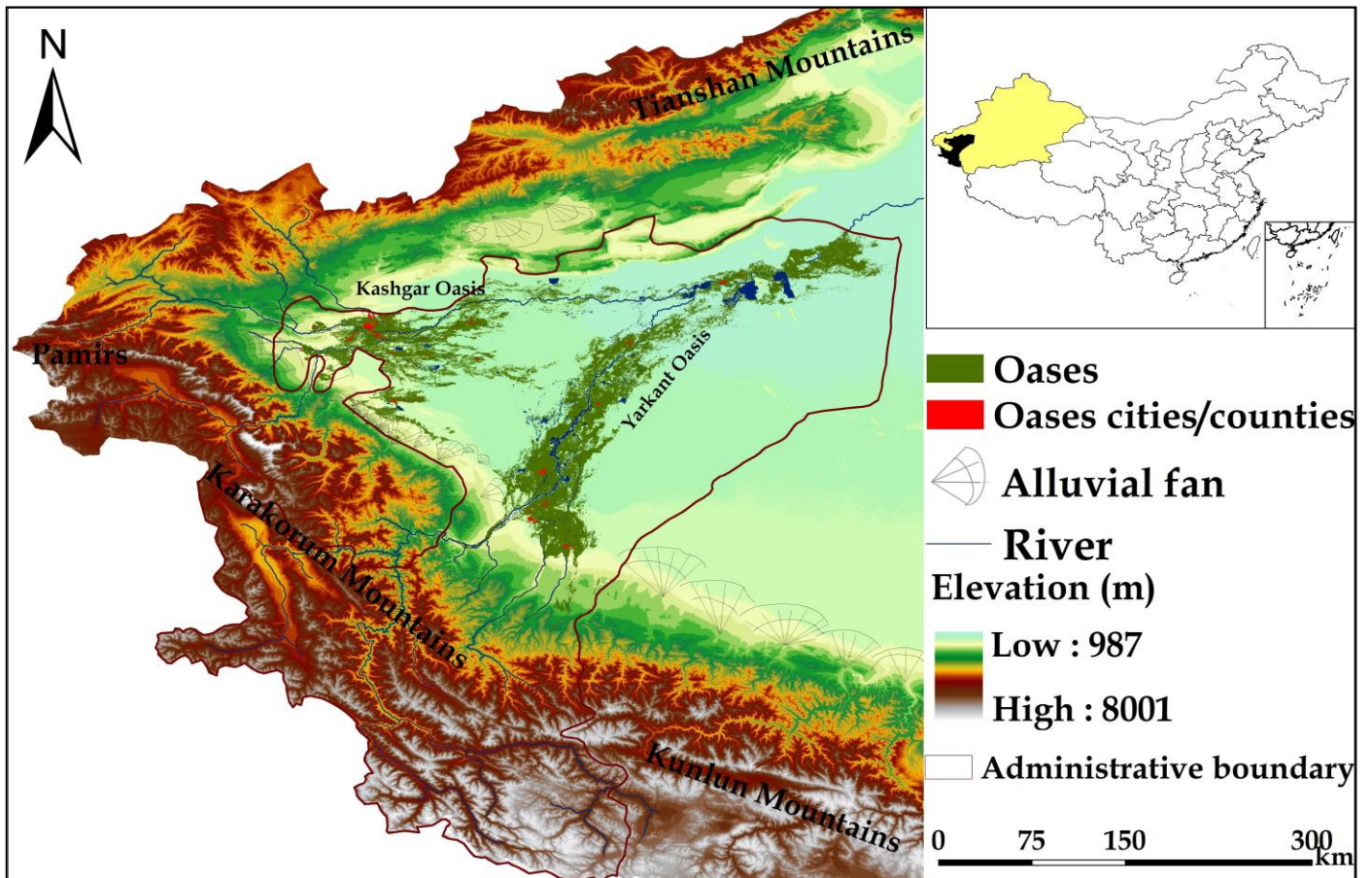


Figure 2.1 Location map of study area

This map is produced by digital elevation model (90m) data (data from USGS Earth Explorer). Red line is administrative boundary of Kashgar Region. Right side includes map of China. Yellow is Xinjiang Uyghur Autonomous Region, and black is administrative area of Kashgar Region.

2.2 Topography of study area

The Digital Elevation Model (DEM) of Kashgar as Figure 2.2 shows elevation in range between about 1000m-8000m. The West Tianshan Mountains trend east to west with an altitude 3500 m above sea level. The West Kunlun Mountains have an altitude of 5000 m above sea level. The Pamir highest peak is 8001 m above sea level. The average altitude of the desert plain is 1100 above sea level. This precipitation is the primary sources of inland rivers. Accumulated snow and glaciers play an important role in regulating the discharge of rivers, reducing inter-annual variations in discharge at the months of mountain valleys (Tang et al., 1992). Mountain uplift, westerly circulation, and the East Asian monsoon have determined its climate, creating a unique geographical unit— mountain – alluvial plain – oasis - desert system. High mountains around the basin prevent ocean air from lowing into the basin. High temperature, strong winds and high evaporation rates in the basin result in a very dry climate. Annual precipitation averages 30-60 mm, and maximum annual evapotranspiration in 2,536 mm (Nian, 2001). The alluvial plain is surrounded by mountains in the north, the west and south. These distribution patterns determine the close interconnection of surface and alluvial fan groundwater resources. The Taklimakan Desert lies to the east, which is the second largest desert in the world. Precipitation and melting ice/ snow are the sources for surface and groundwater recharge. Groundwater is stored primarily in bedrock fractures. There is a small portion of water loss, due to evaporation. Most precipitation runs off, through deep-cut valleys, to flow out of the mountain region as surface water, onto the alluvial plain. The rest supplies the ground-water aquifer in the alluvial plain through underflow and lateral flow. Under the alluvial plain, there is abundant groundwater storage in the thick, porous quaternary strata. The loss of groundwater from a given area can be

attributed to evapotranspiration, spring (surface) outflow, subsurface flow, and withdrawal for human activities. The unique geomorphic environment of the study area has created favourable conditions for the development of the oasis in the region, forming a relatively well-known oasis of the Yarkant Oasis (Yarkant River Basin) and the Kashgar Oasis (Kashgar River Basin), where have great natural diversity such as abundant radiation and heat resources, make it ideal place for cotton and crop growth. The land in oases is mainly used for agriculture, towns, and counties residential areas and cities. Water from these rivers is used mainly for irrigation, groundwater recharge and hydropower generation.

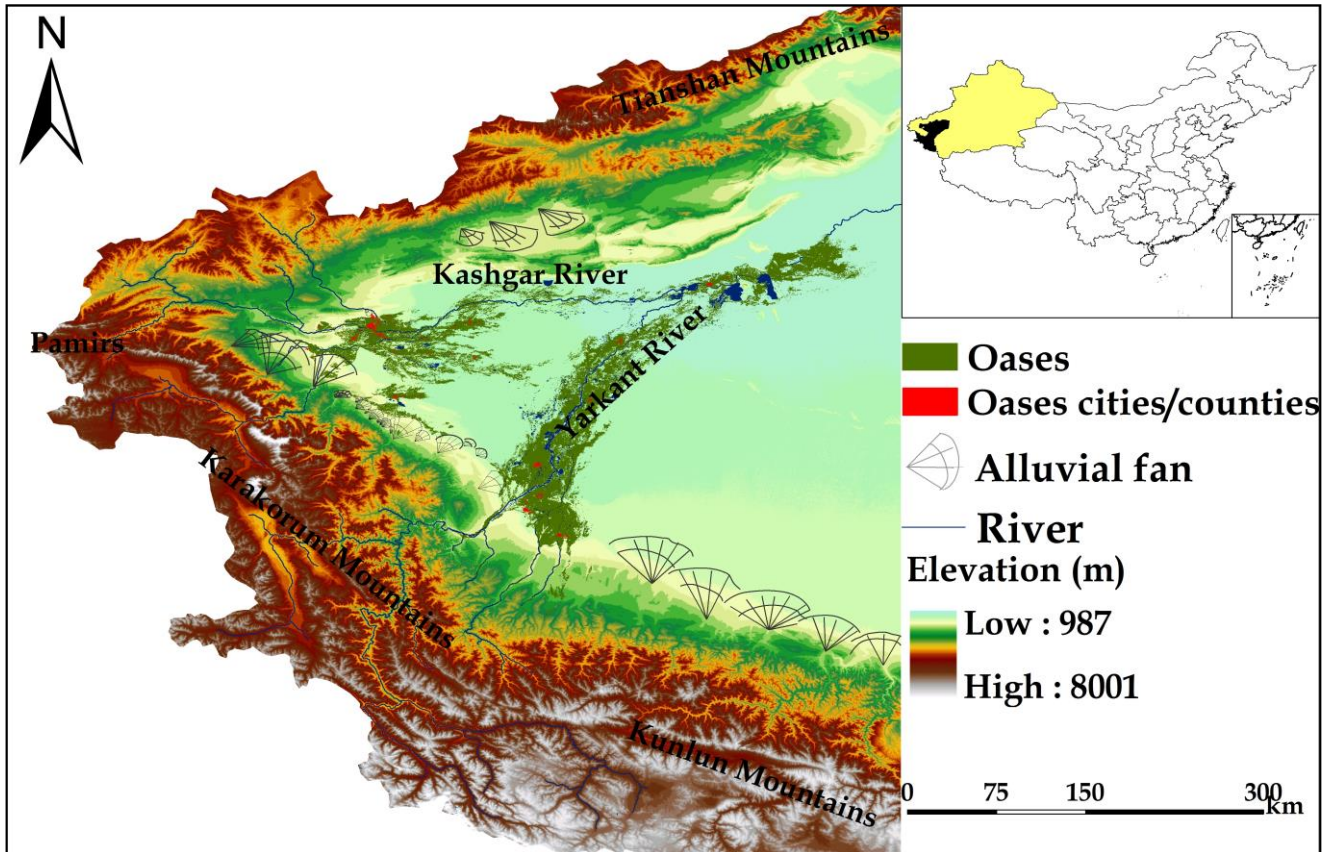


Figure 2.2 Topography of study area

This map is produced by the digital elevation model (90m) data. The blue line is rivers of Kashgar Region. The area is surrounded by mountains on three sides to the north, the west, and the south. The mountain pass distributed alluvial plains.

2.3 Hydrological situations of study area

Water resources in the Kashgar Region depend on mainly melting water from the mountain glacier, snow, and precipitation, which are major supply sources of surface runoff, groundwater discharge, and drinking water for the large population in this area (Chen and Xu, 2005). Kashgar Region is drained largely two main river systems (Figure 2.3), which are Kashgar River and Yarkant River. The river basin originated from Tianshan Mountain and Pamir Peaks. Kashgar River has three tributaries, which are the Kizil River, the Gaz River, and the Kusan River (Figure 2.4, Table 2.1). These three rivers accounted for 91% of total runoff in Kashgar River Basin, they are called Kashgar River. The Kashgar River is one of the main tributes of Tarim River Basin. However, with the aggravating human activities in the middle and upper reaches of Kashgar River, the development of oasis agriculture, supplies of Kashgar runoff to Tarim River was stopped (Zhang et al., 2017). The Kashgar Basin is a deeply inland hinterland and belongs to the arid continental climate. The “dry sea” of the Taklimakan Desert affects it. The evaporation in the plain area is strong, dusty and windy weathers are frequent. The average annual precipitation is less than 100 mm, and the pan evaporation is as high as 2000 mm if solid get sufficient water. The plain area is dry climate, sufficient sunshine, the large temperature difference between day and night, extremely fragile ecology (Huang and Jiang, 2013).

Table 2.1 Water systems of Kashgar and Yarkant River

Yarkant River has four tributaries, which are Tashkorgan, Kelchin, Tiznap, and Yarkant rivers. Kelchin and Tashkorgan River are two large tributaries of the Yarkant. Kashgar River has three main tributaries, which are Kizil, Gaz, and Kusan Rivers.

Drainage area	River name	River range (county)	Length (km)	Catchment area (10 ⁴ km ²)	Annual runoff (10 ⁸ m ³)
Yarkant River	Tashkorgan River,	Tashkorgan	1000	10.81	64.33
	Kelchin River	Kargilik,Poskam,	266	0.78	19.5
	Tiznap River	Yarkant, Makit,	273	2.00	11.5
	Yarkant River	Maralbishi	430	1.46	7.77
Kashgar River	Kizl River	Yingsar, Kashgar	778	1.37	26.83
	Gaz River	city, Konishahar,	320	1.62	9.65
	Kusan River	Yingshahar, Yopurga, Payziwat	224	0.89	6.30

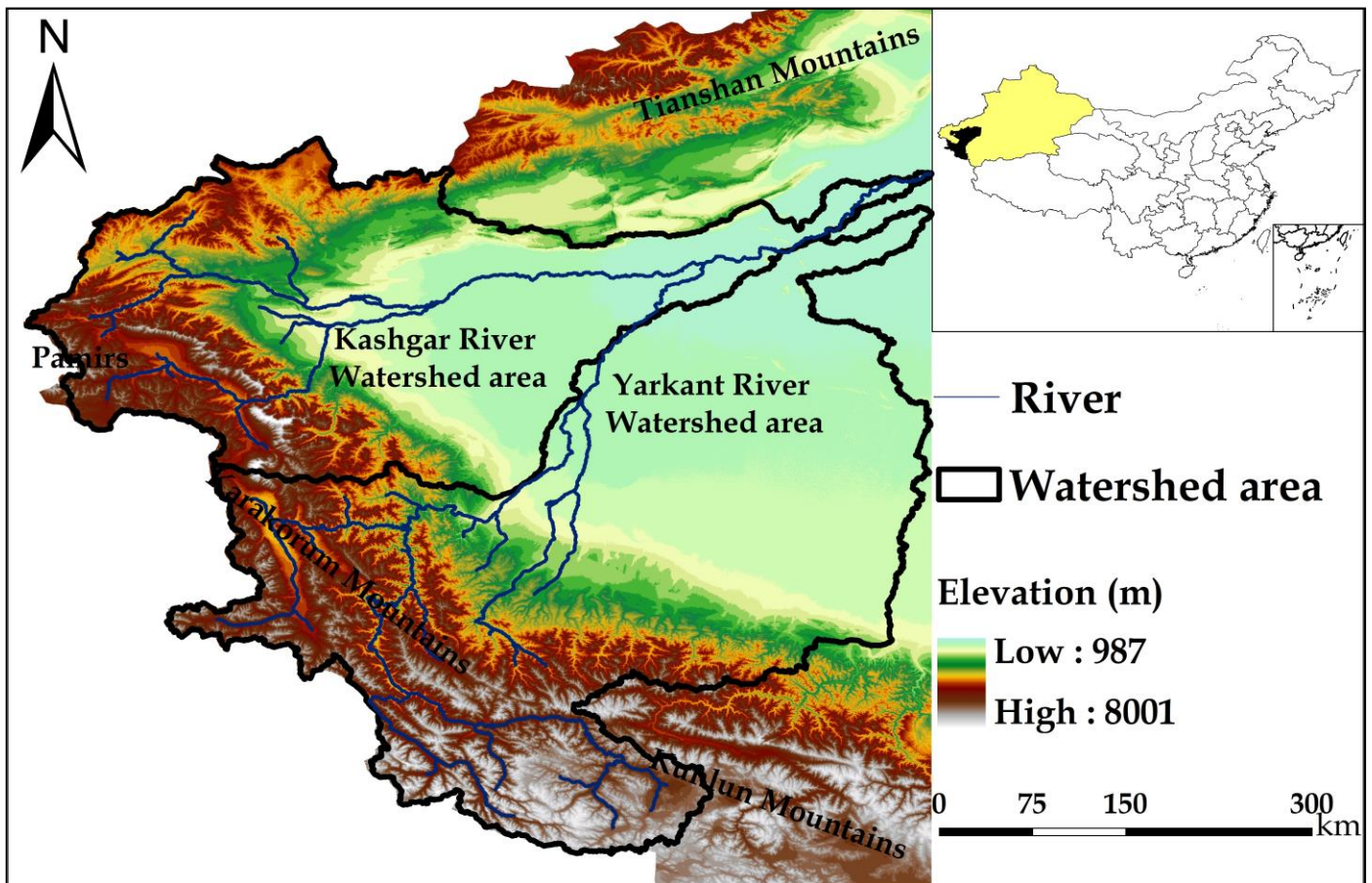


Figure 2.3 Watershed delineation of study area

Kashgar Region includes two watershed systems, which are Kashgar and Yarkant Watershed. The back line is boundary of watershed area.

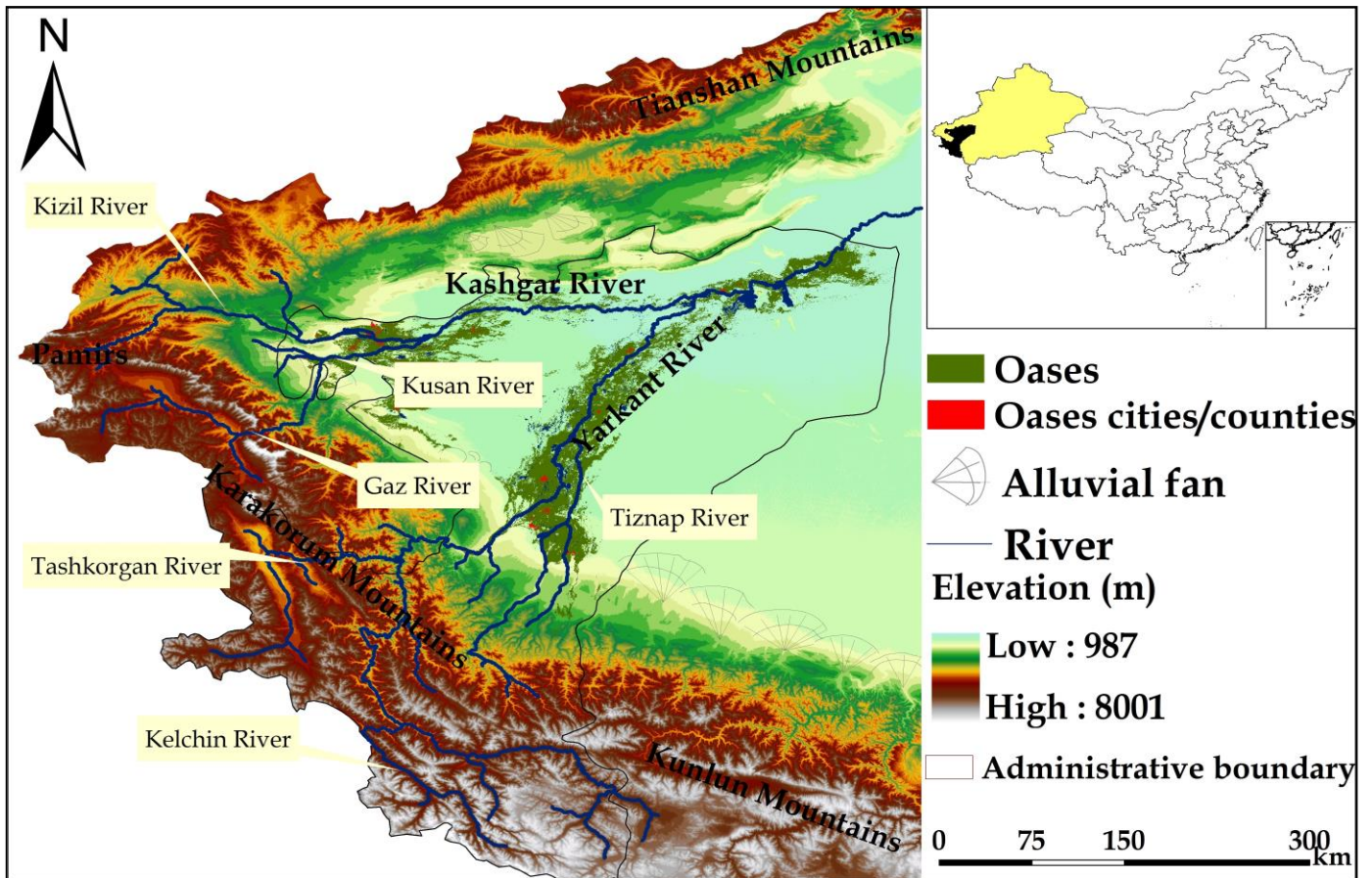


Figure 2.4 River systems of study area

Kashgar Region includes two big rivers, which are Kashgar and Yarkant Rivers. Kashgar River has three streams, Kizil, Kusan, and Gaz Rivers. Yarkant River has four streams, Tiznap, Tashkorgan, Kelchin River and Yarkant River.

The main stream of Yarkant River originates from Pamir, Karakoram Pass in the north slope of Karakoram Mountain, where is full of towering peaks and developmental glaciers, as well as the extremely rare precipitation in plain (Xu et al., 2013). The Yarkant River is a typical ice and snow supply river, in which the multi-year average runoff in Kaqun hydrometric station consists of mean volume of glacial ablation, rain and snow supply. The Yarkant River has two large tributaries, which are Kelchin and Tashkorgan. The Yarkant River is one of the main sources of the Tarim River Basin, supplies accounted for 3.6% (Chen et al., 2003). The occurrence of surface water in this region is strongly related to the climate, hydrological, and geomorphologic factors and human activities (Ayisulitan et al., 2018).

These rivers flow to the basin through three zones. The upstream region in the mountains is the flow accumulation zone, the mountain pass distributed alluvial plains, where are storage zone, the plain area is water consumption zone and the downstream desert area where is runoff disappears, through evaporation and infiltration, so where is disappeared zone. Replenishment of water resources in the Kashgar Region is completely dependent on glacier melt, snowmelt and precipitation in the surrounding mountains (Chen et al., 2016). However, water resources are unevenly distributed. Against the background of global warming, relies on mountain meltwater and precipitation as the basis of its water resources system results this area ecosystem is very fragile, which is reflected by the marked increase in hydrological events (Chen et al., 2016; Sun et al., 2014). The long-term variation sequences at the three hydrological stations (Karbel, Kirik, and Kaqun station) showed that the annual runoff has been an increased trend (Figure 2.5).

In mountains areas, drainage systems are highly developed and winding due to controls by geological structures. Water from melting of ice and snow discharge into plain only a few outlets along the basin border, where it forms Kashgar and Yarkant Rivers. The surface water system leaked a large number of river channels and channels after the mountain pass, which formed abundant groundwater resources in the area (Zhu et al., 2005).

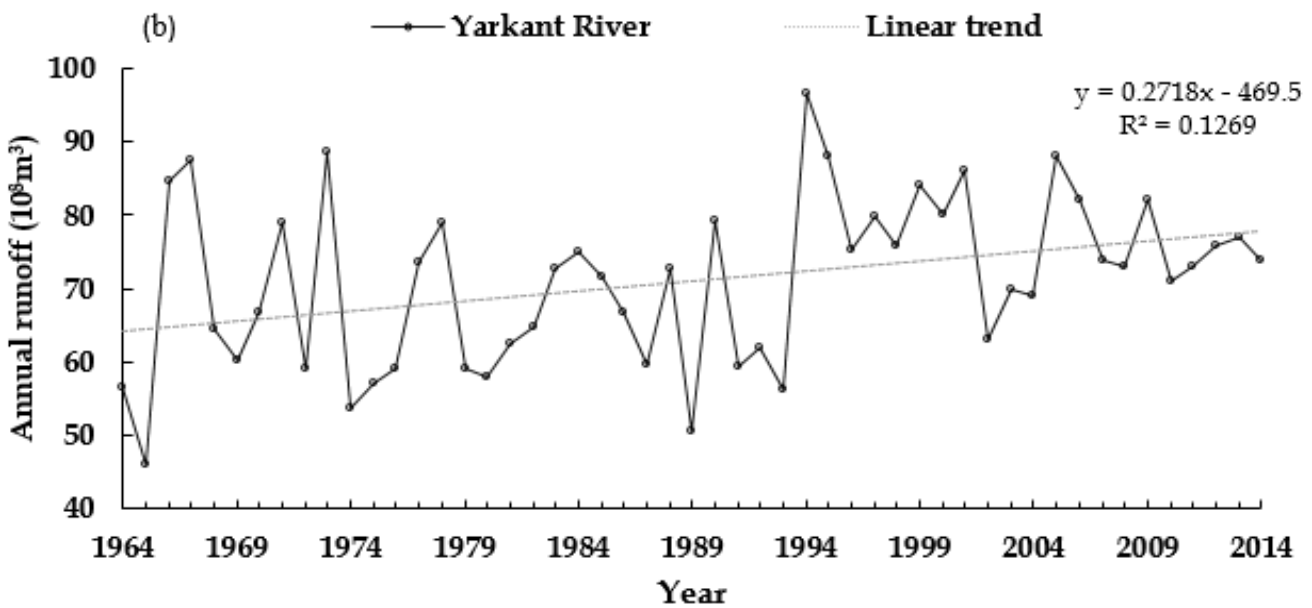
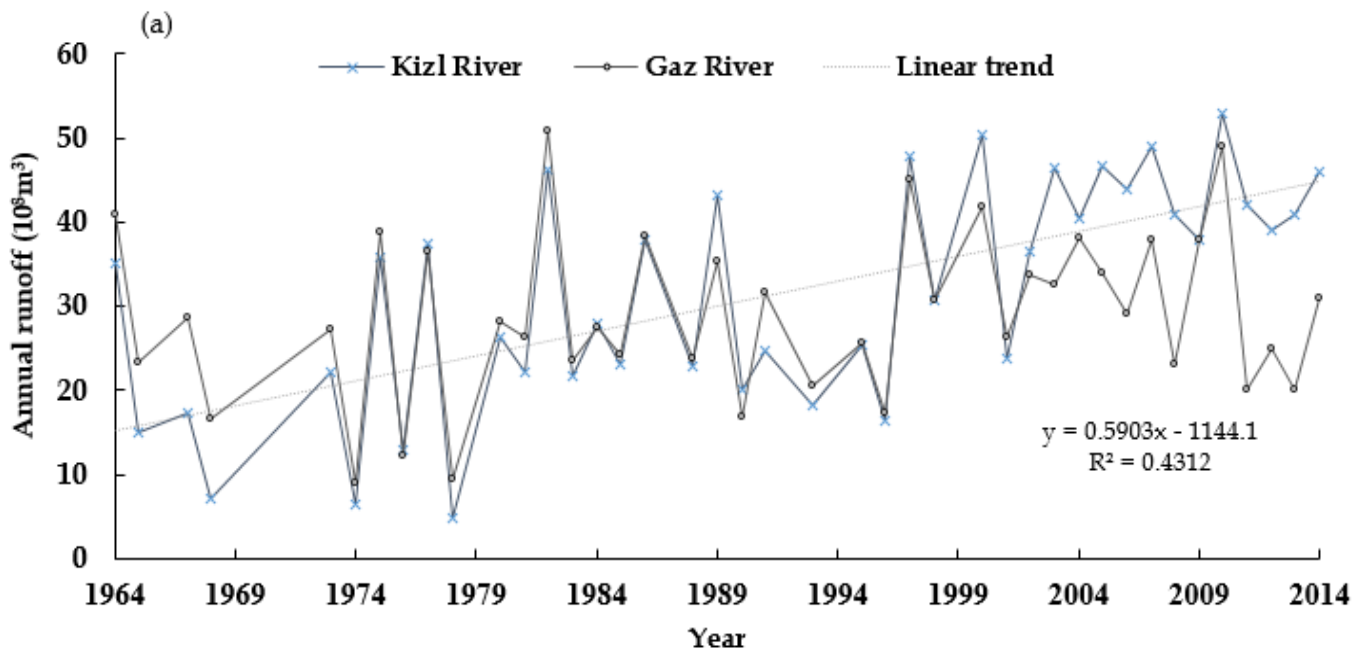


Figure 2.5 Annual runoff variation of Kashgar (a) and Yarkant River (b)
 Data received from hydrological stations of Kashgar Region. (a) kizil and Gaz rivers are represented Kashgar River, (b) is represented Yarkant River. Both rivers have been increased significantly ($p < 0.05$) during the observation period.

However, the destruction of environments has dramatically changed the natural hydrological systems distribution of surface runoff. Resulted in shrinking and drying up of some rivers and lakes (Nian et al., 2001). The most overexploited and loss of surface water resources evaluated based on hydrological data as shown in Table 2.2 (Nian et al., 2001).

Table 2.2 Loss of surface water

Type of Loss		Amount	
		(10 ⁸ m ³ /year)	%
Leakage	Leakage inside 20-40 km of river bed of upper reaches	33.72	30.04
	Leakage of middle, lower reaches, canal, reservoir	39.04	34.78
	Filed leakage	3.74	3.33
	Total leakage	76.50	68.15
Evapo-Transpiration	Soil and shallow groundwater evaporation and transpiration	24.65	21.96
	Lower reaches reservoir storage	5.10	4.54
	Discharge to Tarim River	6.01	5.35
Total		112.26	100

*Data adapted by Nian et al., (2001)

The geology formation of Kashgar Region includes several strata characteristics: First the Proterozoic (Pt), which are distributed in the territory of the Akjorda Sakamoto, Kirik River and other places of Kashgar Region, because they are in contact with some of the strata, the lower limit has not been identified. The main rocks are schist, marble, quartzite, etc., to form the crystallization base of the area. Second, Paleozoic (Pz) is mainly distributed in the West Kunlun Mountains region, located in the south of Yarkant County and TashKorgan County in the vast area. The main lithology is medium - shallow metamorphic schist, phyllite, marble, sandstone, etc., the composition of the cap area. Third, the Mesozoic (Mz) is sporadic in the Mesozoic strata between the Tianshan Mountains, the Kunlun Mountains and the northern Kunlun Mountains. Five, the Jurassic (J) is the most widely distributed and is coal-bearing strata. Six, the Cenozoic (Cz) is mainly distributed in the plains, desert areas and river areas, including the alluvial plains and oases for the survival of the people of Kashgar, mainly by the Quaternary sand, Clay, gravel and other components. The basin is filled with Quaternary alluvium. Windborne sediment covers the alluvial plain with a thickness of 30-150 m and forms the Taklamakan Desert. Infiltration of surface runoff is the principal source of groundwater recharge in the Kashgar Region. Six types of infiltration occurrences resulting in groundwater recharge in the Kashgar Region are shown in Table 2.2.3.

Table 2.3 Source of groundwater recharge

Source	Amount of recharge (10 ⁸ m ³ /year)		
	To phreatic groundwater	To confined groundwater	Total
1.Uderflow of rivers at mountains passes	1.66	6.66	8.32
2.River seepage at upper reaches of rivers	6.74	26.98	33.72
3.River, canal, reservoir seepage at upper and middle reaches of rivers	8.20	30.84	39.04
4.Irrigation seepage in farmland	3.74	-	3.74
5.Lateral recharge at bases of mountain	1.04	1.55	2.59
6.Rainfall seepage in hill county at fringes of basin	0.76	1.13	1.89
Total	22.14	67.16	89.30

*Data adapted by Nian et al., (2001)

The groundwater supplied mainly by surface runoff as Table 2.3 showed, the replenishment by rainfall is of not much significant to groundwater in the Kashgar Region due to less precipitation and arid climate. In addition, the irrigation area, surface water is transformed into groundwater through infiltration not only via natural river way but also via canals, reservoir and field irrigation. The geographical distribution of surface water has changed due to increasing human activities in the recent decades, which have affected the replenishment of groundwater and led to changes to the table and the quality of groundwater (Mansuer et al., 2011). For example, the Kashgar Region established 96 reservoirs already, with a total capacity of $1.891 \times 10^9 \text{m}^3$. But, the evaporation rate of reservoir water is 48%, and the infiltration rate is 10%. The utilization ratio of water by the reservoir is only 30~50%. Moreover, the Kashgar Region established 40~70 wells, and their total yields range from $0.5 \sim 1.2 \times 10^8 \text{m}^3/\text{year}$. The original balance of groundwater is broken by the infiltrate water, and within the context of global warming, the growth of population and economic development activities, ecological and economic issues in the courses of exploiting groundwater resources. The amount of water diversion to the irrigation region is a lager, which caused the groundwater table to rise.

2.4 Climatic features of study area

The study area is located in between the range of $71^\circ 39' \sim 79^\circ 52'$ E and $35^\circ 28' \sim 40^\circ 18'$ N and is a mid-latitude zone in the hinterland of the Eurasian landmass. The climate is deeply affected by the role of plateau uplift, westerly circulation and the East Asian monsoon, which creates a unique climate system. The water vapour comes from the Indian Ocean and the Arctic Cold front has difficult to penetrate, which affected by the role of uplifted high mountains and its barriers. Thus, the study area characterized as the typical inner-continental climate with low precipitation of less than 100mm and

evaporation of higher 2000mm per year in the plain. Annual average temperature of 0°C, 3.5°C, 11°C and 12.2°C for the mountain, oasis, and desert area, respectively. Annual average precipitation of less than 500mm in the mountain Kulun, 70mm in the mountain Pamir, 45-55mm in the plain, and less than 40mm at the desert prevails (Luo et al., 2003).

There are four distinct seasons in the study area. Winter is short. January is the coldest month in the study area. Summer is long. The average yearly temperature is 11.8°C. The average temperature at that month is -6°C, and July, the hottest month with the average temperature of 27 °C. The average rainfall here is the only 121mm, but the evaporation capacity amounts to 2162 mm.

2.5 Population and agricultural structure of study area

Kashgar Region includes one city and 11 counties (Figure 2.6), which are Kashgar City and Konasheher, Yengisheher, Yëngsar, Poskam, Yarkant, Kargilik, Mekit, Yopurga, Payziwat, Maralbeshi and Tashkorgan County. The dry land urban landscape - Kashgar city the biggest city in this region, characterized with high populating rate, weak ecosystem and rapid urbanization with artificially constructed elements such as roads, factories, residential areas, parks.

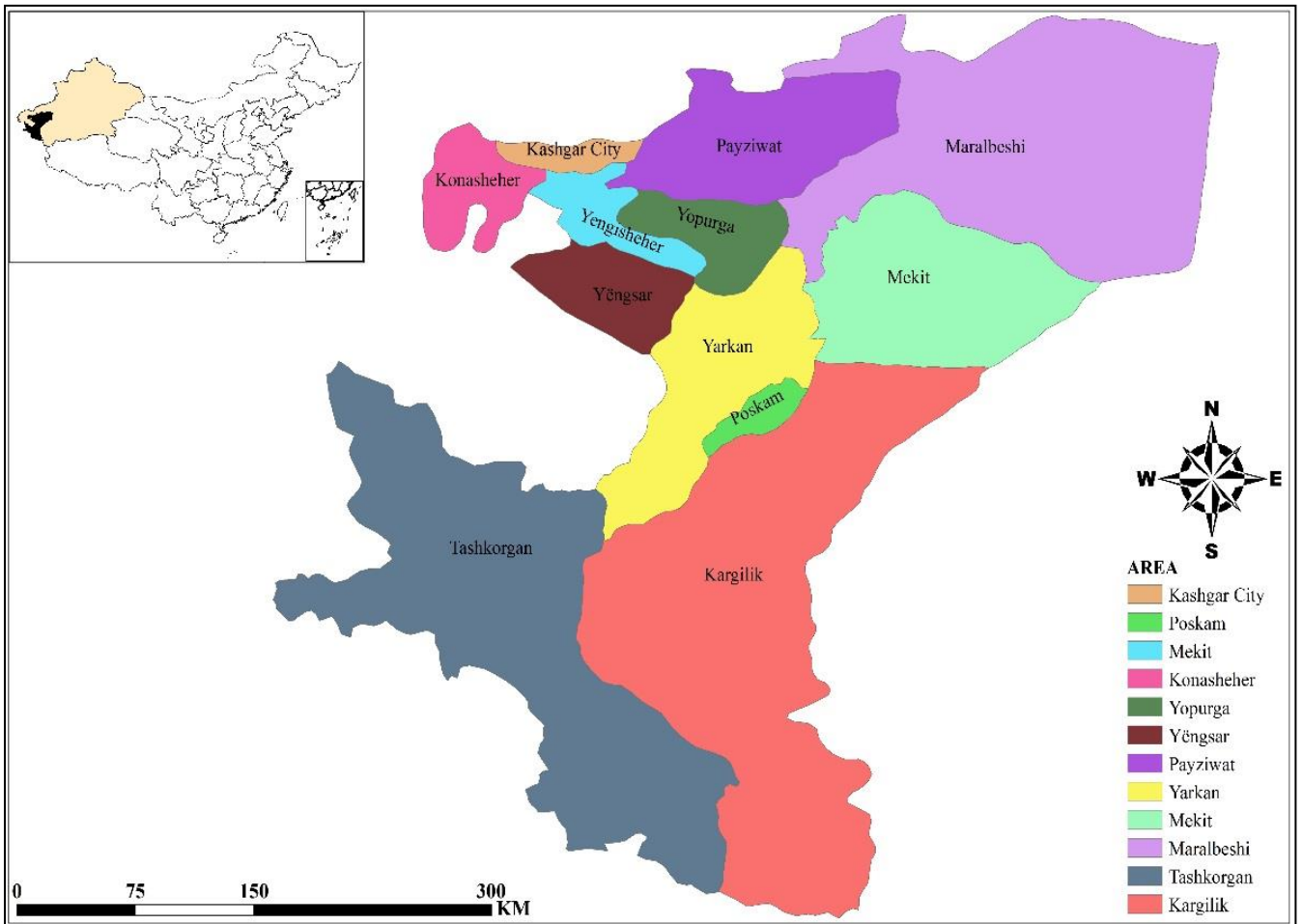


Figure 2.6 Administrative divisions of study area

Kashgar Region administrative divisions are divided one city and 11 counties. Kashgar City (orange) is one of the big cities in Xinjiang. Among the counties, Yarkant (yellow) is one of the big counties of Kashgar Region.

Table 2.4 Demographic changes of Kashgar Region

The population rose from 2,745,362 in 1988 to 4,700,200 in 2014 (XJSYB), increased by 45% during the year.

District	1989	1999	2009	2014
Kashgar city	219,808	311,141	458,900	470,200
Yengisheher	10,732	71,554	101,200	290,000
Konasheher	60,093	17,732	31,300	370,000
Yëngsar	16,382	22,005	28,600	230,000
Poskam	29,423	30,030	55,600	180,000
Yarkan	177,713	244,826	325,500	620,000
Kargilik	77,778	109,576	111,700	370,000
Mekit	21,586	32,950	66,100	210,000
Yopurga	12,328	16,999	44,200	140,000
Payziwat	17,985	27,158	44,700	330,000
Maralbeshi	63,206	79,285	116,900	390,000
Tashkorgan	4,005	6,202	13,400	30,000

*Data compiled from XJSYB 1989-2014

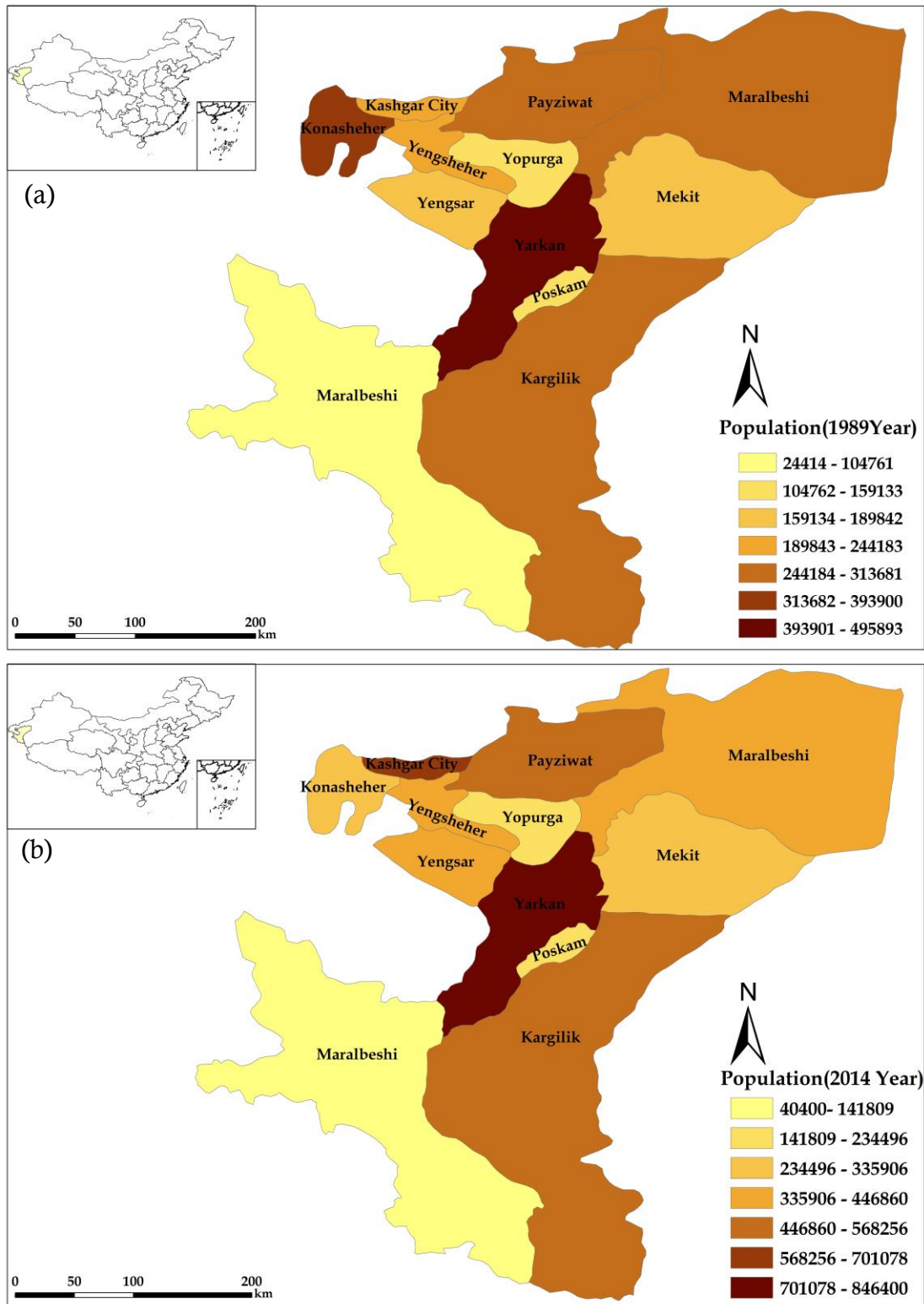


Figure 2.7 Population distribution of study area in 1989 (a) and in 2014 (b)
 The population of Kashgar City and Yarkant County are high. Population increased remarkably at Yopurga, Payziwat and Yingsar in 2014.

According to the XJSYB statistics (2015), population of study area has been increasing as Table 2.4 shown. The population of rose from 2,324,375 in 1984 to 4,700,200 in 2014 (XJSYB), increased by 45% during the year. Figure 2.7 shows population distribution map of Kashgar Region in 1989 and 2014 respectively. Especially, population of Payziwat, Yopurgan, Yengsar and Yengshehar have been increasing very remarkably.

The Kashgar Region relies to a great extent on farming activities for economic development and about 90% of the labour forces engaged in agricultural activities, as intensive farming and raising livestock. Agriculture output value was accounted for 73.2% of the Gross Domestic Product (GDP) (Chen et al., 2015) and agriculture mainly relies on irrigation, which accounts for 91.8% of total water consumption (Anwaer et al., 2010).

Physical conditions of Kashgar Region, abundant radiation and heat resources, make it an ideal place for crop growth, such as wheat, maize, side crops, barley. Especially, cotton is the main and staple crops in the region (Figure 2.8). Wheat is usually rotated with maize each year and is usually planted in early October and harvested in Jun. The maize is sown shortly before or immediately after the wheat is harvested. The fast-economic growth also brings to cotton cultivation, due to the cotton price rise in the market. Kashgar Region has accounted for 43% of Xinjiang cotton production.

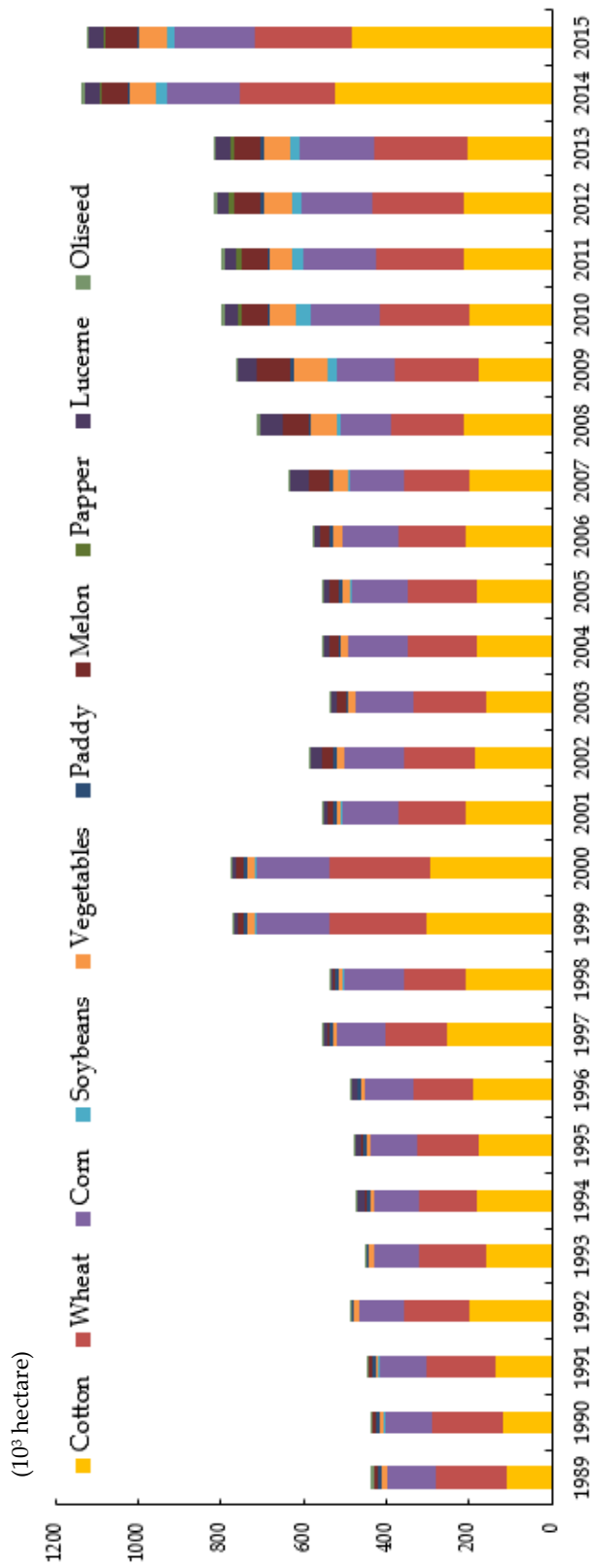


Figure 2.8 Main agricultural plants area of study area (1988 – 2016)

Data from Xinjiang Statistical Yearbook. Each crop of the Kashgar Region has been increased. Previous time (1989 -2000) cotton and grain production were the main. Cotton had been increased from 1989 to 2000, then been stable from 2002 to 2013. Currently (2000- 2014) besides grain and cotton cultivation, vegetable, melon, and soybeans area increased.

Chapter 3. Materials and Methodological approaches

3.1 Data description

In this study, we used five types of data, which are involved: (1) Satellite data, which are Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operation Land Imager (OLI), SPOT VGT multi-spectral 10-day synthesis products and ASTER Global Digital Elevation (GDEM). (2) Hydrological data are including annual runoff, provided from hydrological stations of Kashgar (3) Meteorological data, such as annual (data from meteorological station 1964-2014) and monthly (CRU. 4.01, (1981-2014) temperatures, precipitation (Harris et al., 2014). (4) Socioeconomic-related statistical data, such as population, GDP, primary industry and sown area, these datasets were extracted Xinjiang Statistical Yearbook (XJSYB) from 1984 to 2014. (5) Reference data included Google Earth High-Resolution images, Global 30m Land Cover and GDEM. The datasets are summarized in Table 3.1.

1. Landsat datasets

The Landsat Multispectral Scanner 60 m (MSS) (1972), Thematic Mapper 30 m (TM) (1990), Enhanced Thematic Mapper Plus (ETM+) 30 m (2000), and Operation Land Imager (OLI) 30m (2014) were in Universal Transverse Mercator (UTM) projection Zone 44 and the WGS 84 ellipsoid, as shown in Table 3.1. The Landsat datasets are available the Global Land Cover Facility (GLCF) <http://glcf.umd.edu> and the U.S. Geological Survey (USGS) Centre for Earth Resources Observation and Science (EROS) <http://glovis.usgs.gov/>. These datasets were used to produce LC maps and to quantify the LUCC classes of the study area from 1972 to 2014. The acquisition data ranged between summer seasons. Kashgar Region has covered expand the area, therefore 12 images applied for one scene, a total of 48 Landsat images were applied.

Table 3.1 Information of datasets used in this study

Data Category	Sensor	Date	Resolution	Path/Row	Sources of data
Remote sensing data	MSS	1972(From Jun to October)	60m	P147R32~P149/35	USGS
	TM	1990 (From Jun to September)	30m	P147R32~P149/35	
	ETM+	2000 (From Jun to September)	30m	P147R32~P149/35	
	OLI	2014 (From Jun to September)	30m	P147R32~P149/35	
			1 April 1998-	E74°39~79°52	
	VEGETATION (VGT)	31 May 2014	1km	N35°28~40°18	
Hydrological data (annual runoff)	-	1964-2014	Station data	-	Karbal, Kirik, Kaqun Stations
Meteorological data (annual temperature, precipitation)	-	1964-2014	Station data	-	Kashgar, Yarkant, Maralbeshi and Tashkorgan stations
Climate Research Unit (CRU. 4.01)		1981-2016	0.5°×0.5°		Kashgar, Yarkant, Maralbeshi and Tashkorgan
Statistical data		1984-2014			Xinjiang Statistical Year Book
Reference data	11 August 1972 Landsat	1972-2014	1972/08/11	P147R32~P149/35	
	29 June 1973 Landsat		1973/07/29		
	31 August 1990 Landsat		1990/08/31		
	31 December 2000 Landsat		2000/12/31		
	31 July 2013 Airbus		2013/07/31		
	6 August 2013 Airbus		2013/08/06		
	25 May 2014 Airbus		2014/05/25		
	10 June 2014 Digital Globe		2014/07/10		
	19 September 2014 Digital Globe		2014/09/19		
	ASTER GDEM	17-Oct-2011	30m	P147R32~P149/35	USGS
	GLC 30m (Landsat TM and ETM+)	2000, 2010	30m		

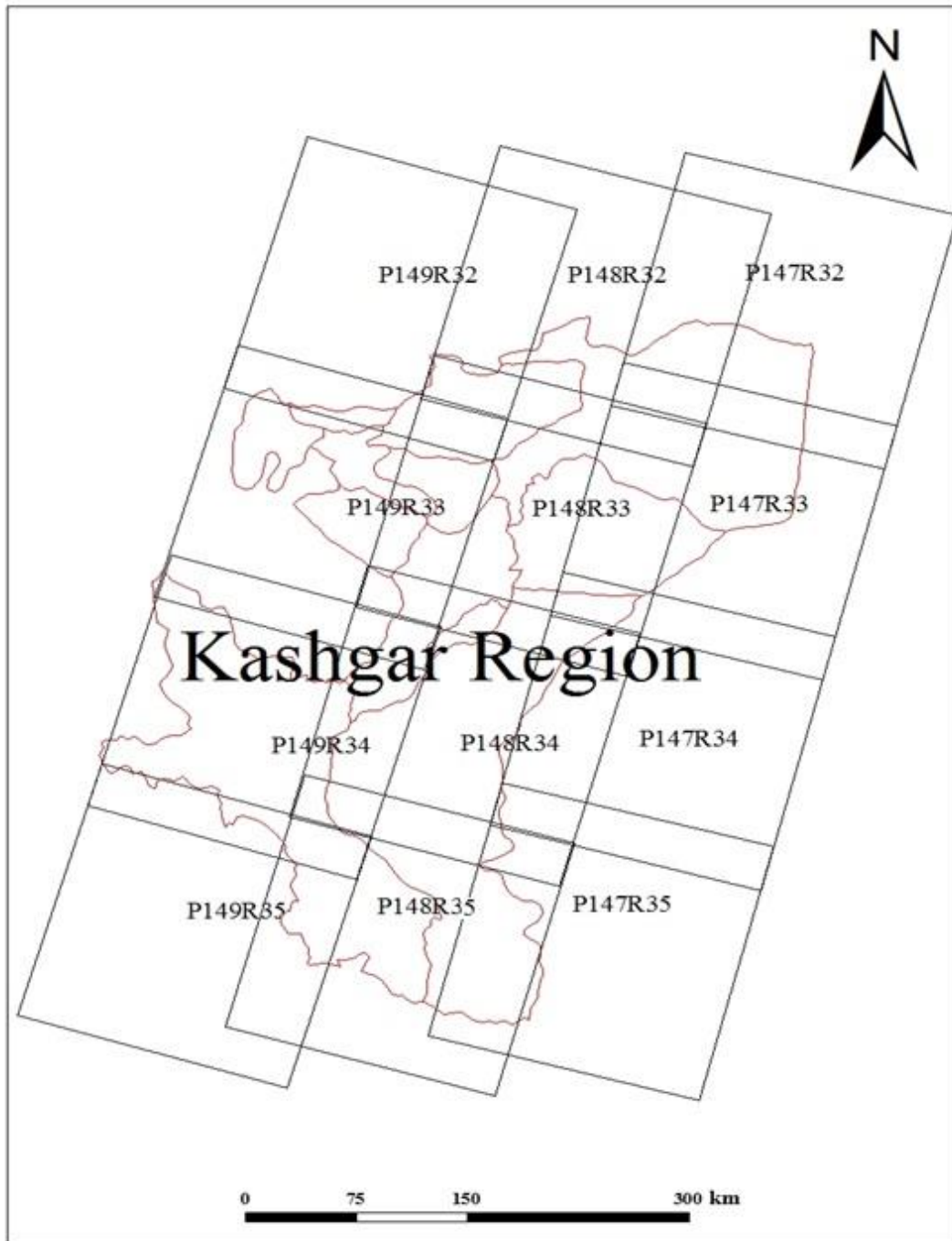


Figure 3.1 Landsat for Kashgar Region, path/row scene Footprints
 Rectangle represented the cover area of Landsat. Kashgar Region is covered
 by 12 Landsat images.

2. SPOT VEGETATION data

Landsat's orbital pattern provides opportunities to collect imagery at high resolution 30 m. However, its revisit interval is 16 days, and obtaining cloud-free images in winter seasons are difficult. To investigate spatial distribution and temporal variability of snow cover with a 10-day composite, we chose as preferred data SPOT VGT, due to its high temporal resolution and cloud-free conditions. SPOT-VEGETATION is a sensor on board of the SPOT-4 satellite, operational since 24 March of 1998 (<http://www.spot-vegetation.com>). It is a joint project of the European Commission, OSTC (Belgian Office of Scientific, Technical and Cultural Affairs), and CNES (Centre National' Etudes Spatiales), SNSB (Swedish National Space Board) and ASI (Agenzia Spaziale Italiana). The VGT instrument is one of a new generation of space-borne optical sensors that were designed for observations of vegetation and land surfaces. The VGT instrument has four spectral bands: B0 (blue, 0.43–0.47 μm), B2 (red, 0.61–0.68 μm), B3 (near infrared, 0.78–0.89 μm) and SWIR (mid-infrared, 1.58–1.75 μm), which are equivalent to Landsat Thematic Mapper (TM) bands 1, 3, 4, and 5, respectively (Xiao et al., 2001). The VGT data provides daily coverage of the globe at 1-km spatial resolution. Unlike scanner sensors (e.g. AVHRR), the VGT instrument uses the linear-array technology and thus produces high-quality imagery at the coarse resolution with greatly reduced distortion. The SPOT-4 satellite carries both the VGT sensor and High-Resolution Visible and Infrared sensor (HRVIR); both use the same geometric reference system and identical spectral bands to facilitate multi-scale interpretation. Three standard VGT products are available to users: VGT-P (physical product), VGT-S1 (daily synthesis product) and VGT-S10 (10-day synthesis product). The spectral bands in the VGT-S1 products are estimates of ground surface reflectance, as atmospheric corrections for ozone, aerosols and water vapour have been applied to the VGT-P images

using the simplified method for atmospheric correction algorithm (Rahman & Dedieu, 1994). There are three 10-day composites for 1 month: days 1–10, days 11–20, and day 21 to the last day of the month. The ten-day synthesis product that composite Maximum Value Composite (MVC), this approach helps minimize the effect of cloud cover and variability in atmospheric optical depth. The data were downloaded from the VITO from April 1998 to May 2014 (<http://www.vito-eodata.be/>).

2. Hydrological data

The long-term annual runoff data (1964-2014) were obtained from Kashgar Hydrological station. The hydrological team at the Kashgar office provided a list of stations, which are Karbel ($E75^{\circ}20'/N39^{\circ}55'$), Saman ($E75^{\circ}65'/N37^{\circ}05'$), Kirik ($E75^{\circ}38'/N38^{\circ}8'$), and Kaqun ($E76^{\circ}90'/N37^{\circ}98'$) stations (Figure 3.2) located in study area.

3. Meteorological data

Due to the distinctive characteristics of temperature and precipitation in the mountain, plain and desert, selected four meteorological observation stations, which are Kashgar (1288.7m, at the northern region), Maralbishi (1116.5m, at the east region), Yarkant (1231m, at the south region), and Tashkorgan (3093.7m, on the mountain region) (Figure 3.2), where provided annual temperature and precipitation from 1964 to 2014.

4. Climate Research Unit (CRU. 4.01) data

The monthly temperature and precipitation dataset used in this study, the CRU. 4.01 climate dataset obtained from the Climatic Research Unit at the University of East Anglia spans the twentieth century and thus covers this study period (1982-2016) (Harris et al., 2014). This gridded dataset with a spatial resolution of $0.5^{\circ}\times 0.5^{\circ}$ was based on climate observations from more than 4,000 meteorological stations.

5. Statistical data

The data of population, GDP, cultivated land area, primary industry output value, per capita agricultural consumption, water consumption, and industrial output value were extracted from Xinjiang Statistical Yearbook (XJSYB) from 1988 to 2017.

6. Reference data

The GDEM 90 m by the Shuttle Radar Topography Mission (SRTM) of the National Geospatial-Intelligence Agency (NGA) 2010 were used in this study. These data are available at the Global Land Facility (GLCF) <http://glcf.umd.edu>. Google Earth was used to perform the accuracy assessment for output resulted from LC maps. In addition, the Global Land Cover (GCL) mapping at 30 m resolution maps in 2000 and 2014 used for accuracy assessment of LC maps in 2000 and 2014 (Chen et al., 2015)

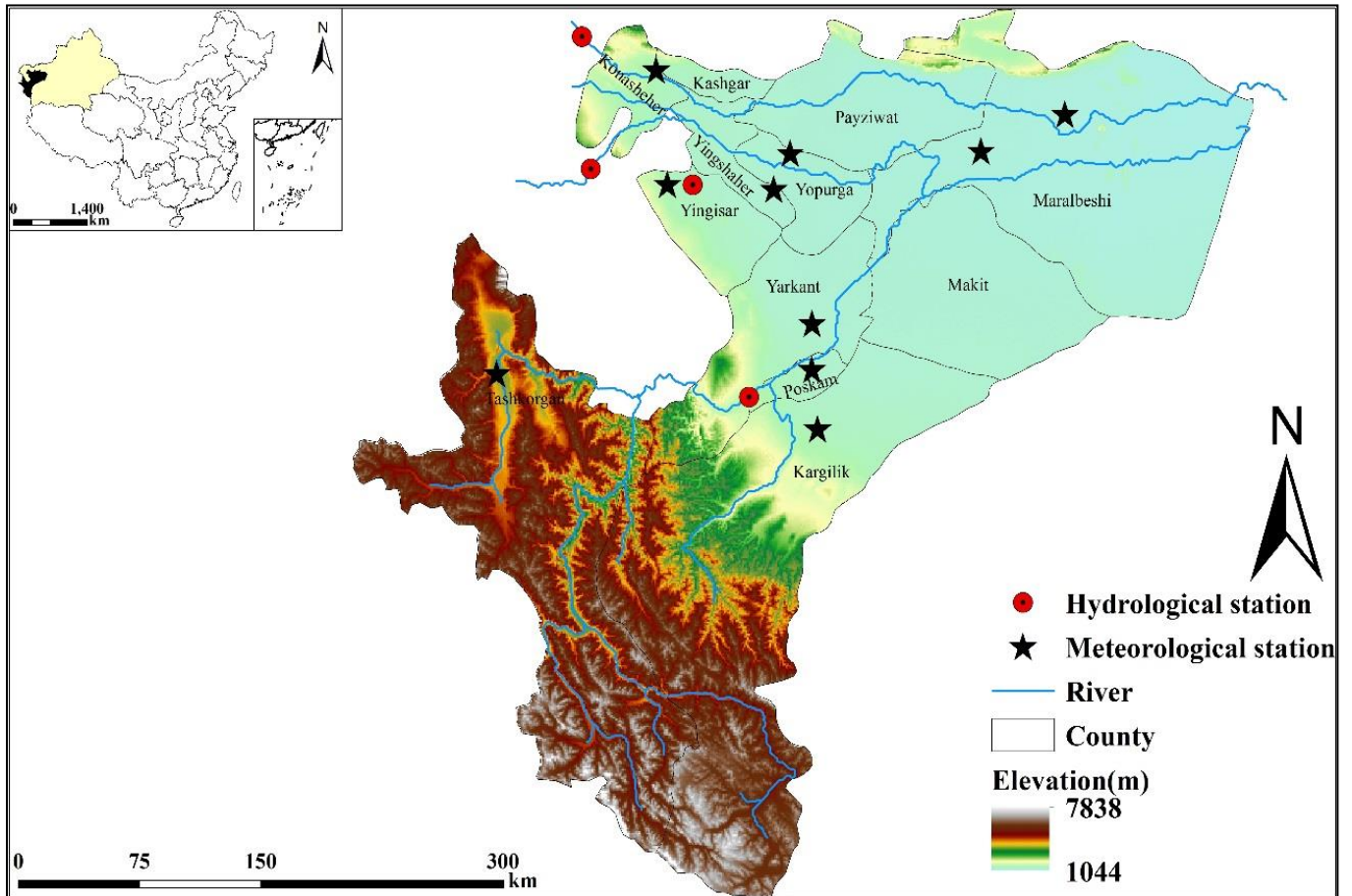


Figure 3.2. Hydrological and meteorological stations location map of study area. Red circle with black points represented hydrological stations, which are located in mountain pass area in Kashgar Region. The black stars are a meteorological station.

3.2 Methodology

3.2.1 Methodology for generate LC maps and quantify its LC classes

The following flowchart (Figure 3.3) showed a methodology process in this study. At the first methodology is to produce land cover (LC) maps at regional scales, using Landsat (MSS, TM, +ETM and OLI) and then estimated snow cover area by SPOT VGT 10-day synthesis product.

Image processing of Landsat data sets:

(1) Pre-processing:

Based on the morphology and landscape of study area and personal experience, possible appearance of land cover types was considered as 21 classes (Table 3.3). A hierarchical classification system of 21 land cover classes were grouped into 7 aggregated classes of land cover, which are urban/built-up area, water area, cultivated land, forest land, grassland, snow/ice (consider only in summer time) and bare land. Decided these classes information was extracted using combined with image segmentation and maximum likelihood classification method (Figure 3.3). A total of 48 Landsat images were acquired during summer seasons with cloud-free condition. Under pre-processing, geometric correction was applied 40 well-conditioned ground control points (GCPs), which were determined from Landsat ETM+ 2000 carried out using ArcGIS. The root mean square (RMS) errors were less than 0.5 pixels for MSS (60m), TM, ETM+ and OLI (30m) images. During the image-to-image registration, the MSS data were resampled from a 60 m to 30m cell size using the nearest neighbour method so that all the data had same cell size at 30m. All images were geometrically corrected, with reference system of UTM map projection Zone 43 North on WGS 1984 datum.

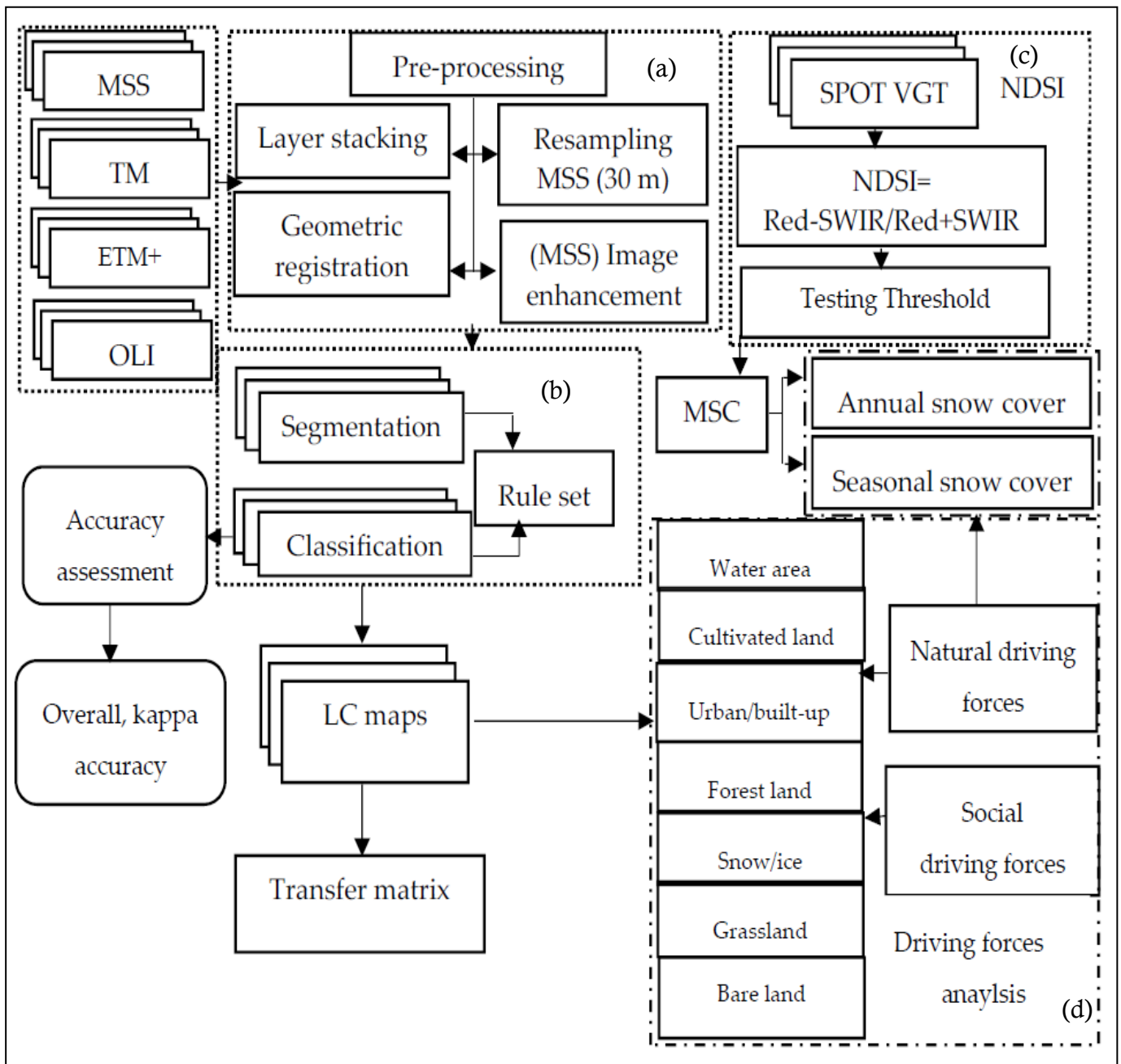


Figure 3.3 Methodology flow chart of this study

First step (a) image pre-processing, second step (b) is image segmentation and classification. The third step (c) is snow cover area estimation. Finally, analysed driving forces.

(2) Image segmentation:

In order to obtain accurate mapping of land cover on a regional scale, image segmentation was implemented first by using eCognition software for purpose of creating objects that delineated LUCC classes. After finish pre-processing, the band-stacked images are segmented that initial step into groups of pixels, as objects as Figure 3.4 showed. Landsat images are at 30m resolution, cultivated land and grassland are very difficult to distinguish and extract more accurately, and even they have different spectral information. Steiner (1970) reported that a combination of the two techniques produced superior results. Therefore, we combined two classification method (image segmentation method and maximum likelihood classification method). First, created a homogenous group of pixels based on cultivated land and grassland size, shape and area those are called image objects. Then, the multi segmentation method utilized as object-based classification, because it generates objects, resembling ground features very closely (Definiens, 2006). This technique is useful in establishing boundaries between patterns, which were recognized, based on similar properties, such as cultivated land and grassland two levels for the segmentation and classification process were applied based on cultivated land and grassland classes. When the segmentation scale is not appropriate, the image can be under or over segmented (Frohn et al., 2011). The segmentation means that the image-objects are large than the objects on the ground while over segmentation results in more subdivision. Under segmentation affects classification accuracy by increasing the chances that two or more land covers will be included in one large image object, thus resulting in errors of commission (Darius and Justin, 2017). Therefore, based on the available studies on Landsat classification with segmentation, the range for segmentation scale for Landsat MSS is 5-10 (Dorren et al., 2003), Landsat TM, ETM+ and OLI the range is 5-20 (Tewolde et al., 2011; Darwish et al., 2003). For all these images,

the other segmentation parameters, shape and compaction, were reported to be 0.1-0.5 and 0.5-0.8 respectively (Kindu et al., 2013; Tewolde et al., 2011). We considered Level one and Level two approaches; Level 1 was applied for small and spread land cover classes, as grassland. The scale parameters were set as 5. Level 2 was applied for large land cover classes, as cultivated land, was setting 10. The colour and shape parameters were adjusted to 0.9 and 0.1 (Yu et al., 2016). We got vector data with better reflected those real study area (Figure 3.5). Finally, extracted grassland and cultivated land.

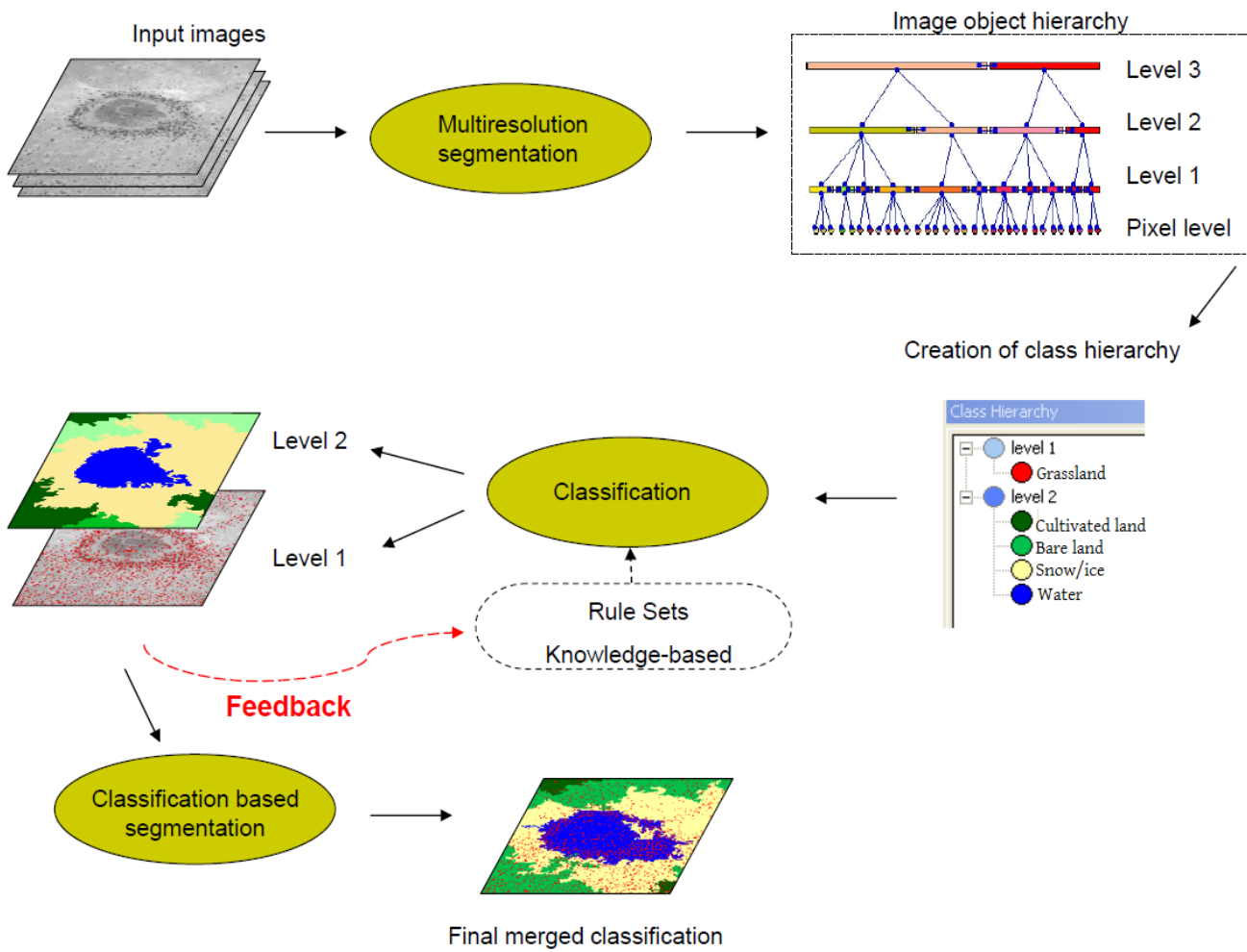


Figure 3.4 Workflow in eCognition software

The image segmentation steps, first, image segmented using multi-resolution segmentation techniques. Then, divided two level, level one is small scale land cover types (grassland) level two is big scale land cover types (cultivated land).

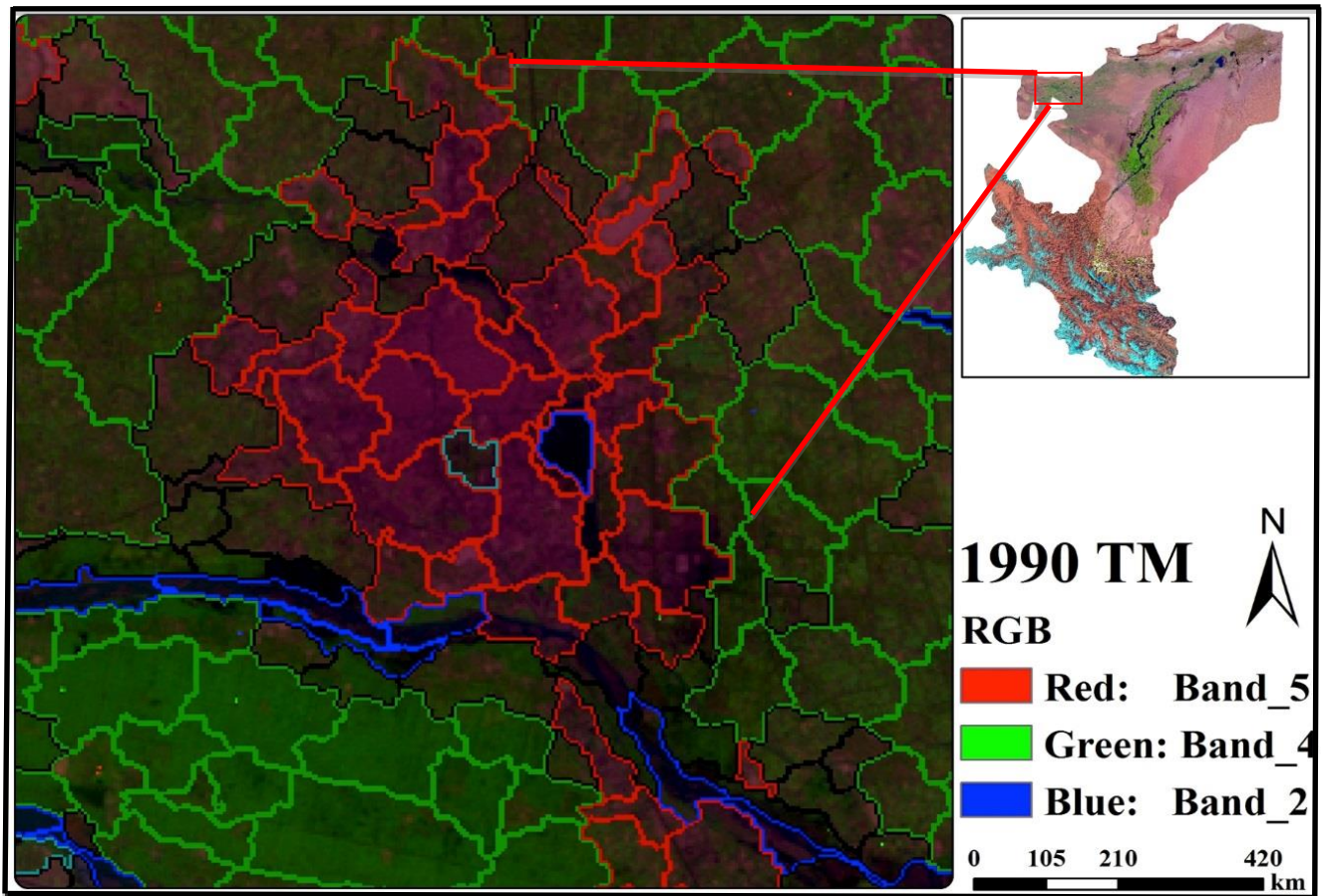


Figure 3.5 Segmentation of TM in 1990

This map showed segmented images, green is cultivated land, blue is a river, red is urban.






(3) Maximum likelihood Method

The colour composites for all images generated from Landsat MSS bands 4, 2, and 1, for TM, ETM+ bands 7, 4, and 2 and Landsat OLI bands 7, 5, and 3 displayed as in red, green, and blue (RGB) channels, respectively. These colour composites had chosen in order to assist the visual interpretations and analysis of each class of LUCC. In order to get high classification results, after segmentation was finished, other land cover type extracted by a supervised classification method. The maximum likelihood classification algorithm was performed using carefully selected from the original Landsat data training samples. We randomly selected 2000-8000 training sample pixels for each per land cover class (Table 3.2), respectively. We collected additional samples for validation and accuracy assessment by Google Earth high-resolution images (Table 3.3). In addition, we applied post-classification refinements for each the results reduce classification errors.

Table 3.2 Land use classification system

1st level	2 nd level classes	Descriptions
1.Cultivated Land		Cultivated lands for crops. Including: mature cultivated land, newly cultivated land, and fallow, shifting cultivated land; intercropping land such as crop-fruiter in which a crop is a dominant species;
		Cropland that has enough water supply and irrigation facilities for planting paddy rice, lotus etc., including rotation land for paddy rice. Crop fields, cotton fields, vegetable lands
2. Forest		Dense forest, Scrubland, Sparse forest, Orchards, Shrub land
3. Grassland		Dense grass, moderate grass, spare grass
	–	Lands covered by natural water bodies or lands with facilities for irrigation and water reservation.
4.Water body	Stream /rivers	Lands covered by rivers including canals.
	Lakes	Lands covered by lakes.
	Reservoir	Man-made facilities for water reservation and ponds
	Urban built-up	Lands used for urban and rural settlements, factories and transportation facilities. Lands used for urban.
5.Built-up land	Rural settlements	Lands used for settlements in villages.
	Others	Lands used for factories, quarries, mining, oil-field slattern outside cities and lands for special uses such as transportation and airport.
6. Snow/ice	Snow-Ice	Lands under snow/ice cover for most of the year
	Bare rock	Bare exposed rock with less than 5% vegetation cover.
	Sandy land	Sandy land covered with less than 5% vegetation cover.
	Gobi	Gravel covered land with less than 5% vegetation cover.
	Salina	Lands with saline accumulation and sparse vegetation.
7. Bare land	Swampland	Lands with a permanent mixture of water and herbaceous or woody vegetation that cover extensive areas.
	Bare soil	Bare exposed soil with less than 5% vegetation cover.

Table 3.3 Characteristics of training samples of study area

Class	Vegetation type	Number of pixel	Feature in the RGB/321 Color composite
Forest	Low-greenness vegetation	1694	
Urban /built up land	-	55,967	
Bare land	-	41,474	
Snow/ice	-	4000	
Water	-	53,083	

Because of the cloud situation during wintertime in high mountains, it is difficult to collect cloud-free Landsat images. Therefore, SPOT VGT data chosen for mapping snow cover, due to its high temporal resolution and cloud-free conditions. A detailed description of the snow cover mapping process has provided in the next section.

3.2.2. Accuracy assessment for land cover classifications

Accuracy assessment decides the quality of information derived from remote sensing data. Three comparative analyses were performed to evaluate the performance and accuracy of the method we used. Several images were used from Landsat and high-resolution images of Google Earth, which are reasonably close to 1972-2014, to evaluate LC each classis over time in the study area.

(1) Overall Accuracy

Overall accuracy assessment of image classification used the stratified random sampling design in this study. Reference points were created randomly from classified maps of the study area for 1972 and 2014. A total of 700 points were selected randomly (100 points for each class). The Google earth high-resolution images were used as a reference source to classify the selected points. The reference points were confirmed by the visual interpretation of the reference source, which was the only available reference data for evaluating the accuracy assessment. The confusion matrix calculated (or error matrix), which is usually used as the quantitative method of characterising image classification accuracy. Table 3.4 shows correspondence between the classification result and a reference image. To create the confusion matrix, we need the reference data, such as cartographic information, results of manually digitizing an image, field work/ground survey results recorded with a GPS-receiver. In this study, we used google earth high-resolution images as reference data. An illustration of the confusion matrix is shown in table 3.4. Columns of table 3.4 are the reference classes, and rows of the table are the classes of the classified image to be assessed. Cells of the table showed a number of pixels for all the possible

correlations between the reference data and the classified image, they are highlighted with blue. Diagonal cells contain the number of correctly identified pixels. If we divide the sum of these pixels by the total number of pixels we will get classification's overall accuracy (OvAc). For the confusion matrix shown in Table 3.4 this index will be equal to:

$$\text{OvAc} = (aA + bB + cC) / N = (37 + 25 + 43) / 142 \approx 0,74$$

Another accuracy indicator is the kappa coefficient. It is a measure of how the classification results compare to values assigned by chance. It can take values from 0 to 1. If the kappa coefficient equals to 0, there is no agreement between the classified image and the reference image. If the kappa coefficient equals to 1, then the classified image and the reference image are totally identical. So, the higher the kappa coefficient, the more accurate the classification is.

(2) Visual analysis

The visual analysis category includes a visual interpretation of multi-temporal image composite and results. This method can make full use of an analyst's experience and knowledge (Lu et al., 2004). The results of LC maps in 2000 and 2014 were compared with the Global 30m land cover map in 2000 and 2010, under the assumption land cover did not big changed in 2014, respectively. China's Global 30m Land Cover (GLC) datasets of 30 m resolution produced by the National Geometrics Centre of China for their years 2000 and 2010 (NGCC, 2014). The datasets were generated using satellite images of the Landsat TM/ETM+, the Chinese Environmental Disaster Alleviation Satellite (HJ-1) and other ancillary data. The overall accuracy and kappa coefficients were 79.6% and 0.81 in 2000 and 83.5% and 0.78 in 2010, respectively.

(3) Areal comparison

The quantify results of LC map in 2000 and 2014 were compare with the GLC quantify results in the same year, respectively.

Table 3.4 Example of calculation of confusion matrix

Columns of the table are the reference classes, and rows of the table are the classes of the classified image to be assessed. Cells of the table showed a number of pixels for all the possible correlations between the reference data and the classified image, they are highlighted with blue. Diagonal cells contain the number of correctly identified pixels.

Reference images

	A	B	C	Total
a	37	3	7	$\Sigma a=47$
b	9	25	5	$\Sigma b=39$
c	11	2	43	$\Sigma c=56$
Total	$\Sigma A=57$	$\Sigma B=30$	$\Sigma C=55$	N=142

3.2.3 Estimation of snow cover area

Snow is a form of precipitation, but, in hydrology, it is treated differently because of the lag between when it falls and when it produces runoff, groundwater recharge, and is involved in other hydrologic processes. The hydrologic interest in snow is mostly in mid-to-higher latitudes and in mountainous areas where a seasonal accumulation of snowpack is followed by an often-lengthy melt period that sometimes lasts months. During the accumulation period there is usually little or no snowmelt. Precipitation falling as snow and (sometimes rain) is temporarily stored in the snowpack until the melt season begins. Snowmelt is an important component of any snow-fed river systems. The Kashgar River Systems are one such transnational mountain river flowing through Kashgar Basin. The river and its discharge are largely governed by seasonal snow cover and snowmelt. Therefore, accurate estimation of seasonal snow cover dynamics and snowmelt induced runoff plays a key role due to the extremely arid climate of lowlands.

Snow cover in this study refers to the amount of land cover by snow at any given time. In order to monitor snow cover dynamics on the Kashgar Region, SPOT VEGETATION (VGT) images of April 1, 1998, until May 31, 2014, were used to investigate snow covered areas. Investigation of snow cover area was completed in two steps, including the selection of critical threshold values for Normalized Difference Snow Index (NDSI), and threshold values imply the NDSI index for extracting snow cover information. The data delivered by VITO were in HDF format. For the snow cover extraction, they had to be transformed "tif" first. The methodology flowchart as Figure 3.6 showed SPOT VGT data processing for the estimation of snow cover area. The images have a full cover over East Asia as Figure 3.7 showed. The study area had to be extracted in order to fast up the processing times and lower the storage space by watershed shapefile. The Kashgar and

Yarkant watershed area were extracted by shapefile as Figure 3.8. In order to have the same projection as the shapefile and VGT data (from 1 April 1998-31 May 2014), there is chosen to project the images to GCS_WGS_1984. After, band 2 (red) and band 4 (mid- infrared=VGT SWIR) were used to calculate the NDSI (Kondoh & Suzuki, 2005). The NDSI takes advantage of the difference in reflectance of a snow-covered and snow-free area in the near infrared and shortwave infrared bands (Crane and Anderson, 1984). An algorithm was originally developed from the Moderate Resolution Imaging Spectroradiometer (MODIS) (Hall et al., 1995; Xiao et al., 2001). The NDSI was calculated as follows:

$$\text{NDSI} = (\text{bandRed} - \text{bandSWIR}) / (\text{bandRed} + \text{bandSWIR}) \quad (1)$$

Where Red and SWIR are band 2 and band 4 of reflectance of SPOT VGT. To determine whether a pixel is covered by snow or not, an observed pixel must meet a certain NDSI threshold value. A threshold value of 0.4 has been used to distinguish snow from bright soils, rocks and clouds. Kondoh and Suzuki in (2005) modified the 0.4 of NDSI threshold using an NDVI adjustment to take into account forest effects on snow detection in Northern Eurasia. In this study, the original threshold value of 0.4 underestimated snow-covered areas. Therefore, several threshold values of 0.4, 0.3 and 0.2 were tested for NDSI, and the best agreement was found with a slightly lower threshold value of 0.2 (Figure 3.9). The best agreement for snow and ice pixels extraction using VGT data should correspond to broad snow-cover characteristics of the local area. Thus, a lower threshold value of 0.2 was adopted for VGT snow and ice detection in this study area. Then, 567 stages for the entire duration of time-series VGT data were collected to investigate snow cover changes from April 1, 1998, to May 31, 2014. From the first year of September to next year, August 36 images were composited, representing the annual maximum snow cover area.

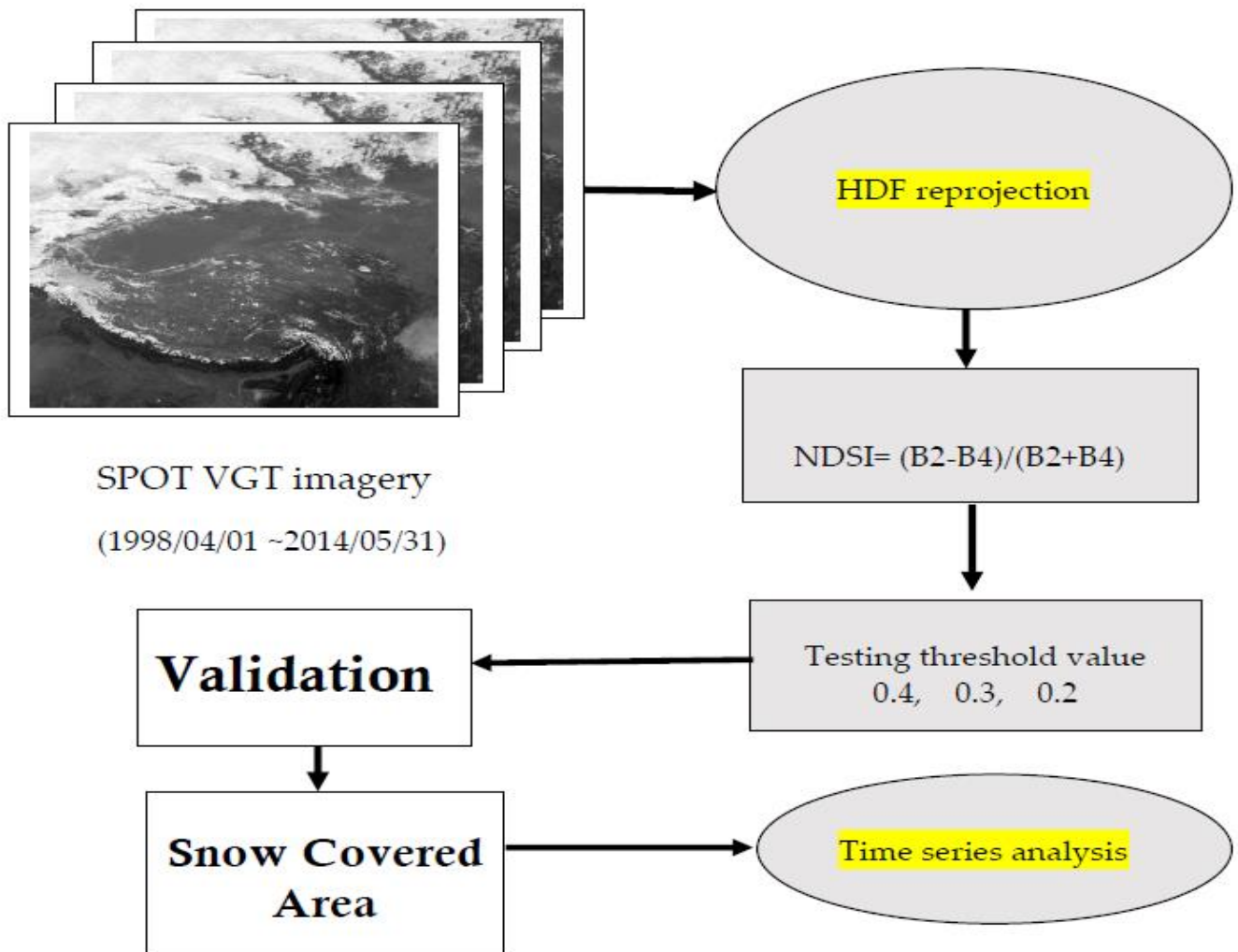


Figure 3.6 Methodology for snow cover area estimation

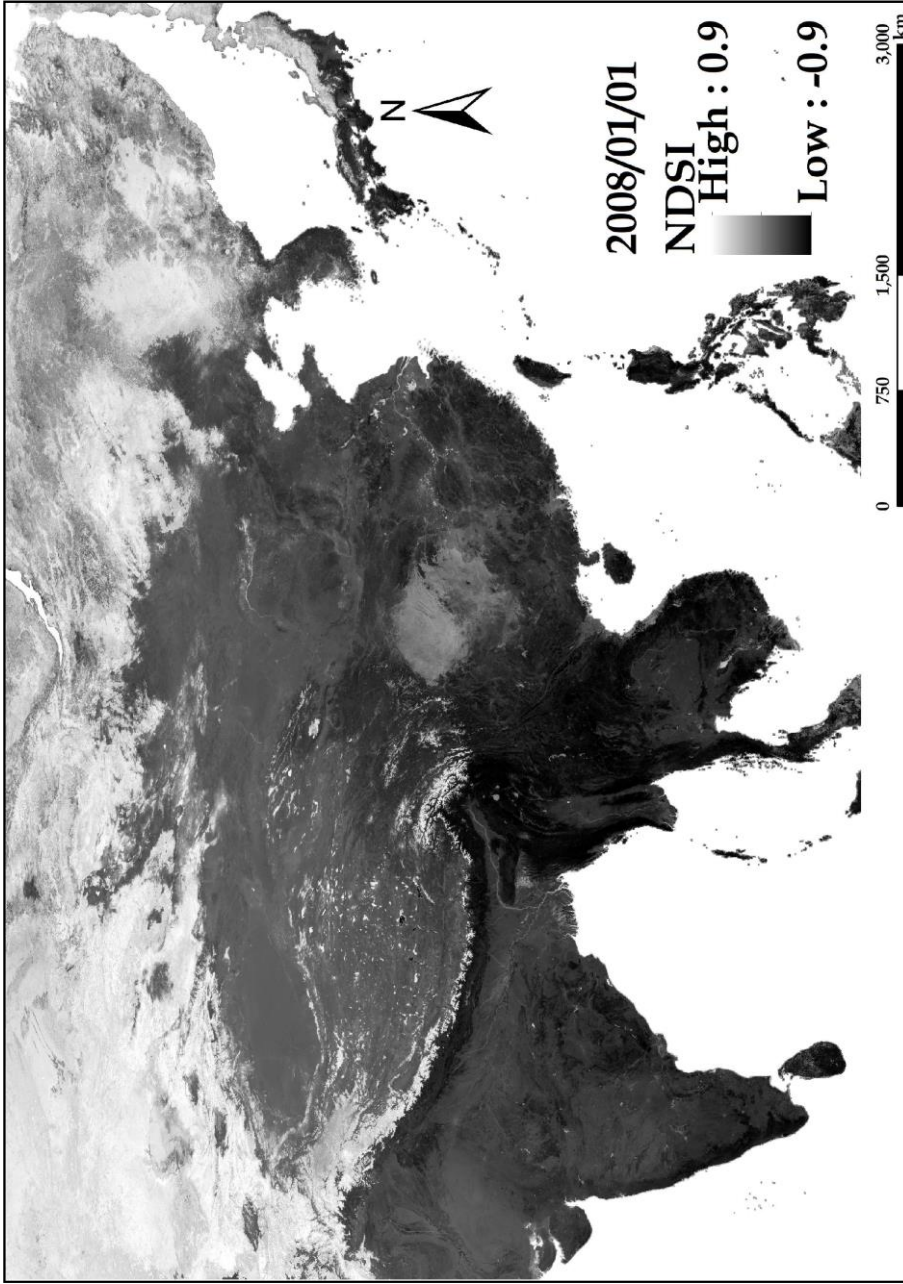


Figure 3.7 Distribution of snow covered area (white) with threshold ≤ 0.2

and snow-free area (black) (First 10-day in 2008)

NDSI ≤ 0.2 . NDSI value is high, means high snow covered area. NDSI value is low, smaller than 0.2, which means no snow covered area.

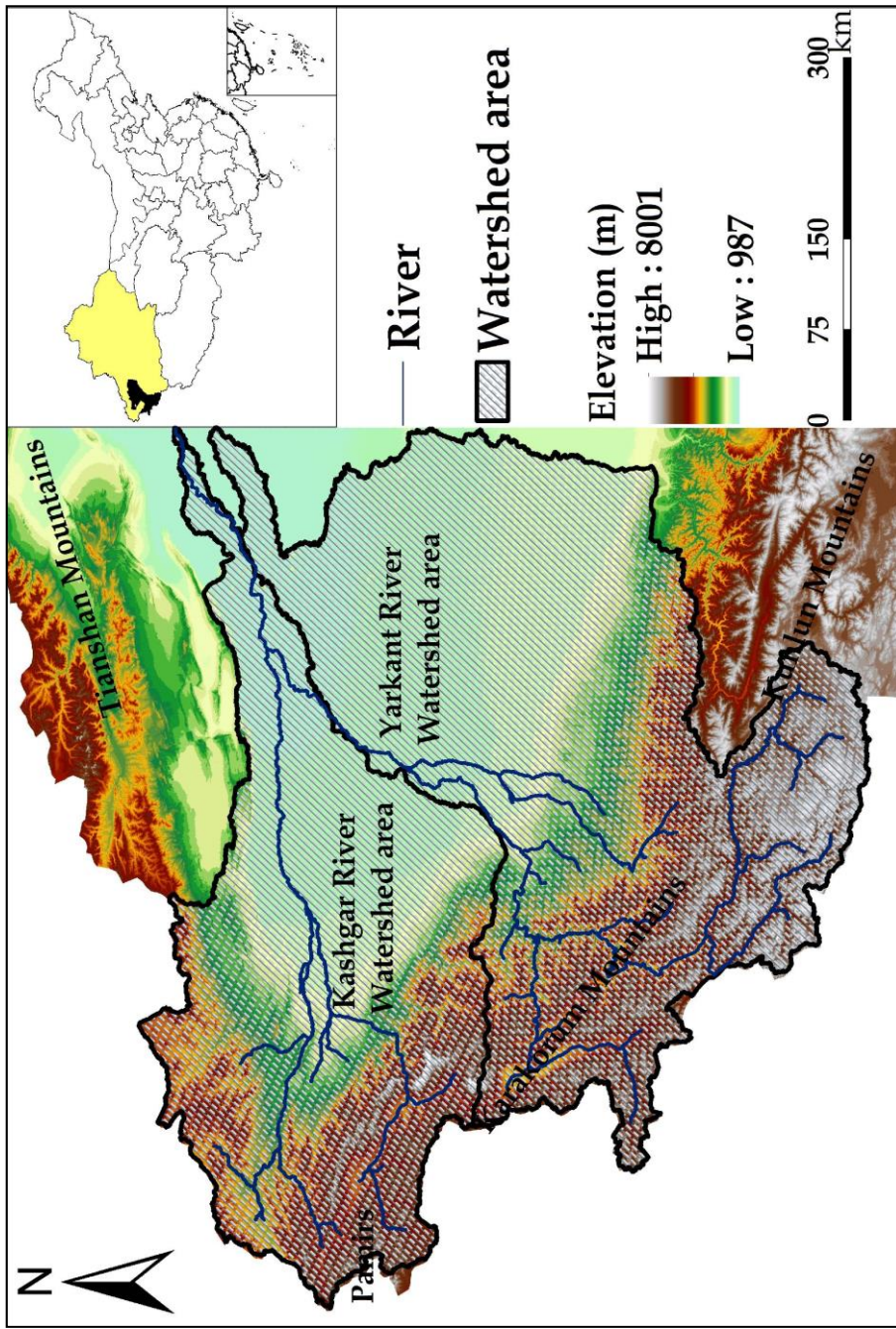


Figure 3.8 Watershed delineation map of study area

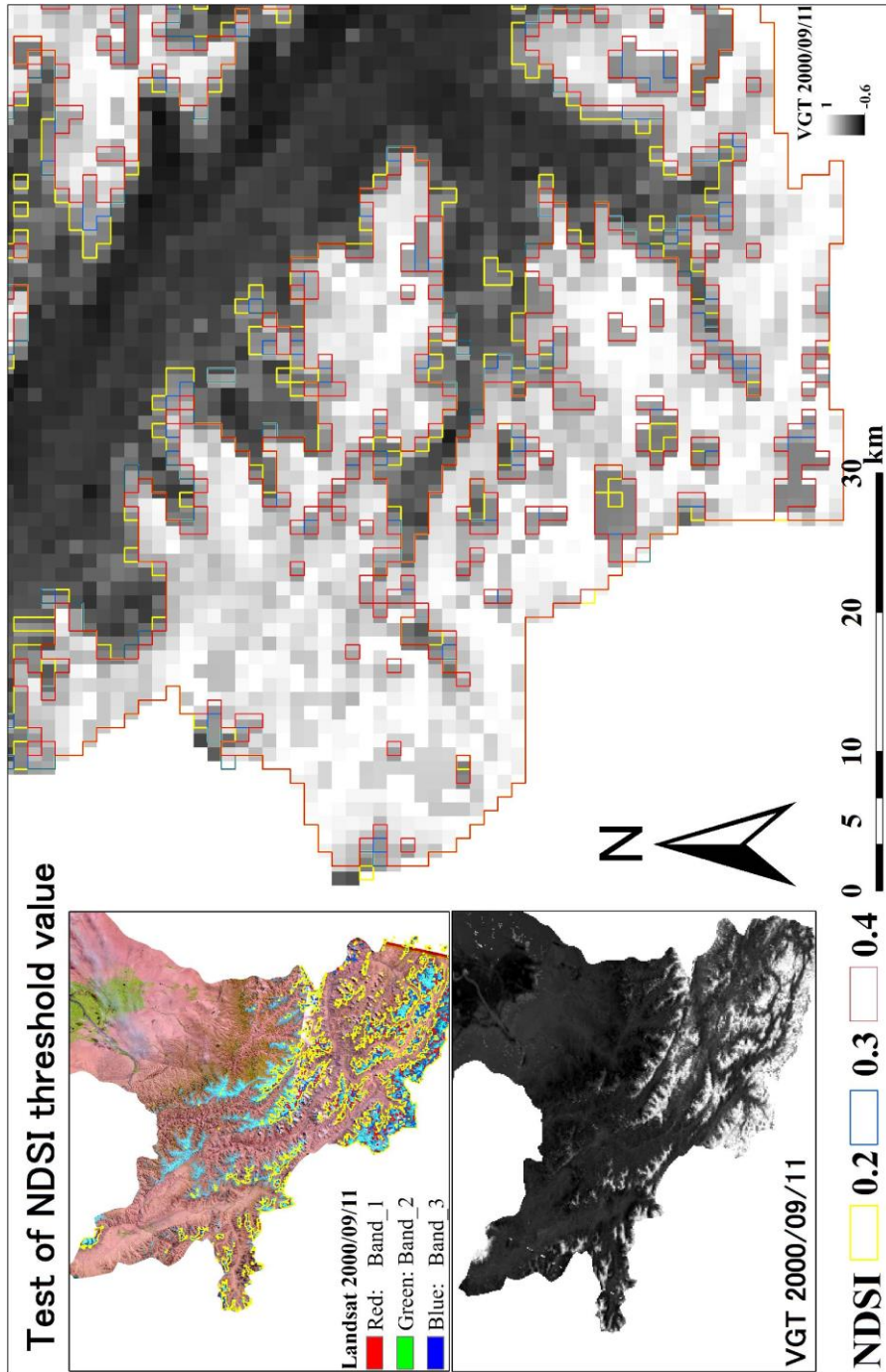


Figure 3.9 Test results of different threshold values for NDSI

(a) is test results, the red line is NDSI =0.4, while snow cover area, blue is NDSI=0.3, while snow cover area, yellow is NDSI=0.2, while snow cover area. (b) is original Landsat data on 11 August 2000, yellow is snow cover area. (c) is SPOT VGT data on 11 August 2000, white is snow cover area.

3.2.4 Trend analysis of hydro-climatic variables

The characteristics of hydro-climatic changes in the Kashgar Region were analyzed based on data collected from four meteorological stations and three hydrological stations for the period 1964-2014. The Mann-Kendall (MK) test (Kendall, 1975; Mann, 1945) can test trends in a time series without requiring normality or linearity and is highly recommended for use by the World Meteorological Organization (Mitchell et al., 1966). Therefore, the MK trend test has been widely used to test for randomness against the trend in hydrology and climatology. This study also used the MK trend test method to analyze trends within the temperature, precipitation, and annual runoff of the study area. The MK trend test was adopted in this study as follows:

First MK test statistic is calculated as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(X_j - X_i) \quad (1)$$

where

$$\text{sgn}(X_j - X_i) = \begin{cases} +1, & x_j > x_i \\ 0, & x_j = x_i \\ -1, & x_j < x_i \end{cases}$$

and n is the sample size. The statistics S is approximately normally distributed when $n \geq 8$, which the mean and the variance as follows:

$$E(S) = 0 \quad (2)$$

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^n t_i i(i-1)(2i+5)}{18} \quad (3)$$

Where t_i is the number of ties of extent i . If no ties between the observations are present and no trend is present in the time series, the test statistic is asymptotically normal distributed with

$$V(S) = \frac{n(n-1)(2n+5)}{18} \quad (4)$$

The standardized statistics (Z) for one-tailed test is formulated as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & S < 0 \end{cases} \quad (5)$$

At the 5% significance level, the null hypothesis of no trend is rejected if $|Z| > 1.96$ and rejected if $|Z| >$ at the 1% significant level.

$$\beta = \text{Median} \left(\frac{x_i - x_j}{i - j} \right) \quad (6)$$

Where $1 < j < i < n$. A positive β denotes a rising trend, while a negative β means a decreasing trend.

The MK test can be used in following manner: for the null hypothesis of $H_0: \beta=0$, if $|Z_c| > Z_{1-\alpha/2}$, then the null hypothesis is rejected, where, $Z_{1-\alpha/2}$ is the stander normal variance, and α is the significant level for test. To assess either a trend is significant or not, we have selected two tailed test with 5 % significant level ($p < 0.05$). Therefore, the results with p value < 0.05 were considered statistically significant. The MK test was performed by XLSATA software.

Chapter 4. Results

4.1 Classification accuracy of Land Cover (LC) Maps

Three comparative analyses were performed to evaluate the performance and accuracy of the method used. Several images and ancillary global land cover product were used from Landsat and high-resolution imagery in Google Earth that are reasonably close to 1990, 2000 and 2014 and Land Cover Mapping project at 30m (GlobeLand30) data to evaluate LC maps to reveal the dynamics and changing of LC classes over time in the study area.

(1) Accuracy assessment

The results of overall accuracies of LC maps were a ranged between 88% and 91%, standard overall accuracy for LC maps was set between 85% (Anderson et al., 1976). Kappa coefficient values were range from 0.86 to 0.90 and user`s and producer`s accuracies of individual classes were ranged from 100% to 65% (Table 4.1). However, we applied to image segmentation techniques for separated grassland and cultivated land extractions, there is still low accuracy in 1990 and 2000, that could be explained by the fact that the area is arid region and the vegetation was sparse which lead to confusion with each other land cover type. Overall classification accuracy and Kappa statistics were acceptable classification requirements and satisfactorily accurate.

(2) Visual comparison

China launched a Global Land Cover Mapping project at 30m (GlobeLand30) in 2010, with 10 classes for years 2000 and 2010. The LC maps of in this study were compared with the present GLC maps of 2000 and 2014, the assumption that the LC map in 2014 not big changed from 2010. The LC maps of this study showed good agreement in terms of the regional and spatial distribution of GLC of 2000 and 2010 (Figure 4.1 and Figure 4.2).

Table 4.1 Accuracy assessment of LC maps for 1972, 1990, 2000 and 2014

Land cover class	1972		1990		2000		2014	
	User Accuracy	Producer accuracy	User accuracy	Producer accuracy	User accuracy	Producer accuracy	User accuracy	Producer accuracy
Urban	86%	67%	100%	95%	100%	91%	100%	68%
Water	100%	78%	97%	97%	100%	88%	100%	90%
Grassland	91%	91%	88%	65%	100%	69%	100%	96%
Cultivated land	80%	97%	89%	97%	94%	100%	91%	100%
Forest	90%	60%	76%	73%	98%	91%	87%	81%
Snow/ice	100%	100%	100%	100%	100%	94%	100%	97%
Bare land	87%	100%	92%	100%	68%	100%	73%	100%
Overall accuracy	88%		93%		93%		91%	
Kappa statistics	0.86		0.92		0.91		0.90	

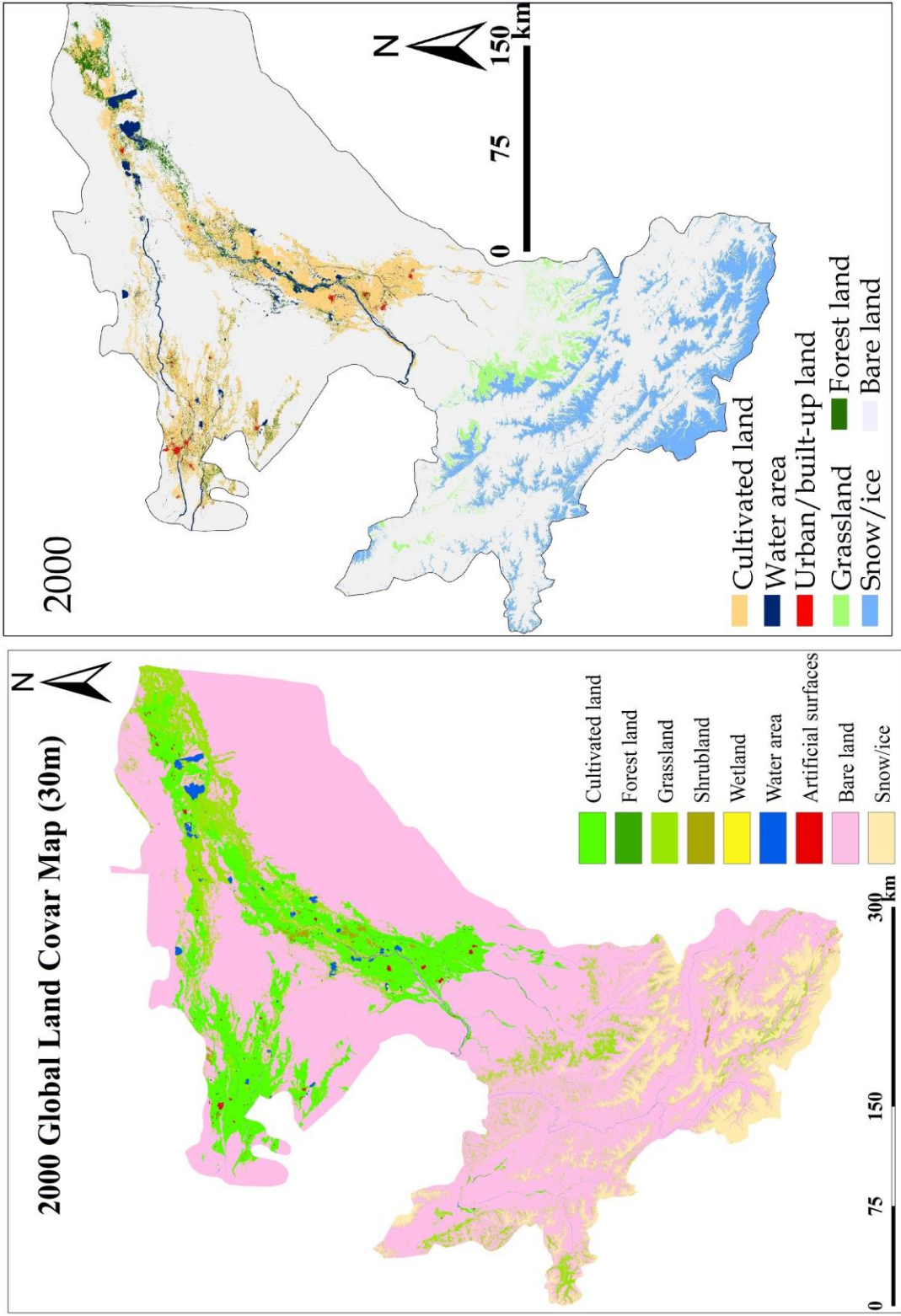


Figure 4.1 Comparison results of GLC map (left) and this study (right)

Although both maps are a 30m spatial resolution. Due to the different classification scheme and produced purpose, two maps give different results. However, GLC map overestimated grassland, underestimated cultivated land.

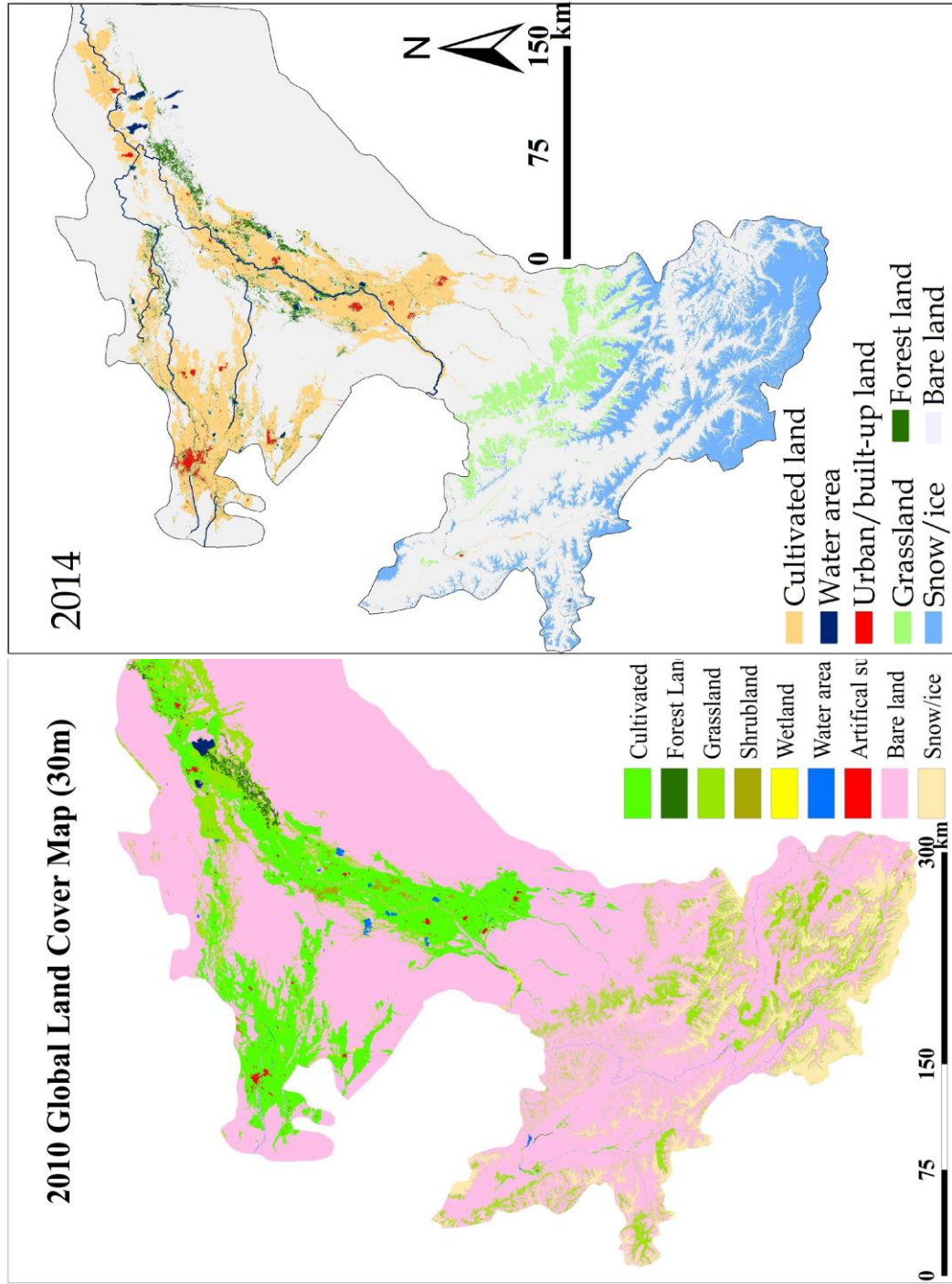


Figure 4.2 Comparison results of the GLC map (left) and results of this study (right) in

However, grassland and cultivated land of the GLC project is overestimated (Figure 4.1). It is considered that the study area is an arid region, due to the low precipitation in the plain, grassland was less distributed. However, the GLC product is overestimated grassland, quantify results showed grassland area were 10302.2 km² in 2000 and 11492.1 km² in 2010, respectively. In addition, cultivated land area was also overestimated that 12578.8 km² in 2000. Moreover, our results and cultivated area of Xinjiang Statistical Yearbook (XJSYB) showed that cultivated land expansions very remarkable from 2000 to 2014. However, GLC quantifies results showed cultivated land expanded only 1118.1 km² during the ten years. The accuracy of GLC maps, some part of world high accuracy has been reported such as Italy, Germany, and Iran the overall accuracy of GLC higher than 80% (Brovelli et al., 2015), 92% (Arjanjani et al., 2016a) and 78% (Arjanjani et al., 2016b), respectively. However, the overall accuracy was lower (46%) reported in Central Asia, where the majority of misclassifications came from the GL30 bare land class, accuracies of the GL30 grasslands and forest classes were low, and the confusion between shrub land and grassland also resulted in misclassifications (Sun et al., 2016).

(3) Areal comparison

Areal comparison results presented in Table 4.2 showed large variations among the cultivated land and grassland between GLP products and our results. Urban, water, forest and snow/ice almost consistent. The accuracy results of this study LC maps higher than the GLC product. Because our objective is to produce a land cover map on a regional scale. These comparison results showed that the LC maps were acceptable classification requirements and satisfactorily accurate for continuing analysis in this study.

Table 4.2 Estimated areas of each land cover classes by GLP and this study

<i>Year</i>	2000	2000	2010	2014
<i>Land cover class</i>	(GLP)	<i>This study results</i>	(GLP)	<i>This study results</i>
	(Km²)	<i>(km²)</i>	(km²)	<i>(km²)</i>
<i>Water area</i>	870.9	1291.2	574.2	1062.4
<i>Cultivated land</i>	12578.8	6572.5	13696.9	11677.5
<i>Urban/Built up</i>	191.6	169.2	291.1	392.8
<i>Grassland</i>	10302.2	2680.6	11492.1	3302.5
<i>Forest land</i>	522.7	1545.7	1070.6	1344.5
<i>Snow/ice</i>	8229.9	7987.8	6817.5	10001
<i>Bare land</i>	81,507	92,665	80,261	86,131
<i>Total area</i>	114,203	113,912	114,203	113,912

4.2 Land Cover (LC) Maps and quantify results

Each LC type's (cultivated land, urban/built-up land, water area, grassland, forest land and bare land) area changed significantly during the 42-year study period, as shown in Figure 4.3 (a-d) and Table 4.3. Especially, the cultivated land is made up of the largest part of the total area and increased from 4148.6 km² (3.6%) in 1972 to 11,677.5 km² (10%) in 2014. The results of agricultural land derived from Remote Sensing Satellites (RS) data were compared with the sown area of Xinjiang Statistical Yearbook (XJSYB); Because, XJSYB is only available sources of time service land use changes statistics in China (Buhe et al., 2013). The data of XJSYB started in 1988, we compared with only available time from 1990, 2000 and 2014 of LC maps and XJSYB. The correlation coefficient was 0.9 as Figure 4.4 showed and there was the same increasing trend. The quantify results of cultivated land area are an acceptable and robust classification for further analysis in this study.

The cultivated land expansions took place in different geophysical zones with different intensities during the study period. The spatial expansion of cultivated land occurred mainly in the upper and middle parts of Yarkant River, upper part alluvial fan areas of the Kashgar River, and peripheral extension of the existing oases can be observed LC maps in Figure 4.3. Hydrology determines the distribution and extent of the oasis in the arid zone (Pan, 1993). The increase or decrease in the size of the oasis is closely related to the change in water volume and river course. Due to the basin area receives less than 100 mm precipitation. The cultivated land mainly distributed on river banks from 1972 to 1990, as can be seen, LC maps in 1972 and 1990. As the topography is smooth in the lower reaches of rivers and not necessary to build the complicated water conservancy project for irrigation, only a few simple channels were needed to draw the runoff into the oases. Therefore, mainly distributed in the upper reaches of the rivers. Water diversion is

convenient from rivers and depending upon accessibility and most of them are the main part of the old oasis. Continue expansion of cultivated land, their spatial distribution and has caused higher water consumption at different parts of the rivers.

The most significant changes of after the 2000s, cultivated land has been expanded along the alluvial fans below the mountains, where have been attractive sites for cultivated land. The alluvial fans are surrounded by mountains in the north, the west and the south of Kashgar Region. Cultivated land expansions are high determined by the availability of fresh water from the groundwater flow system in alluvial fan since 2000. The alluvial fan groundwater in the Kashgar Region plays an important role in the agricultural expansion after the 2000s. The groundwater was recharged by surrounding mountains, flowed through the alluvial fan and subsequently discharge along the toe of the fans in Kashgar Region. So, these areas have favourable conditions for agricultural land expansions. These findings demonstrating that at the geographic characteristics of Kashgar controlling LUCCs, especially water conditions. Therefore, LUCCs, cultivated land has taken place, around alluvial fans, due to the water resources are stable these alluvial fan areas and is used in an area that lacks convenient surface-water supplies.

The lands for urban/ built-up area were increased from 40.2 km² (0.4%) in 1972 to 392.8 km² (3%) in 2014. The distribution of the built-up land was more centralized and while a noticeable trend of outward expansions along the Kashgar city and each county, occupying cultivated land and water body. But there were also some rural settlements scattered evenly in the whole study area. Although, percentage of urban in this study is not big, but urbanisation level (as the proportion of total population residing in the state's urban areas) increased from 19.63 % in 2000 to 22.76 % in 2014 (XJSYB), and it is the most concentrated area of human activity in an arid area also the largest area where

artificial disturbances occur at a regional scale. Urbanization and urban growth have been considered as one of the essential indicators of economic growth and development of a country (Mohapatra et al., 2014). Due to the increasing population of the Kashgar Region is associated with urban and built-up land expansion. Because the growing population has requested more land for the basic needs of living. According to the Central Department of Statistics and Information in 2015, the population of Kashgar Region rose from 2,745,362 in 1988 to 4,683,114 in 2014, an increase of approximately 70%. Which reflected that human intervention and its influence on the environment become more significant and intensity.

One of the most noticeable features in the presented classifications is surface water area, is a very important component of the Kashgar Region and provides important ecological functions, due to the arid region. However, water area has consistently decreased from 2762.9 km² (2.4 %) in 1972 to 1062.4 km² (0.9 %) in 2014. It will be considered that water (including open water area, as rivers) draw from Yarkant and Kashgar Rivers and other tributaries for irrigation. The consequence of intense agriculture activity has resulted in decreasing surface water area. Hai et al. (2011) also showed that stream flow along the mainstream of Yarkant River has decreased. This implies that anthropogenic activities such as irrigation and increased population instead of climate change dominated the stream flow change of the river (Hao et al., 2008).

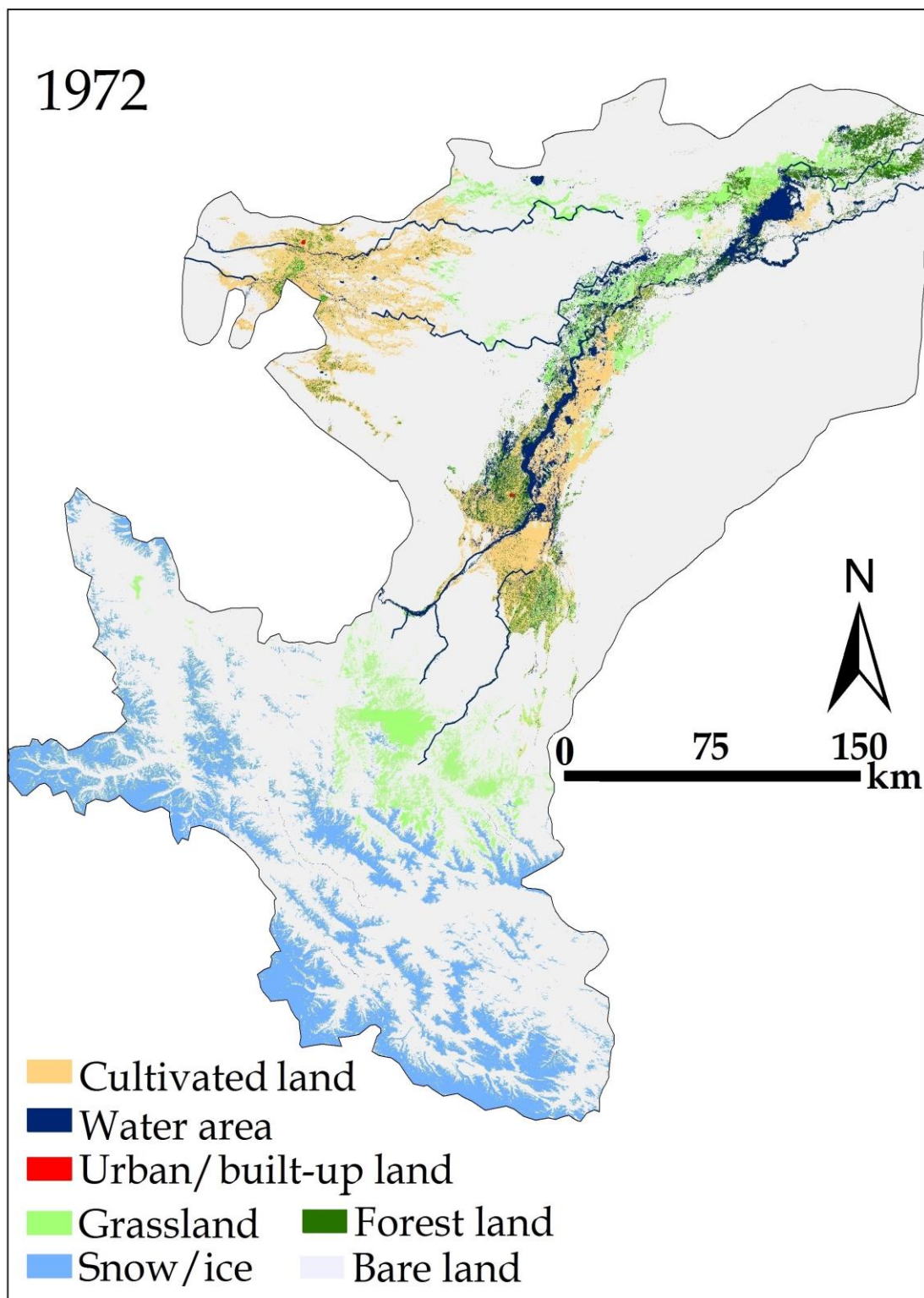


Figure 4.3 Land cover map of study area in summer seasons in 1972 (a)

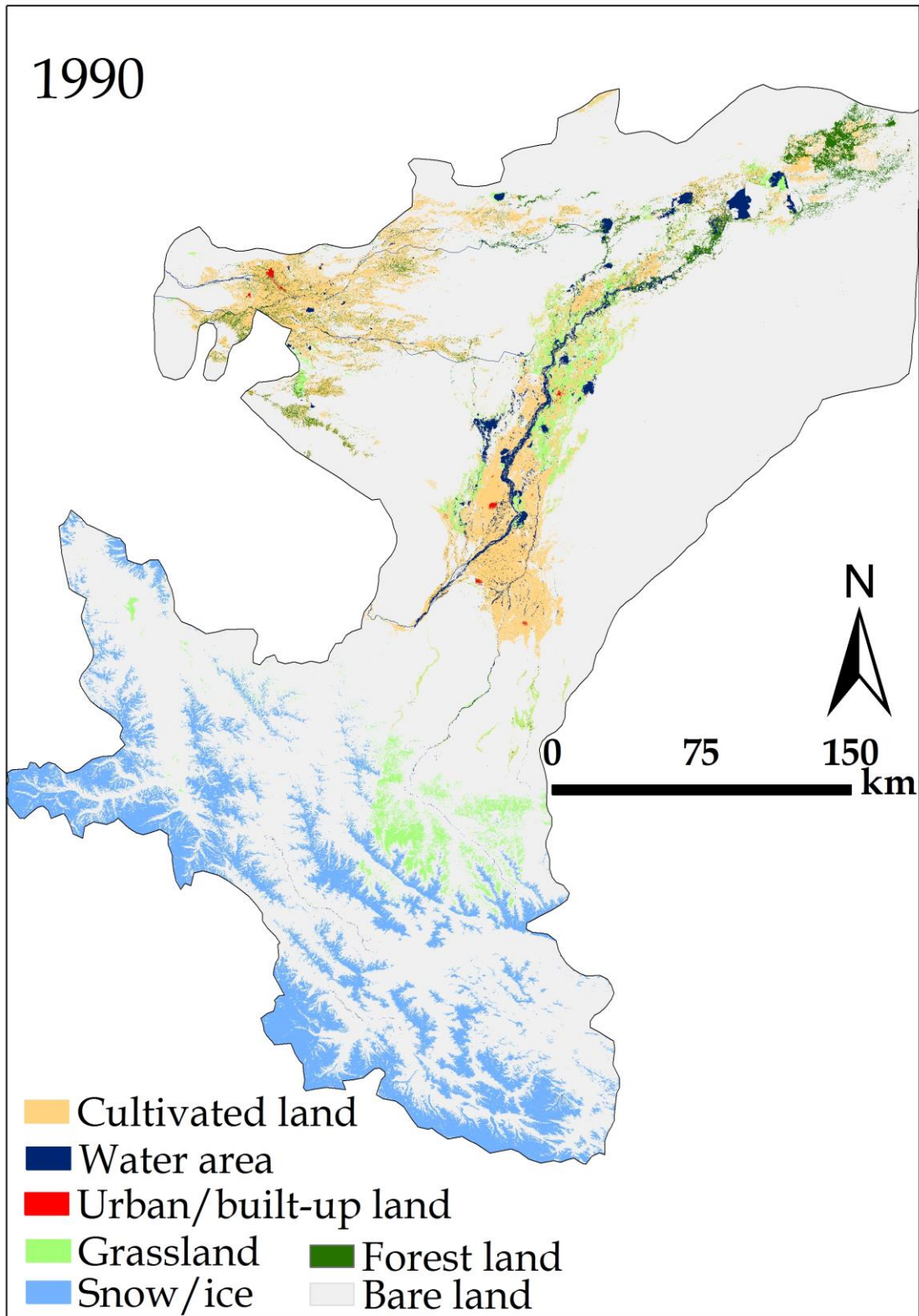


Figure 4.3 Land cover map of study area in summer seasons in 1990 (b)

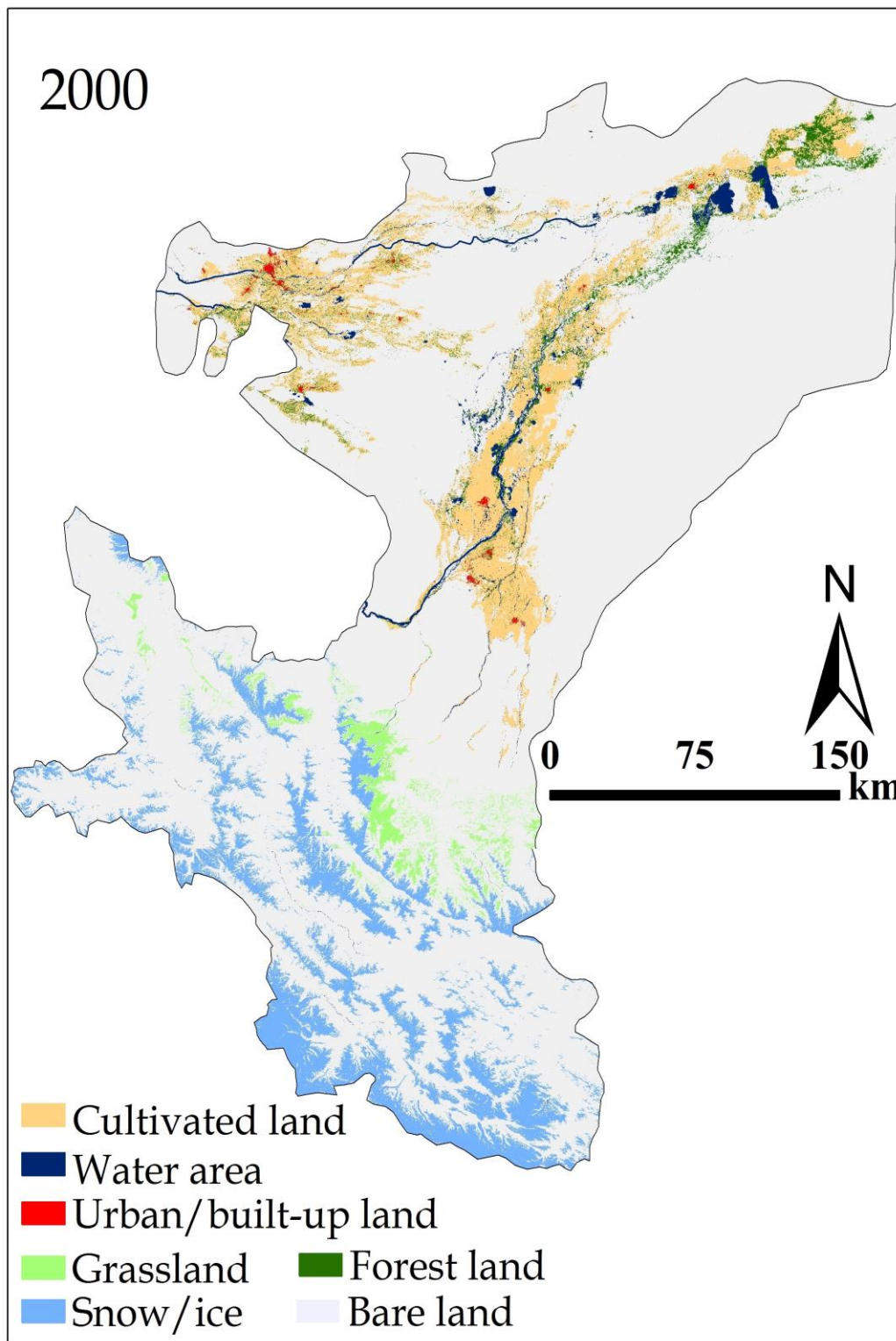


Figure 4.3 Land cover map of study area in summer seasons in 2000 (c)

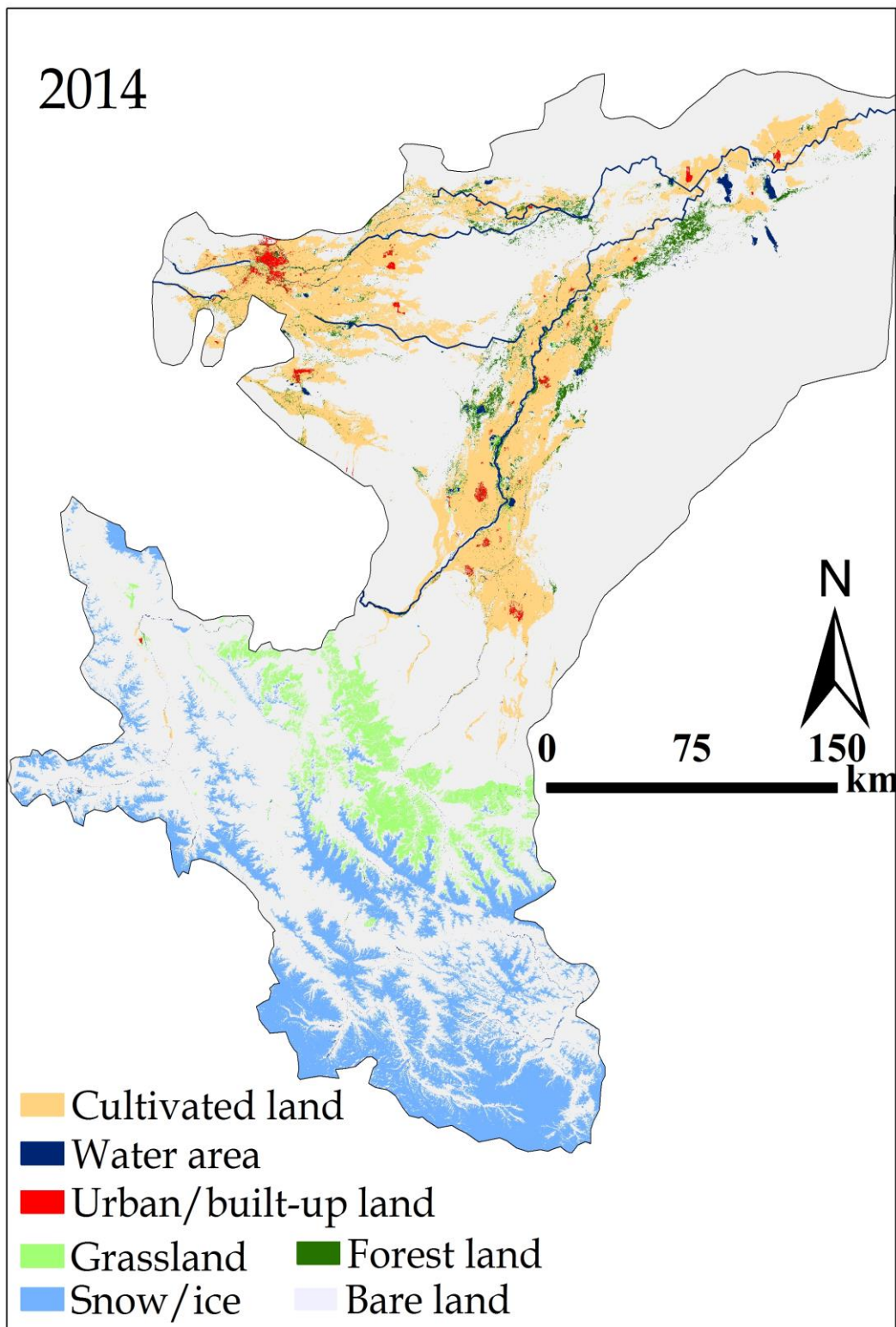


Figure 4.3 Land cover map of study area in summer seasons 2014 (d)

Table 4.3 Results of LUCC statistics for 1972, 1990, 2000 and 2014

Year	1972		1990		2000		2014	
Land cover class	Total area (km ²) percentage (%)							
Water area	2762.9	2.4	1925.6	1.6	1291.2	1.1	1062.4	0.9
Cultivated land	4148.6	3.6	5991.4	5.2	6572.5	5.7	11,677.5	10
Urban/Built up	40.2	0.4	96.3	0.8	169.2	1.5	392.8	3
Grassland	4779.1	4.1	3701.3	3.2	2680.6	2.3	3302.5	2.9
Forest land	3284.5	3.1	2991.1	2.6	1545.7	1.3	1344.5	1.2
Snow/ice	10,038.8	8.8	10,789.5	9.4	7987.8	7.8	10,001.2	8.7
Bare land	88,358.4	77	88,417.3	77	92,665.5	80	86,131.7	74
Total area	113,912.5	100	113,912.5	100	113,912.5	100	113,912.5	100

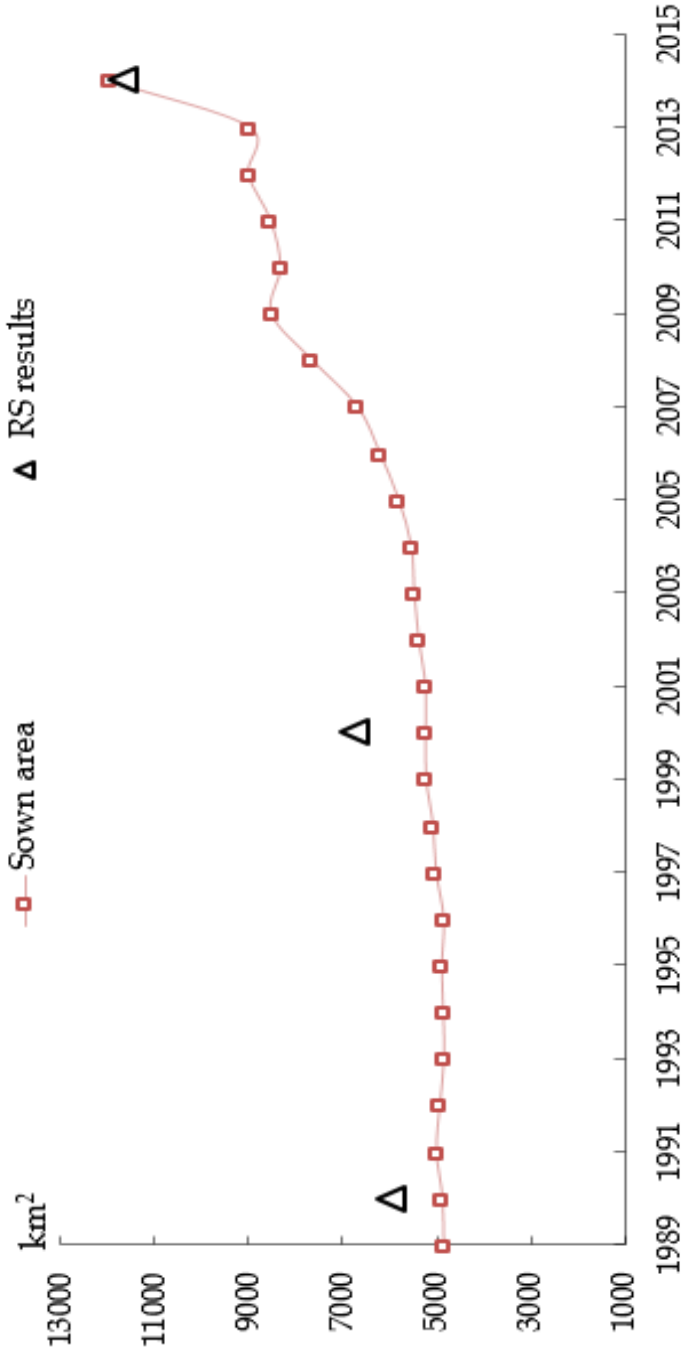


Figure 4.4 Area comparison results of RS results and sown area ^{AA)} of XSYB

Triangle mark is cultivated land quantify results of this study, red rectangle mark with line is sown area of XSYB.

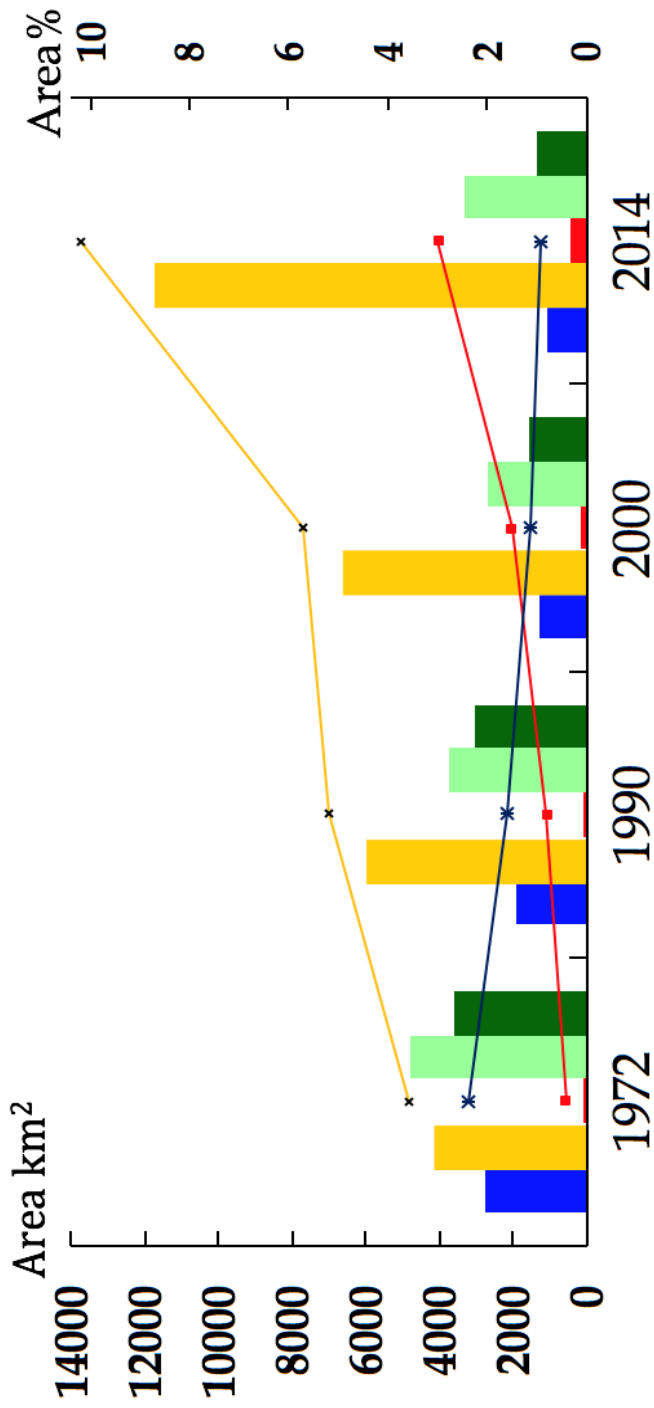


Figure 4.5 Quantify results of land cover classes

Orange colour represented cultivated land, the orange line is its percentage, had been increased. The blue colour is water, the blue line is its percentage, had been decreased. Red is urban- built-up land, the red line is its percentage. Light green is grassland, dark green is forest area.

Besides, the natural vegetation in arid regions plays a very important role in the conservation of biodiversity, soil stabilizer, prevent water, soil erosion and reduction of desertification (Saco et al., 2006). However, the grassland of Kashgar Region decreased from 4779.1 km² (4.1 %) in 1972 to 2680.6 km² (2.3 %) in 2000, then increased to 3302.5 km² (2.9%) (Figure 4.5). The grassland was mainly distributed in the south part of the mountain to the north part of plain in along with the rivers of Kashgar Region. The trend of grassland can be explained by precipitation distribution and variability in the mountain regions of Kashgar. Because, the sensitivity of grassland cover to changes in precipitation is supported by other studies in arid and semi-arid regions (Gessner et al., 2013; Li and Dawson, 2002; Richard and Pocard, 1998). In addition, the inter-annual response of vegetation to precipitation is very strong in many parts of Central Asia (Nezlin et al., 2005; Nicholson et al., 1994). Figure 4.6 displays the precipitation difference between both years for a month time period. In fact, the monthly precipitation was a significant change. The mountain part received more precipitation in 2014, especially, during winter and spring periods. In the southern arid regions of Central Asia, winter and spring precipitations are essential for vegetation developments as the vegetation response is very sensitive, with a lag of 1-3 months (Gessner et al., 2012). In years with more positive precipitation in mountains are covered with grassland, which reflected in spectral information and shape of Landsat and thus leads to change in classification. Additional impact on, conversion of grassland to cultivated land is considered to another reason for grasslands' decreasing on the plain. Which are considered to groundwater and land quality of Kashgar Region (1), due to the low precipitation of plain area, the grassland survival depends on groundwater and soil water. Therefore, the area covered by grassland is the first target converted into cultivated land due to available water resources for agricultural activity. (2), distributions of grassland in the plain area could be considered good land quality. Because,

study area bare land including saline-alkali soil, sand and rock, where is difficult to open for cultivation. The area covered by grassland, it may have good land quality than other bare land areas. Changes and fragmentation of natural habitats are often proposed as an indicator of land quality (Pieri et al., 1995). Hence, natural grassland decreased most in the plain area by the destruction of human activities. Table 4.4 showed that cultivated land expansions mainly replaced grassland. Newly cultivated land was converted from grassland. These results are also consistent with several studies related to cultivated land expansions of the Xinjiang Uyghur Autonomous Region (Zhao et al., 2012; Chen et al., 2010).

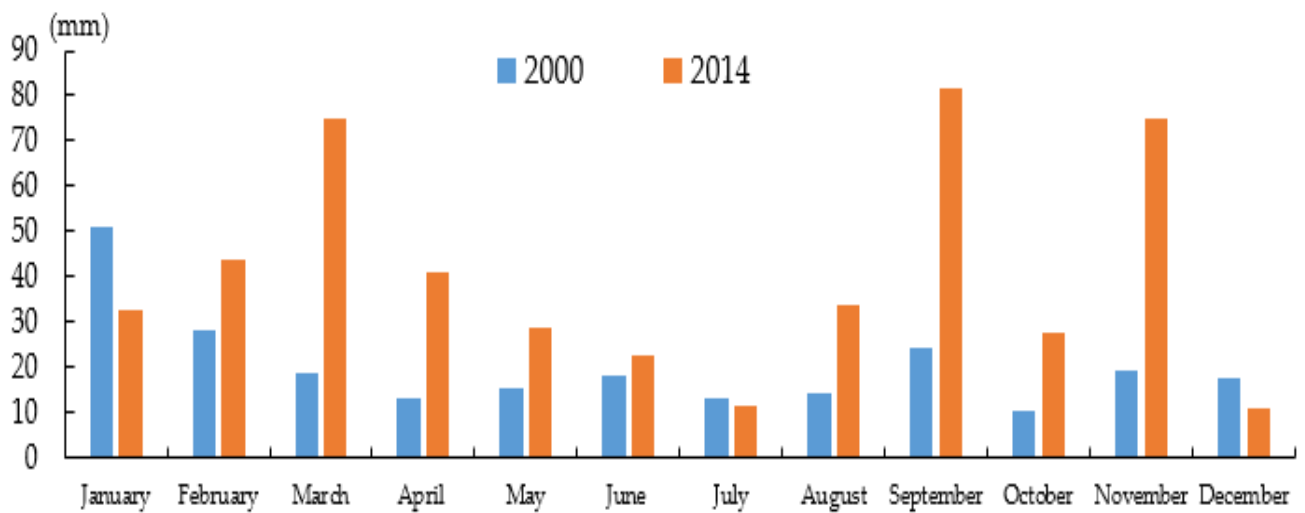


Figure 4.6 Monthly precipitation of mountain region in 2000 and 2014

Mountain area is elevation higher than 2500m. Blue has represented precipitation that falling in 2000. Orange is precipitation that falling in 2014. More precipitation was falling in 2014.

Table 4.4 Area transition matrix of Kashgar Region from 1972 to 2010

Cultivated land mainly occupied grassland and forestland

Land cover classes in 1972 (km ²)	Land cover classes in 2014 (km ²)							
	Water	Cultivated land	Urban/built-up	Grassland	Forestland	Snow/ice	Bare land	Total
Water	954	151	0.01	157	70	456	974.8	2762.8
Cultivated land	27.1	2631	205.75	711	402	0.21	171.5	4148.5
Urban/built-up	0.23	5.9	28.99	0.1	0.02	0	5	40.2
Grassland	0.12	1913	13.6	2196	29.06	316	311.9	4779.6
Forestland	0.1	2328	10.74	9.4	843	52.4	340.8	3584.4
Snow/ice	1.45	1.6	0.00	38.9	0.19	7,656	2340.6	10,038.7
Bare land	79.4	4647	133.4	189.9	0.01	720.6	81987	88,757.4
Total 2014	1062.4	11677.5	392.4	3302.5	1344.5	10,001.2	86,131.6	113,911.88

Forestland is mainly being situated in around the study area's riverbanks, and it depends on groundwater resources, which is seeping from a river. From 1972 to 2014, forestland decreased from 3584.5 km² (3.1 %) to 1344.5 km² (1.2 %). In the presented LC maps, forest losses are localized in riverbanks of the central and north part of the Kashgar Region and are decreases when the distance from the river increases. Most of the forestland is distributed within 200m from the river, there is a negative correlation between the distribution of forest and distance from the river (Tayierjiang et al., 2011; Cheng et al., 2012). The agricultural expansions were a key factor for forestland's reduction as Figure 4.7 showed. The area covered by forest has been converted to cotton cultivation (Table 4.4), due to the economic desires of cotton cultivation. On the other hand, over-extraction of groundwater for irrigation is another reason for decreasing forest area (Tayierjiang et al., 2011).

The area of snow/ice cover decreased slightly during the study period from 10,038.8 km² (8.8 %) to 8978.8 km² (7.8 %) but then increased to 10,001.2 km² (8.7 %) in 2014. Overall, snow/ice cover shows a decreasing trend, it related to precipitation in winter and temperature of the study area. The orbiting pattern of Landsat provides an opportunity to collect imagery at high-resolution 30m but revisit times 16 days. To obtain snow cover changes with daily and clearly, we choose preferred data for snow cover change. Snow cover is a very important freshwater resource of the study area. Therefore, more detailed snow cover information we will discuss further the next natural factor part of this research.

Bare land was the Kashgar Region's most dominant LC, accounting for 77 %–74 % of its total overall area. Due to decreased of snow/ice, bare land remained at 92,665.5 km² or 80 % of its 1990–2000 measurement. Bare land is characterised by sand, desert and rock, so it is difficult to reclaim. Additionally, due to the low precipitation in the study area, water resources were irrationally allocated. Therefore, changes in bare land were unremarkable and slight decreasing during the study period, as summarised in Table 4.3.

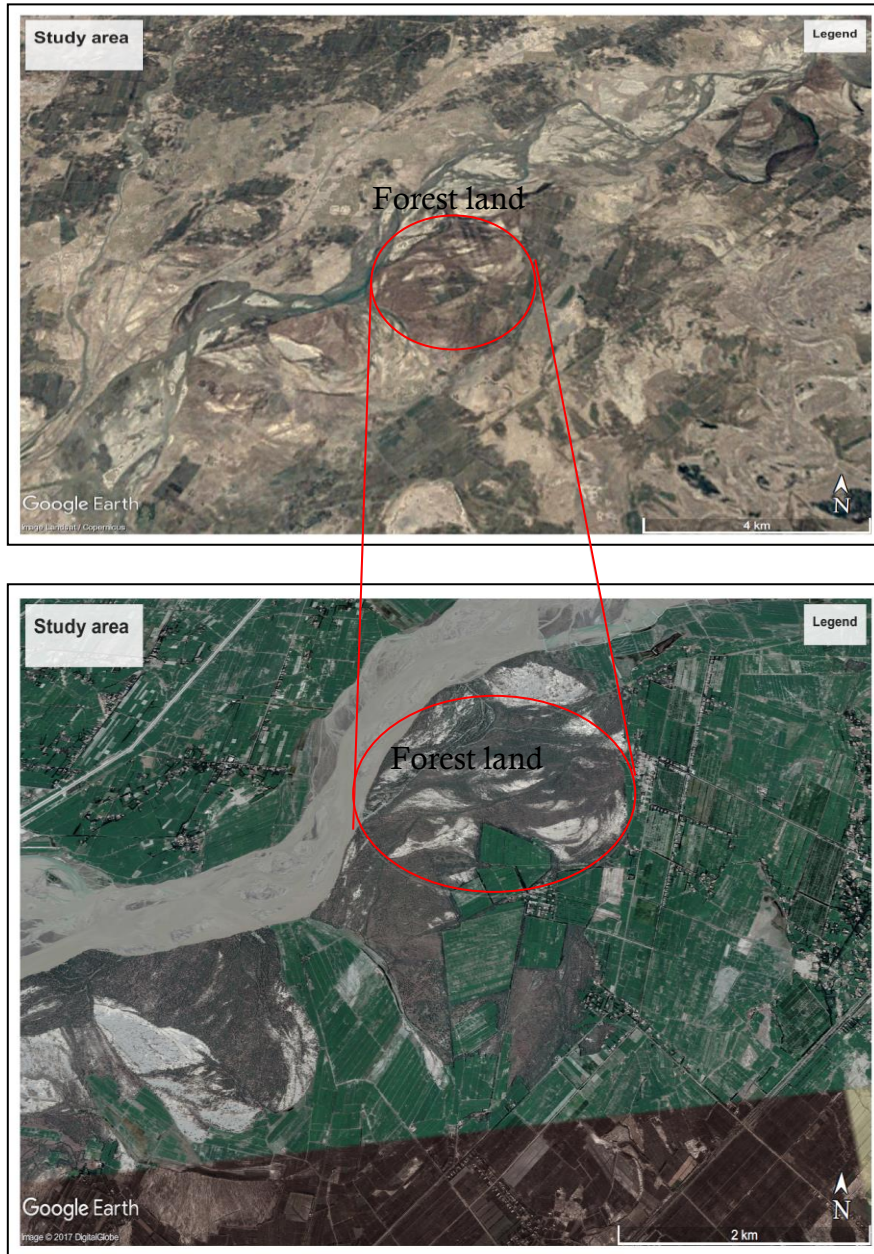


Figure 4.7 Landsat images in 1972 (a), Google Earth high-resolution image (b) in 2014

Red circles are forest area. Forest area mainly distributed along the rivers in 1972, forest area has been converted to cultivated land area in 2014, due to the available water resources.

4.3 Results of Snow cover investigation

Our second intentions were to investigate snow cover changes in the Kashgar Region. Because snow cover and its seasonal changes provided important water resources to the plain. We extracted the snow cover area by watershed delineation. Kashgar Region includes two watersheds, which are Kashgar and Yarkant River watershed area (Figure 2.3). The Kashgar River watershed occupied 59% of the mountain area; Yarkant River watershed occupied 58% of the mountain area. The results of snow cover changes of Kashgar and Yarkant River Watershed area during April 1998- May 2014 (ten-day composite) as Figure 4.8 showed. Of special interest are the regions where the difference in snow cover frequency there are several peaks occurred both Kashgar and Yarkant River watershed area in 2002, 2006 and 2008, respectively and snow cover have strong interannual changes.

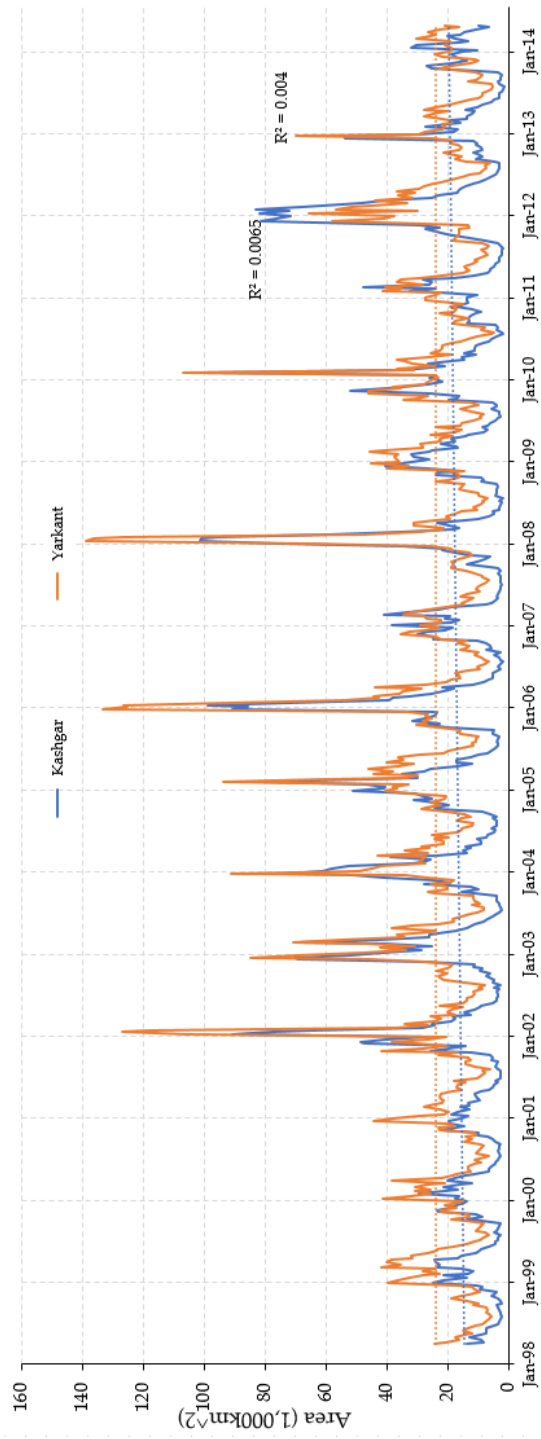


Figure 4.8 Snow cover area of Kashgar and Yarkant Watershed area from 1998 to 2014

Orange is snow cover area of Yarkant watershed, blue is snow cover area of Kashgar watershed.

We analysed monthly and annual time scales snow cover over the larger regions.

(1) Monthly snow cover changes

The Mountain of Kashgar and Yarkant River are a mean elevation above 4000m and elevation of some mountains area reaches 5000-6000m. The terrain complexity of the study area results from a great variation in the distribution of temperature and precipitation. Because of the importance of the mountain snowpack, the study of its spatial and temporal behaviour, as well as the processes which control the snowmelt, is crucial. The primary conditions for the accumulation of snow are sufficiently cold air temperature to favour precipitation in the form of snow, and the persistence of temperature below freezing to preserve the snowpack. In many studies, air temperature and precipitation have been used as the sole explanatory variables of the snow accumulation (Cayan, 1996; Hamlet et al., 2005). This is in part because the air temperature is known to serve as a good proxy indicator of snowmelt (Anderson, 2002) and despite there is generally a lack of radiation observations, whereas air temperature and precipitation are readily available from climatological and operational hydro-meteorological networks. Therefore, two data sets, monthly precipitation and temperature time series from Climatic Research Unit (CRU. 4.01) data in the Kashgar Region covering 1981 to 2014, were analysed to examine the effect of climate change on snow. Figure 4.9 and Figure 4.10 showed monthly mean precipitation and monthly mean snow cover area of Kashgar and Yarkant River watershed area. Maximum snow cover existed about 64905 km² and 84493 km² in Kashgar and Yarkant River watershed area on January 2002, respectively. The mean precipitation was high 140 mm and 120 mm range during a month and previous month in Kashgar and Yarkant River watershed, consequences this contributed to high snow cover extended. High snow cover was also accumulated 91822 km² and 12835 km² both Kashgar and Yarkant River

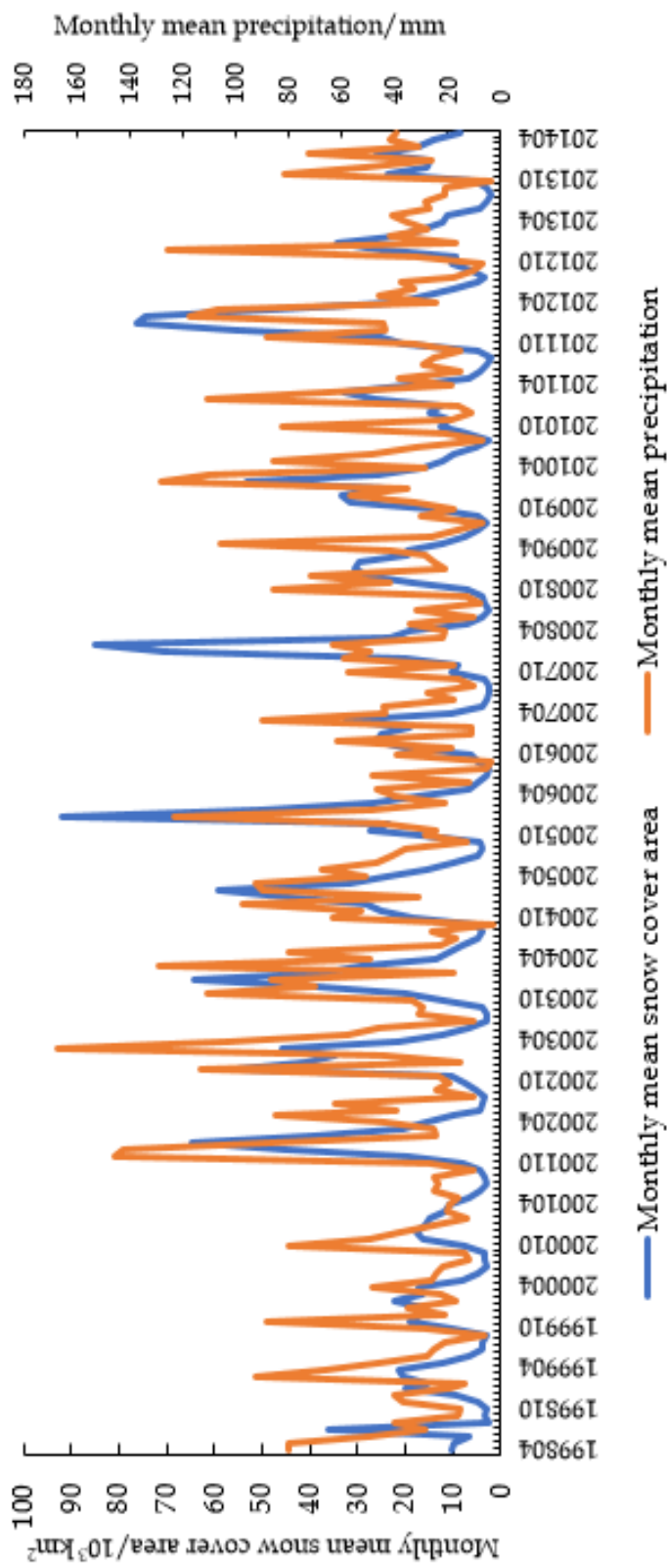


Figure 4.9 Monthly mean precipitation and monthly mean snow cover area of Kashgar River watershed Area

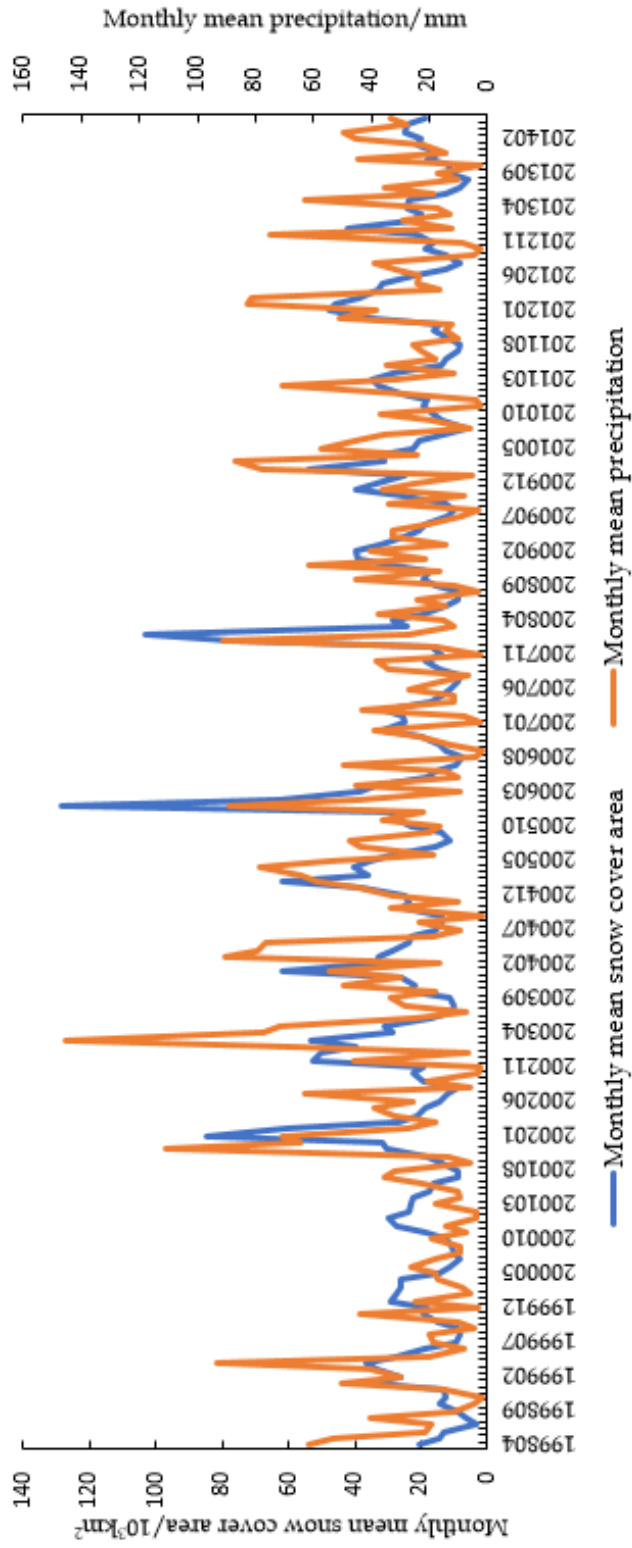


Figure 4.10 Monthly mean precipitation and monthly mean snow cover area in Yarkant River Watershed Area

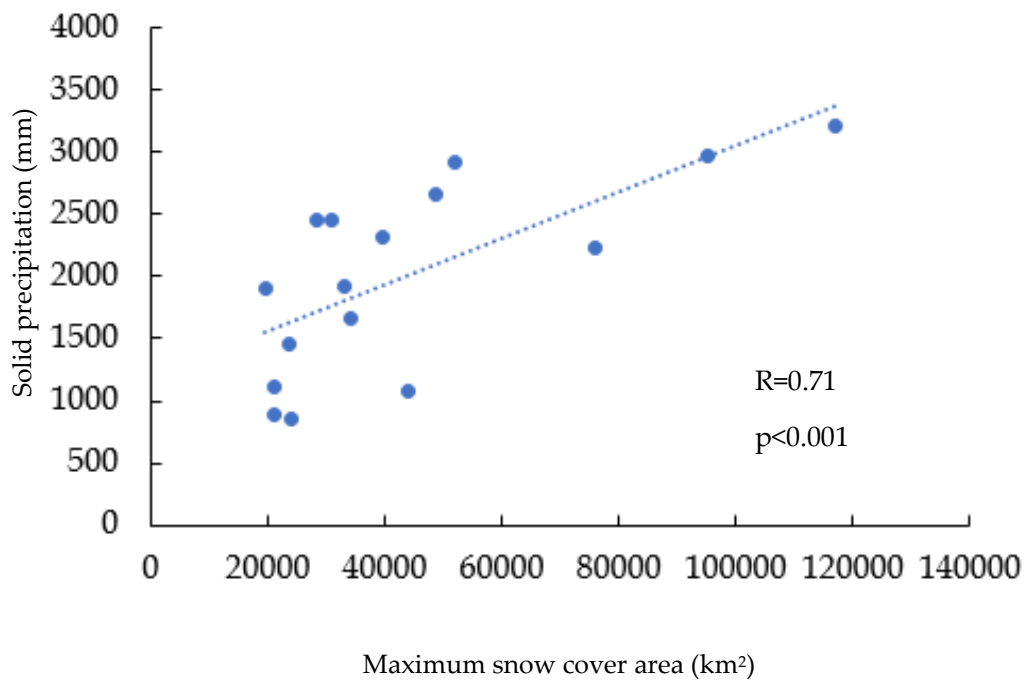
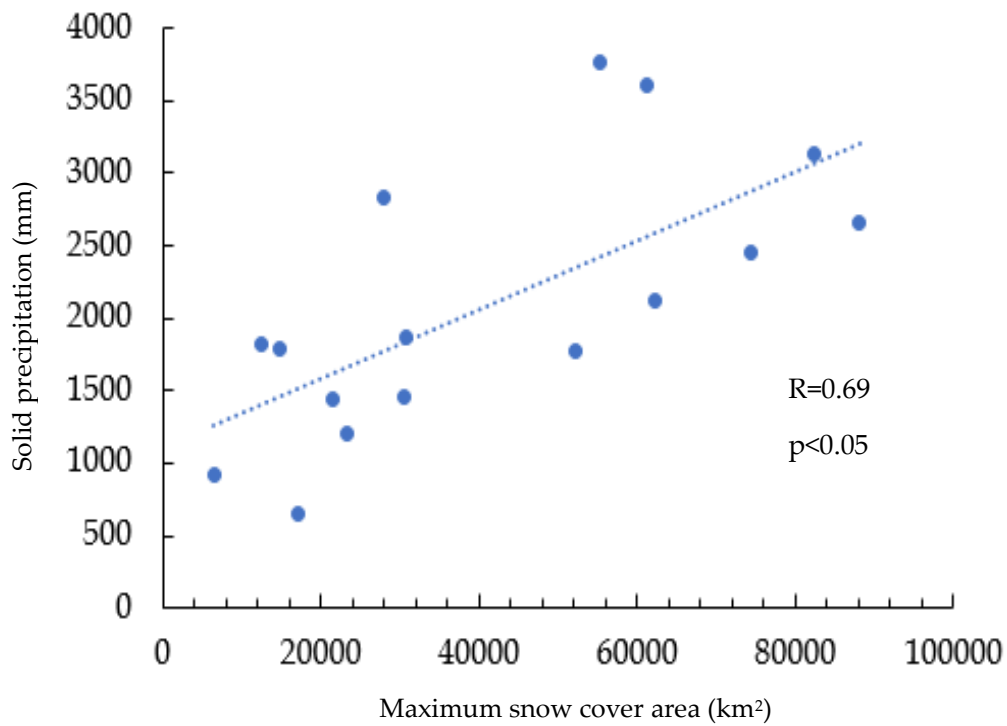


Figure 4.11 Correlation between maximum snow cover and solid precipitation of Kashgar (a) and Yarkant (b) river mountain area from 1998 to 2014

a watershed in 2006. The monthly mean precipitation was 90 mm and 140 mm, respectively; In addition, high snow cover was accumulated 70623 km² and 77106.6 km² of Kashgar and Yarkant River watershed in 2008. Compared with precipitation of other years, precipitation of this year is not big changes, but high snow cover accumulated in 2006 and 2008.

The precipitation throughout the year is unevenly distributed. More than 80% of total annual precipitation occurs between May and October and less than 20% between November and April (Chen et al., 2008). According to snow cover accumulations started from minimum to maximum snow cover area was highly correlated with solid precipitation of Kashgar River Mountain area as Figure 4.11 showed (a), correlation coefficient (R) was 0.69, the significant levels was 0.05. However, the correlation coefficient (R) was 0.71, the significant level was 0.001 in the Yarkant River Mountain area (Figure 4.11 (b)). Moreover, in January 2006 and February 2008, although precipitation was not a big change the same as in 2002, snow cover was high accumulated. It would be reasonable to consider in the previous month with relatively cold temperature and associated with high snow cover accumulated. Therefore, Monthly mean temperature data analysed (Figure 4.12). The monthly mean temperature of Kashgar and Yarkant Watershed area showed that low temperature occurred in December 2005 and January 2008. Compared with other years, in December 2005 and January 2008 winter temperature were low as -14 and -11, respectively (Figure 4.12). The correlation monthly mean snow cover and monthly mean temperature (R) was 0.6 and 0.7 respectively (Figure 4.13), which indicates low temperature favourable high snow cover accumulations in both watershed area.

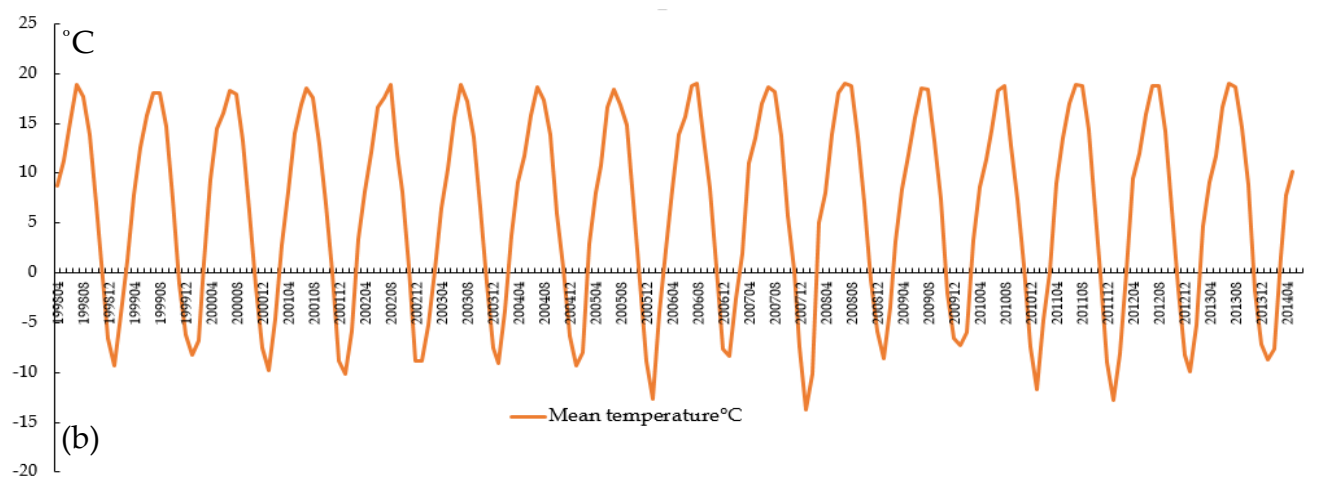
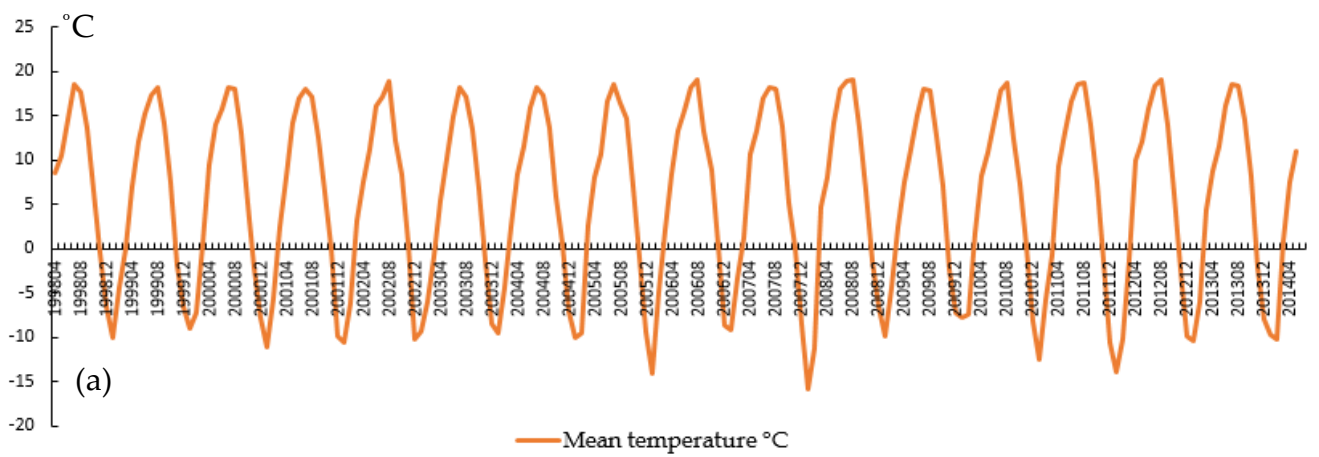


Figure 4.12 Monthly mean temperature of Kashgar (a) and Yarkant (b) River

Watershed from 1998 to 2014

(CRU. 4.01 data)

The low temperature was occurred in December, 2005 and February, 2008.

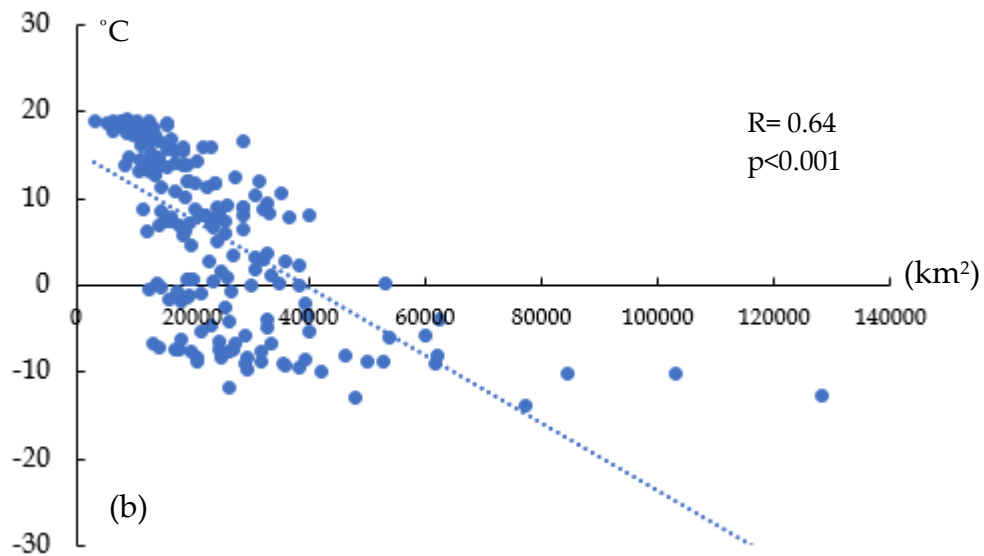
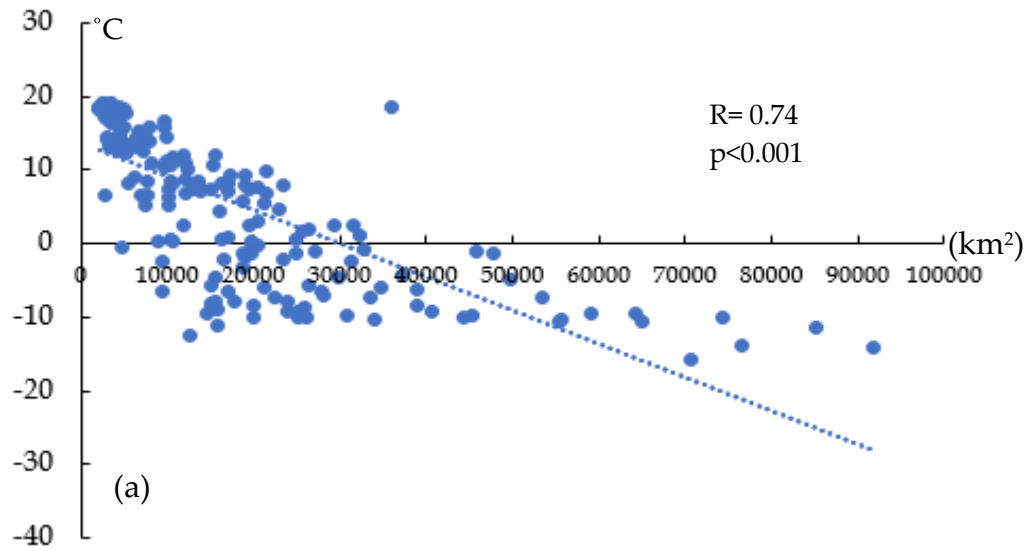


Figure 4.13 Monthly mean snow cover and monthly mean temperature of Kashgar (a) and Yarkant River (b) Watershed area from 1998 to 2014. If temperature is low, high snow cover extent. If temperature is high, small snow cover extent.

(2) Annual snow cover changes.

The analysis of monthly snow cover area indicated that plain area also winter seasons covered by snow. In order to investigate snow cover and its melting contributions to runoff, we separated mountain and plain area. We examine data for at the mountain scale of snow cover for a hydrological year (HY). HY from 1 September to 31 August; for example, HY 2002 referring to the hydrological year 2002, from 1 September 2002 to 31 August 2003. Figure 4.14 shows annual mean snow cover for Kashgar and Yarkant mountain area each hydrological year. There are several peaks occurred in 2005, 2009 and 2012. Total snow cover area no significant decreasing trend for a fifteen years study period.

A high snow cover accumulation recorded in 2005 and 2009, the time lag of seasonal melting was attributed to the precipitation in a mountain range in the same year (Figure 4.15). The annual precipitation was evaluated using the time series based on the meteorological station data as Figure 4.16 shows. The long-term trend of precipitation increased at an 8.11 mm/10 year. However, the annual mean temperature also increased the trend (Figure 4.16). The impact of warming temperature would be to decrease the areal extent of mountain snow cover and changes the length of the snow season. As temperature rise, more precipitation falls as rain instead of snow leading to smaller snowpack, decreased in the proportion of solid precipitation, and enhanced snowmelt.

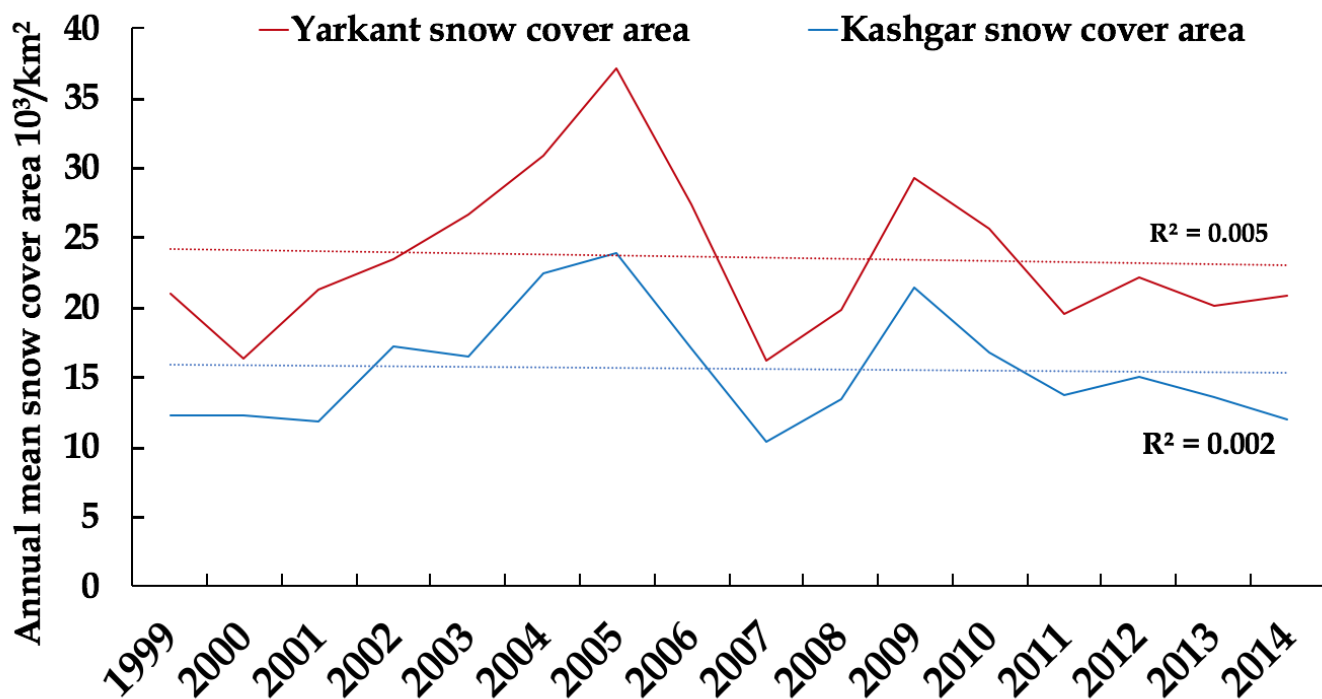


Figure 4.14 Annual mean snow cover of Kashgar Region Mountain area
(1999- 2014 hydrological year)

Red is an annual snow cover area of Yarkant, green is an annual snow cover area of Kashgar snow cover area. Annual represented a hydrological year. A hydrological year is the first year of snow September to next year of August.

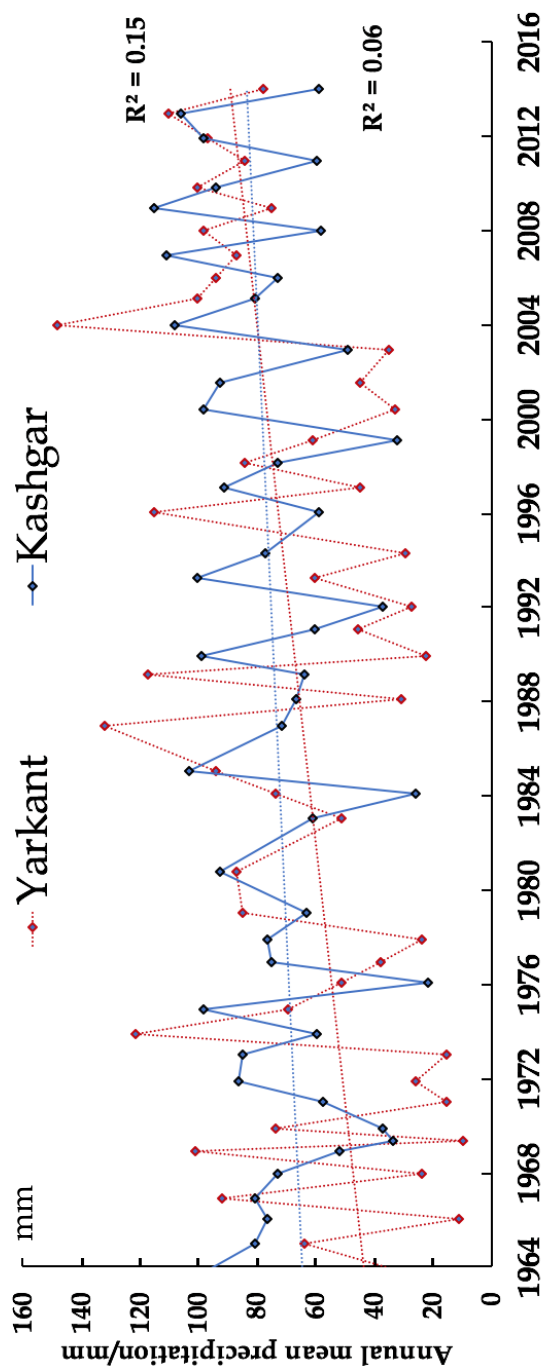


Figure 4.15 Annual mean precipitation of Kashgar and Yarkant (data from meteorological stations)
 Red line is Yarkant, Blue line is Kashgar. Precipitation of both areas has been increasing during the observation period.

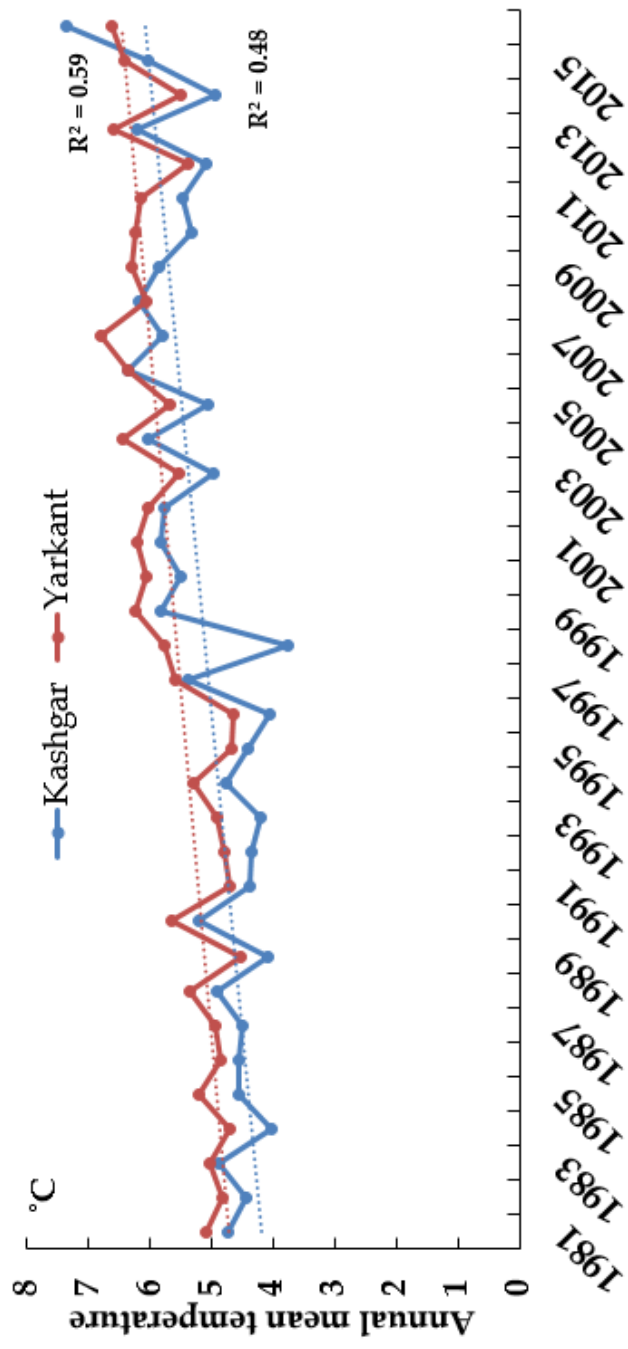


Figure 4.16 Annual mean temperature of Kashgar and Yarkant

(data from CRU.4.01)

Red is Yarkant River Mountain Area, blue is Kashgar River Mountain Area. The temperature of the mountain area has been increasing during the observation period.

Chapter 5. Discussion

LUCC of oasis in regional scale is one of the key contents in the environmental change and has an accumulating effect on environmental change in the arid land. LUCC in arid region is mainly caused by unique natural and social factors (Luo et al., 2003; Hietel et al., 2005) and is result of the complex interactions between human activities and natural factors. Therefore, research on cause of LUCC in arid region is conducted between social and natural sciences, requires an interdisciplinary approach. In this respect, research on causes of Kashgar Region mainly focuses on social and natural factors.

5.1 Social factors

LUCCs are the results of the interplay of a wide variety of factors which operate over a range of scales in space and time. Temporal series analysis of based LUCC analysis by Landsat in 1972, 1990, 2000 and 2014 and time series data of XJSYB combined to explain and identify social causes and its interrelationships of LUCC in Kashgar Region. We concentrated on only cultivated land, because, cultivated land is characterized by most dramatic and dynamic land cover changes to great attention subtle changes of human interactions with natural surroundings in Kashgar Region.

The quantify results of cultivated land had compared with sown area of Xinjiang Statistical Yearbook (XJSYB). As for the usage of statistical yearbook, there is some report about its low reliability (Buhe et al., 2013). However, the statistical yearbook is unique data sources while considering the land use changes. Because, these data provided temporal changes of cultivated land in Kashgar Region. Therefore, we would use the statistical yearbook data before analysing the land use changes by remote sensing considering that it had constant accuracy. There are same trends, both expanding of cultivated land

with RS results and statistical data as Figure 4.4 showed. It is evident that the cultivated land results obtained by RS are in good agreement with existing Statistical results.

Due to the lack of XJSYB data of early period, we applied government statistics for early period by <http://www.kashi.gov.cn/>. Then, we extracted each crop from XJSYB and observed temporal changes. According to cultivated land change patterns (Figure 2.8), we organized cultivated land expansions as some major events into the following distinct historical periods.

Early period:

Historically, China has always had an effective central government in most of the past 2000 years (Xu, 2001). As a result, national policy on agricultural played a vital role in shaping the land system in China by, for example, enforcing land institutions (Tang, 1994), implementing taxes or subsidies on agricultural production (Li et al., 1998), regulating land markets (Ding et al., 2003), and directly redistributing land for different uses (Dean et al., 2010). Chinese political policies played an important and complex role for cultivated land expansions (Miao et al., 2016). Especially, agricultural policy has been changed greatly in the past decades as 1949-1957, 1958-1982 and 1978-1989, moreover, 1963-1966 natural disasters occurred. These processes greatly impacted on cultivated land changes of Kashgar Region.

1949~1957: Kashgar Region experienced rapid cultivated land expansion for a short period from 1949 to 1957, due to the implemented Mutual Aid Group system ^{A)}. Then after, implemented Production Cooperative System ^{B)}. According to official statistics, during these periods, the cultivated land area increased from 2937 km² in 1949 to 4166 km² in 1957, increased 41.4%, the average annual increase rate is 4.46% (data source: <http://www.kashi.gov.cn/>)

1958~1962: The framework for rural development throughout China was provided by the People's Commune ^{C)}. The consequence of this program with collectivization led to changes in agricultural production and natural

resources management. As results, cultivated land expanded from 4166 km² in 1958 to 4601.8 km² in 1962 (<http://www.kashi.gov.cn/>).

1963 ~ 1966: during this period, natural disasters were occurred (Tayierjiang and Anwaier, 2013), called “Three-year natural disaster’s year”^{D)}. After the natural disaster finished, agricultural production recover and agricultural land had been expanded from 4632.5 km² in 1963 to 4833.5 km² in 1966, increased by 4.34% (<http://www.kashi.gov.cn/>).

1967~1977: The Cultural Revolution ^{E)} had occurred. This social chaos had impacted on agricultural production (Miao et al., 2016). Cultivated land had been decreased from 4874.4 km² in 1967 to 4413.6 km² in 1977 (<http://www.kashi.gov.cn/>).

1978~1989: The most recent policy, which is began to be introduced from 1978, was the Household Responsibility System (HRS) ^{F)} (Kojima, 1984a, 1988b; Maruyama, 1987a, 1987b; Nizam, 1995). The goal for the new system was to improve farm efficiency and production through the shifts of management right from the collectives to the individual farm households. Since then, Chinese agriculture developed remarkably (Miyajima, 1993). Especially, Xinjiang Uyghur Autonomous Region (XUAR) has made remarkable progress in agriculture after the rural reforms (ZDDY, 1998). As a result, the importance of XUAR's agriculture in China has increased. Meanwhile, policy changes associated with HRS have led to a new regional differentiation of farm production in XUAR. Consequence, Kashgar Region cultivated land has been expanded.

Since the late 1978s, with the shifts in agricultural policy in China, XUAR’s government has attempted to promote a rural economy by the diversification of agricultural management, sticking to the policy of self-sufficiency in food grains at the county levels (Nizam, 2000).

Since 1980, crop specialization had proceeded in XUAR. The regional government of XUAR has promoted the regional division of agriculture,

under the policy of "southern cotton and fruits, northern food and sugar beet" which was based on the physical conditions of different areas in the region (Nizam, 2000). At the results, cotton cultivation of Kashgar Region increased remarkably. The statistical data was available from 1989, we analysed cultivated land expansions according to its changes patterns by two separate time periods, 1989-2000 and 2001-2014 based on statistical data.

(1) *From 1989 to 2000*, during the period, we can observed that cotton cultivation expanded remarkably than other crops in Kashgar Region (Figure 5.1). The planted area of cotton accounted 109.01×10^3 ha in 1989, it increased sharply at 304.38×10^3 ha in 1999 and 293.5×10^3 ha in 2000. The agricultural output of cotton in Kashgar also increased from 1144 kg/hm^2 in 1989 to 1320 kg/hm^2 in 2000. The cotton planting changes are complex, and its influencing factors include natural and social cause, such as effective accumulated temperature, frost-free period, sunshine duration, rainfall, natural disasters, cotton production policy, cotton price, cotton planting technology, management level, non-agricultural employment, labour input, policy environment, etc. The Kashgar Region temperature has been increasing (Ayisulitan et al., 2018). Increasing temperatures have favoured cotton production average yield per acre increase $373.5 \text{ kg} \cdot \text{hm}^{-2}$ per decade from 1990 to 2013 (Abdokerimu et al., 2015). On the other hand, due to the world cotton consumptions and cotton price were increased remarkably (Figure 5.2), its stimulated expansion of cotton cultivation area. Globalization increases the interconnections of places in the world by international trades. Increasing global connections, globalized markets, decisions by distant governments and global agenda setting influence local land use decisions (Peter, 2015). China's agricultural and regional policy designated XUAR for building a national cotton base area in China (Kamardin, 1999; Xiaokaiti, 2013). Cotton was traditionally grown in eastern China near the Yellow River (in Hebei, Henan, and Shandong provinces) and the Yangtze River (Anhui, Hubei, Hunan, and

Jiangsu provinces Figure 5.3). As a consequence, XUAR has become China's dominant cotton-growing region. Especially, since 2000, XUAR has become China's dominant cotton-growing region. Cotton accounts for 45% of its crop sector and 3/5 of its total agricultural sector (Mac et al., 2015). The cotton from other crops in China is the large share of production concentrated in XUAR, in the upper northwestern corner of the country.

In a rapidly globalizing world, goods and services are often not where they are produced (Yang, 2013). Therefore, local land use changes are increasingly triggered by demands for products as cotton that are part of global supply chains oftentimes involving large geographic distance and creating land conversions (Yang, 2013). Consequence of this telecoupling processes great effect on Kashgar Region cotton cultivation. Cotton cultivation area has been increasing, which makes an enormous contribution to Kashgar and XUAR agricultural development (Figure 5.4). The cotton sector accounted for more than 17% of Kashgar's GDP in 2013. This agricultural policy (Central Government designated XUAR for building a national cotton base area in China) and economic development, especially, increasing in cotton demand of the outside as telecoupling has one of the main causes triggered expansion of cotton cultivation in Kashgar Region.

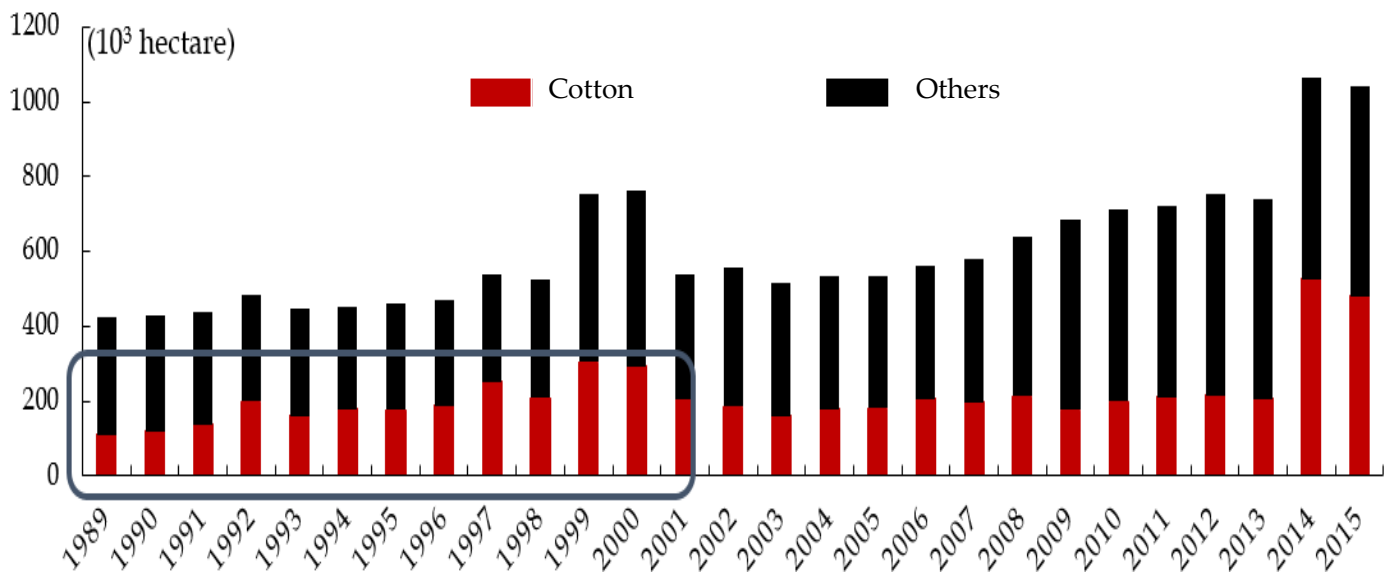


Figure 5.1 Area of cotton and other crops in Kashgar Region from 1989 to 2015

(data from XJSYB)

The black line is represented by increasing cotton cultivation from 1989 to 2000. From 2001 to 2013, the government-controlled cotton price tightly.

Therefore, the cotton area is a stable trend.

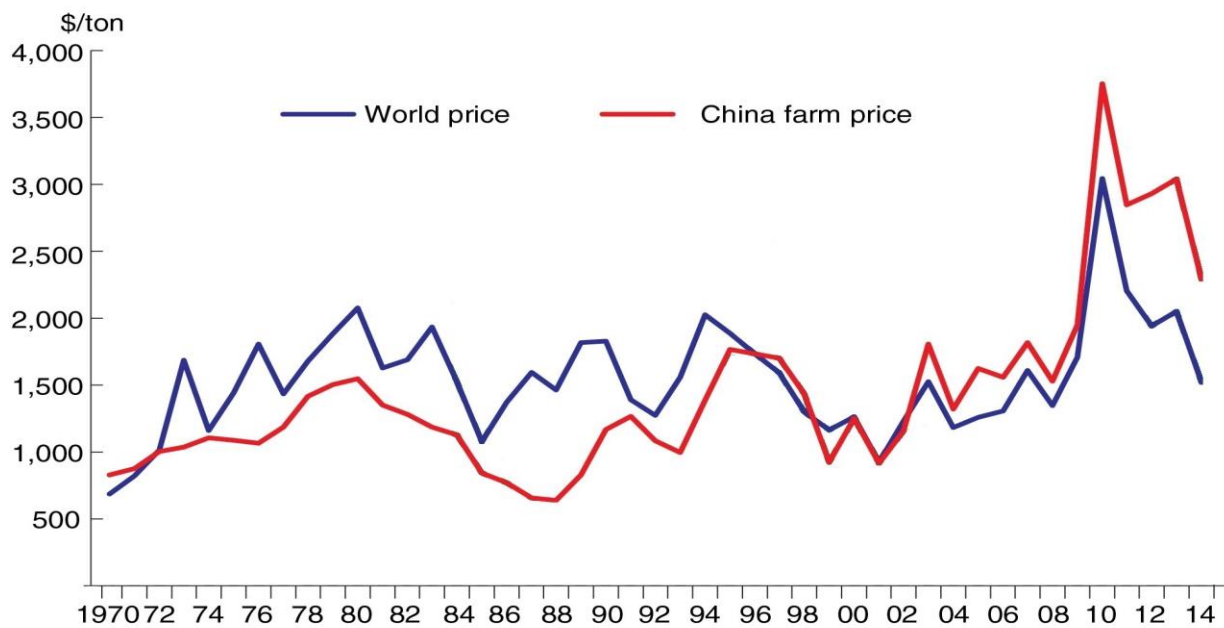


Figure 5.2 Cotton price of world and China

(data from the United States Department of Agriculture). The blue line is a world cotton price, red is China farm price.

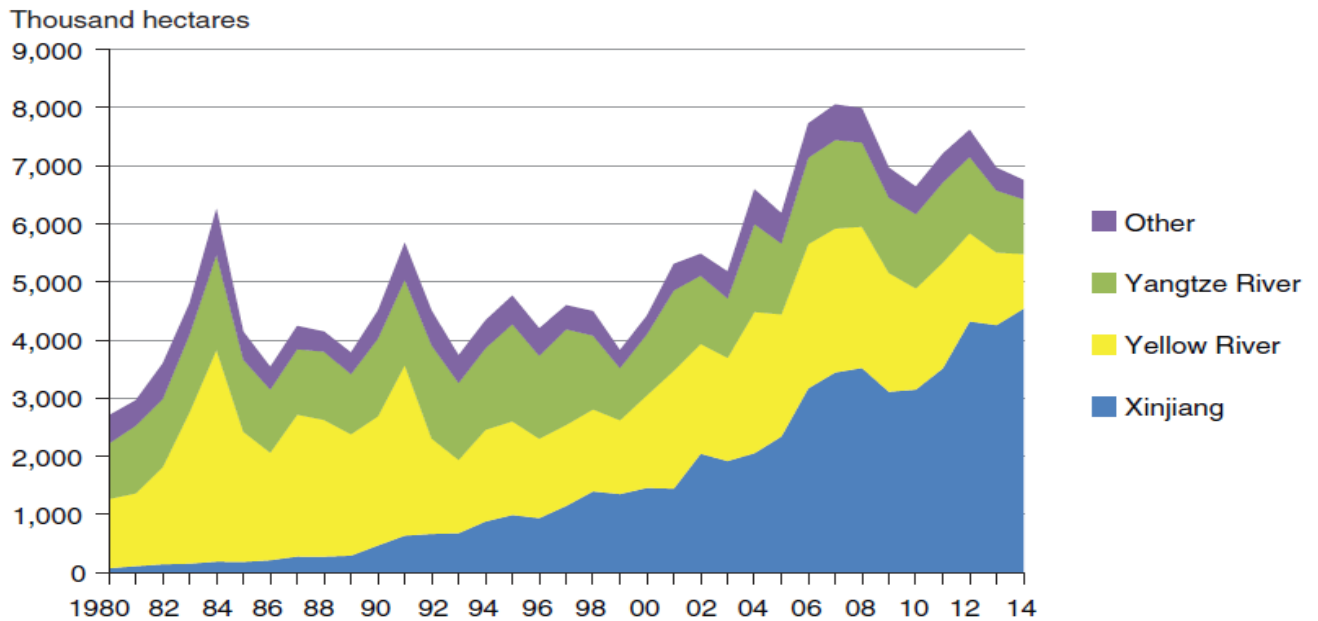


Figure 5.3 China cotton production by producing region from 1980-2014
(data from United States Department of Agriculture)

Cotton was traditionally grown in eastern China near the Yellow River (in Hebei, Henan, and Shandong provinces) and the Yangtze River (Anhui, Hubei, Hunan, and Jiangsu provinces). But since 2005, Xinjiang has become China's dominant cotton-growing region. Virtually all of the cotton grown in the eastern regions is genetically modified (GM), but only a small share of the cotton grown in Xinjiang is GM cotton. Xinjiang's climate and geography limited the bollworm infestations that drove production costs sharply higher in eastern China during the late 1980s and early 1990s, and the introduction of GM varieties has not been necessary. Since 2010, Xinjiang has accounted for about 50 percent or more of China's cotton output and is likely to see its share continue to rise.

Table 5.1 Cotton price of Kashgar Region

Year	Ton	Price (RMB/ton)
1990	1	4500
1992	1	5500
1995	1	6500
1999	1	7400
2000	1	7300
2006	1	7900
2007	1	7900
2009	1	7200
2013	1	8000
2014	1	15000
2015	1	15000

(Data:<http://www.cnce.com>; <http://www.moga.gov.cn>; www.cottonchina.org)

(2) From 2001 to 2014,

During the period, the main issue of agricultural production of this region is to balance the cultivated land area of cash crops and grain crops, due to the increasing demand of outside. In order to attain the proper balance between cash crops and grain crops, the XUAR government strengthened policies on the self-sufficiency of food in each county, requiring the main grain-producing counties to expand grain supply since 2001 (Nizam, 2001). On the other hand, the government-controlled cotton price and stabilized by the government through market control during 2001-2013 and the county governments have been trying to increase the grain production from 2001. As Figure 5.2 showed government cotton price response to world market price fluctuations. The government's changing trade distortions insulate the domestic market from international price fluctuations by setting trade protection lower (higher) when the world price is higher (lower) than a targeted domestic reference price (Yan, 2016). Table 5.1 showed a cotton price of the Kashgar Region from 1990 to 2014. Cotton price had fluctuated from 1990 to 2000. After the price of cotton had been stable by government control. Therefore, during these periods, cotton yield had been stable, other grain areas have been increased, remarkably. A consequence, agriculture enabled people to produce surplus food. Kashgar Region grain production has increased from 392 kg per capita in 1989 to 660 kg per capita in 2016 (Figure 5.5). The government standard per capita was 500 kg. The agricultural production enough support to a rapidly growing population.

However, Kashgar Region located at the southwest of Xinjiang and head part of Tarim Basin. The territory of the Kashgar Region is 113,912 km², composed of 11 counties (Figure 5.6). The significance of Kashgar prefecture has a border of 888.5km and four border-crossings, with neighbouring countries of Tajikistan, Afghanistan, Pakistan and Kyrgyzstan to its west, and India to its southwest (Figure 5.7). However, Economic activities of the

Kashgar Region are limited, separated from other regions. Because most of the area occupied with mountain and desert in XUAR. It is a nodal point for land transportation to Central and South Asia and is therefore considered China's frontier in trade and economic cooperation with Central Asia (Mei, 2011).

In addition, the textile industry is based on the east coastal regions of China. The major cotton output from XUAR being shipped to the coastal region (Fang et al., 2009). However, Kashgar locates at a special geographic position and the relatively backward transport is a disadvantage in its distribution and export agricultural products (Li et al., 2010). Kashgar Region is far from the main grain producing provinces in eastern China. Without the highway's agricultural products of Kashgar cannot be shipped out of the region smoothly, and logistics costs will remain high. Transportation and roads were poor within the region, as well as between XUAR and another part of China (Nizam, 2000). Therefore, the Central government has planned to improve Kashgar's transportation networks and connect to other countries. Central government invested 7 billion RMB (G) (Chinese yuan) for railway and highway construction from 2001 (China Highway, 2014; Mu and Jong, 2012) Paved of 807 km highway until 2012. Road network systems have been increasing trend continually (Figure 5.6).

Transport infrastructure development, such as railway and expressway, results in the "collapse" or "compression" of time and space between places (Janelle, 1969), which can be reflected in the change in accessibility. In Kashgar Region far behind other regions of the country in railway development. Established a railway construction from Kashgar to Urumqi (Figure 5.8) in 2000. The total length of the railway was 1588km. By the end of 2008 railway construction has started from Kashgar to Hotan, the end of 2011 was finished. The total length of railways was 488.27 km (Figure 5.8) and the average speed rose to 120 km/h. The development of expressways in Kashgar also started in the late 2008s. The Kashgar Region will become the only district in southern XUAR that owns the expressway.

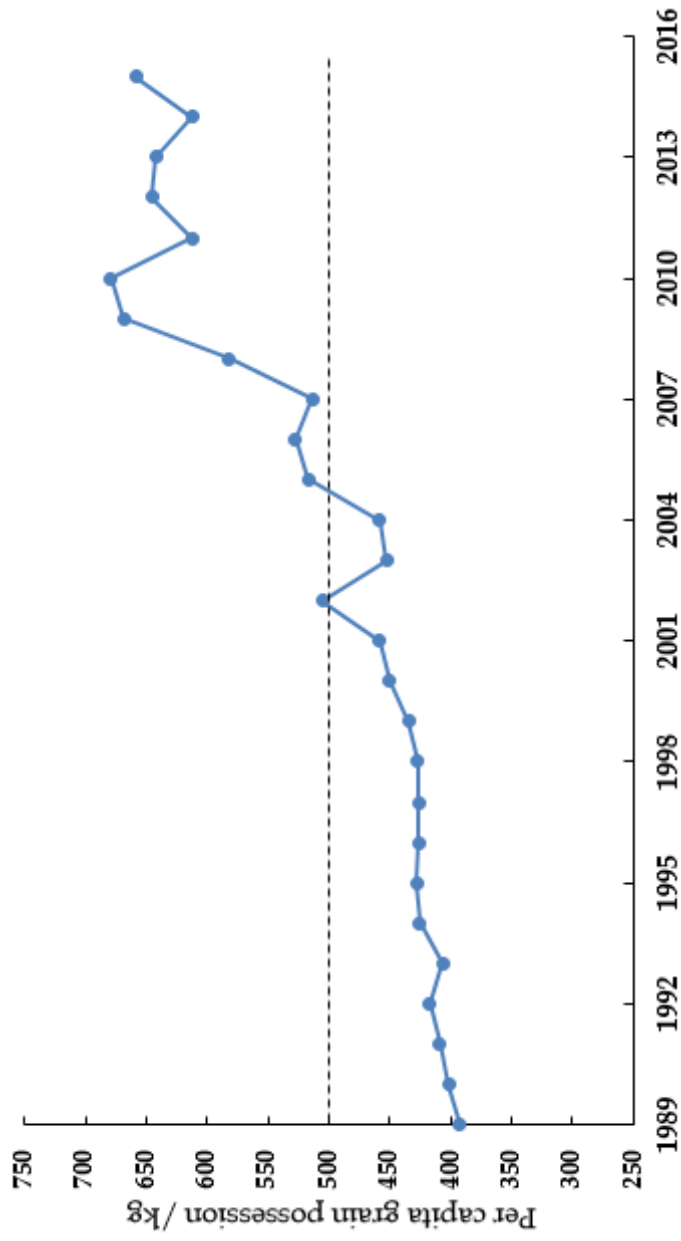


Figure 5.5 Grain production of Kashgar Region from 1989 to 2016

The government stander is 500 kg per capita, the line is represented government stander. Grain production exceed local consumptions from 2001.

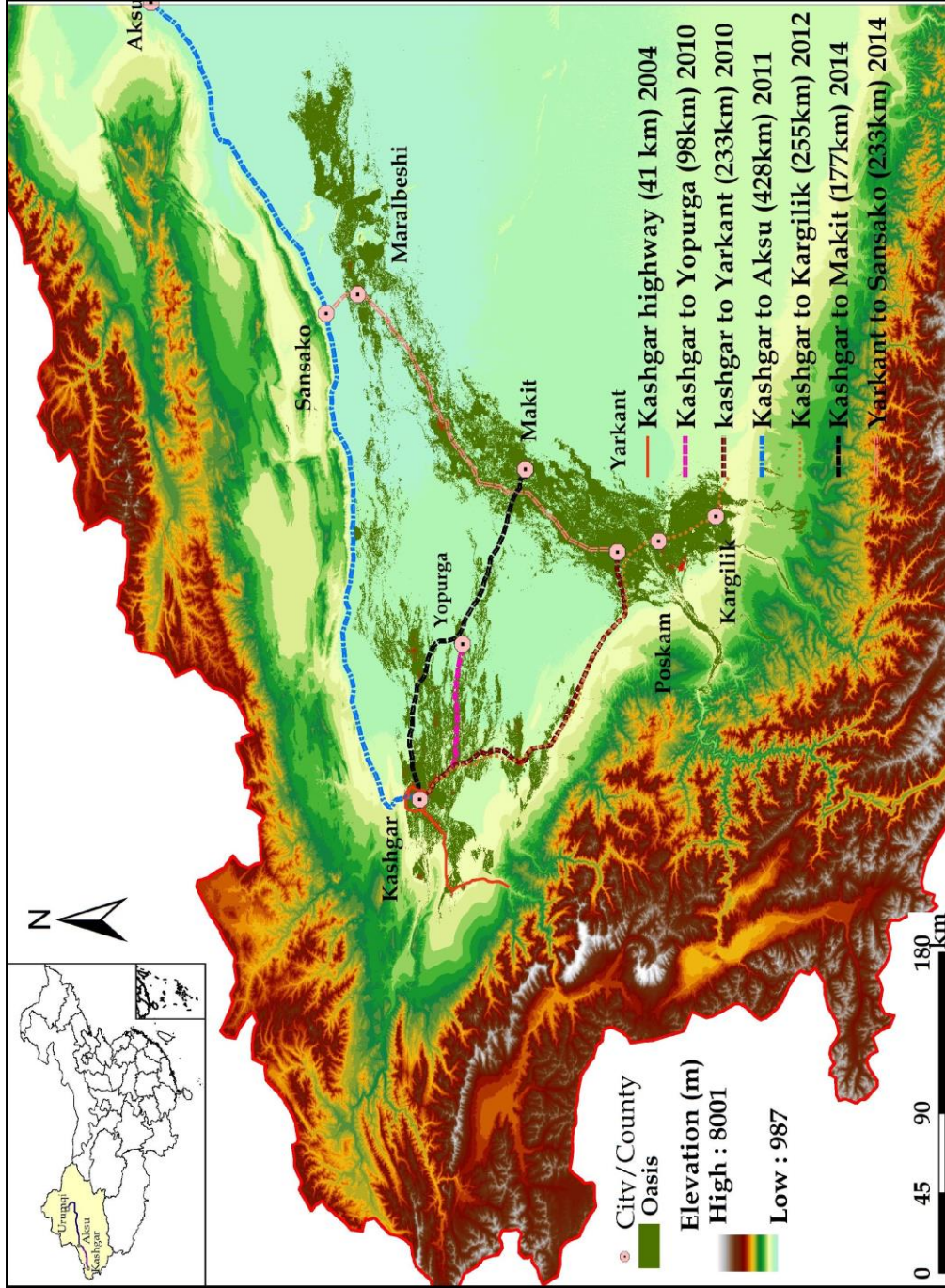


Figure 5.6 Oasis and road network of Kashgar in 2014

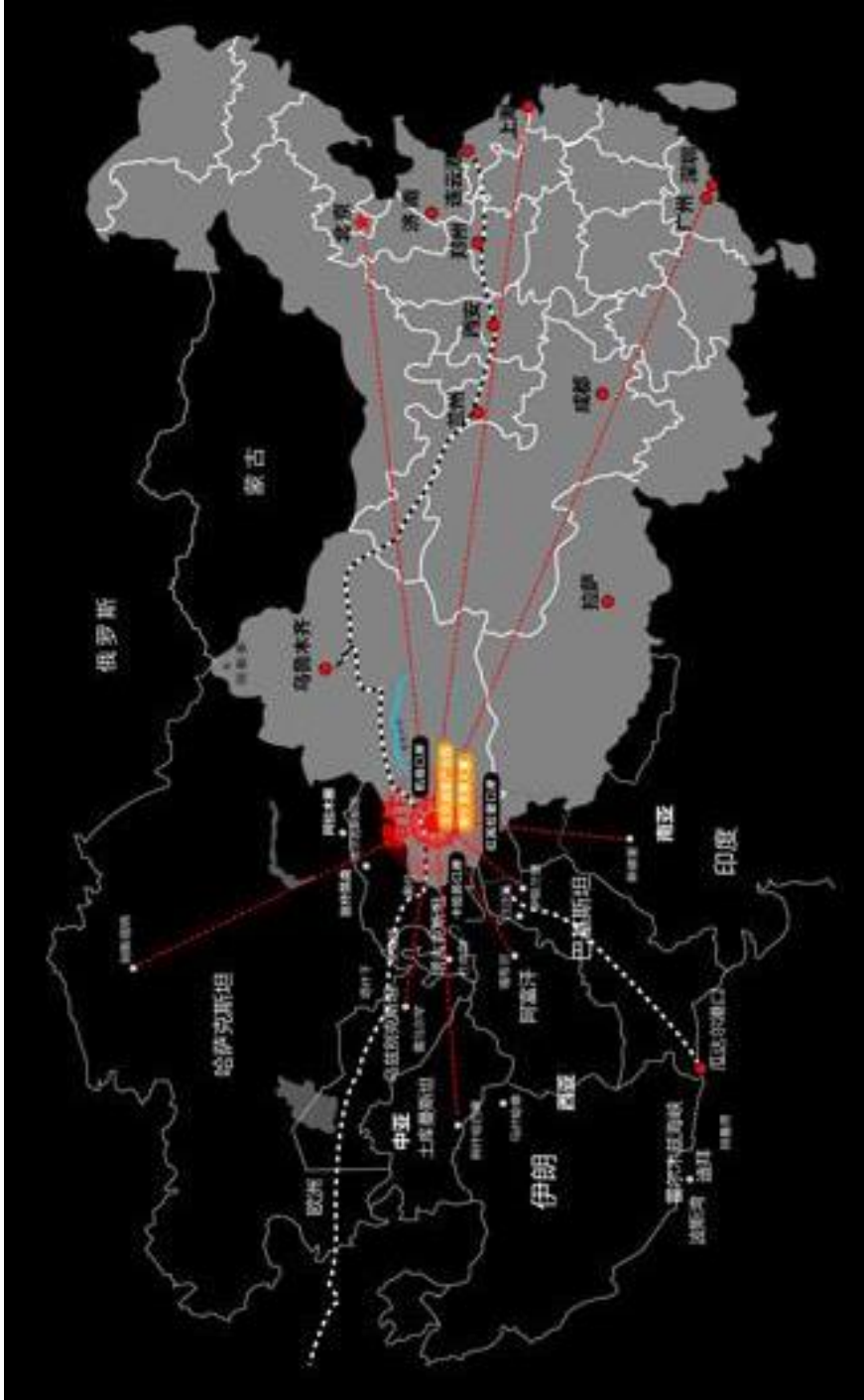


Figure 5.7 Kashgar Region and its bordering countries (data from Wikipedia)
Red circle represented Kashgar. Kashgar Region bordered with Afghanistan, Kazakhstan, Kyrgyzstan, Pakistan, Tajikistan and India. Geographic location of Kashgar Region is very important to connect with east to west of China.

The government invested and improved for main road constructions of each county. The Kashgar - Makit Expressway, which are 143 kilometres long (from Kashgar City connected to Magneti County, Payziwat County, Yopurga County); Kashgar - Yarkant Expressway (connected Sanchakou Township and Maralbeshi County). The total length of the Kashgar section is approximately 234 kilometres; Kashgar section from the Aka highway (from Aksu to Kashgar) is approximately 200 kilometres long. In addition, the Kashgar - Qargilik Expressway G3012 (Kashgar City to Qargilik County, which was officially opened to traffic in September 2012 and has a total length of 230 kilometres. Kashgar Region currently has four expressways with a total length of 807 kilometres (Figure 5.6). Consequently, a paved new road for linked regional and convenience in transport connection with expressways. The transport infrastructure was a major bottleneck for regional development. However, the development of a road network is one of the strongest causes of LUCC, especially, cultivated land and urban/ built-up land expansions in the Kashgar Region. High- resolution satellite images of 2000 and 2014 were used to quantify analyse spatial and temporal changes of road networks, which were digitized manually. Road network density (RD) (Alphan, 2017) was calculated following formula:

$$\text{Road density} = \frac{\sum_{j=1}^n L_{ij}}{A_i}$$

L_{ij} : length of road segmented

A_i : area of landscape

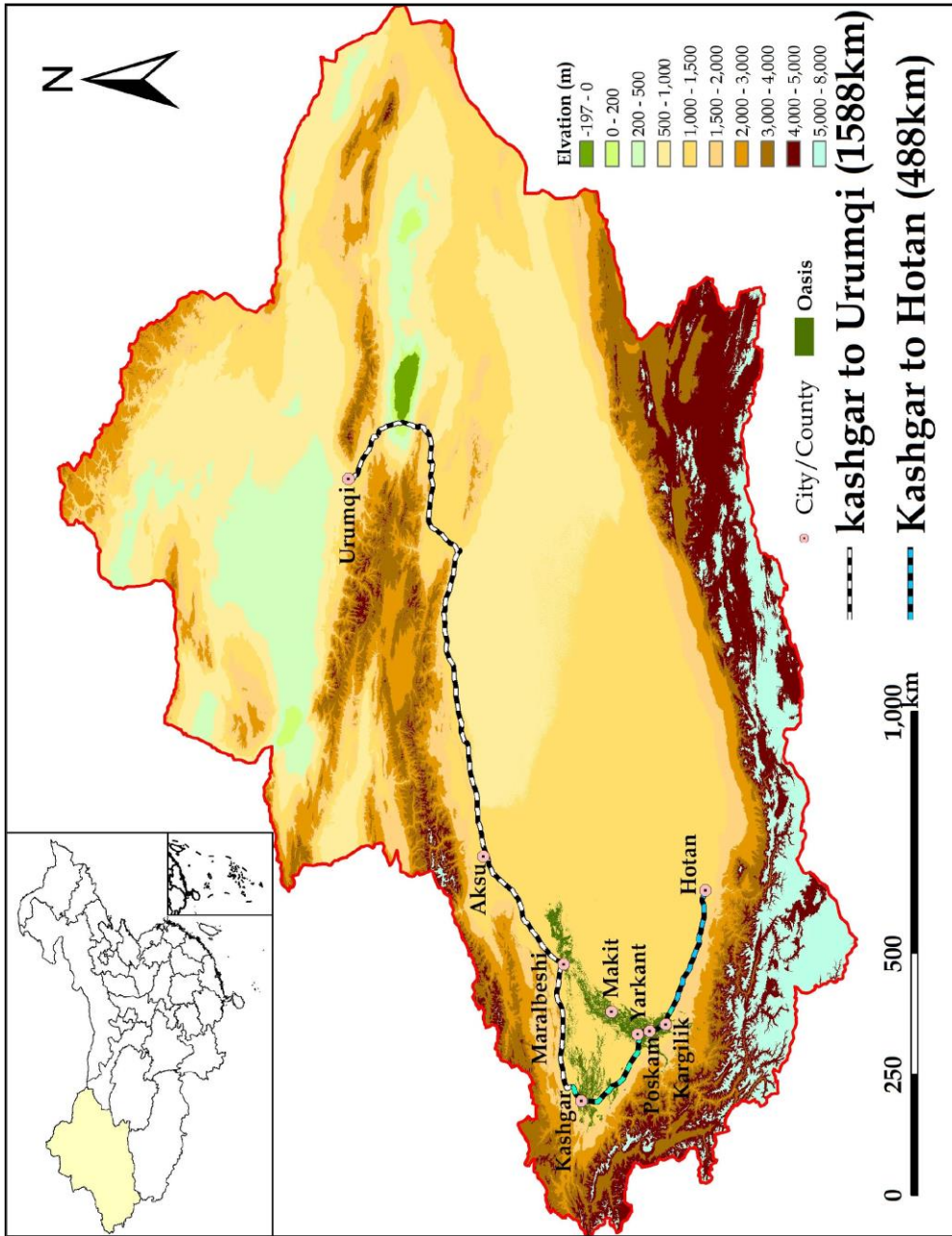


Figure 5.8 Kashgar – Urumqi railway

Total railway length of Kashgar and Urumqi (capital city of Xinjiang Uyghur Autonomous

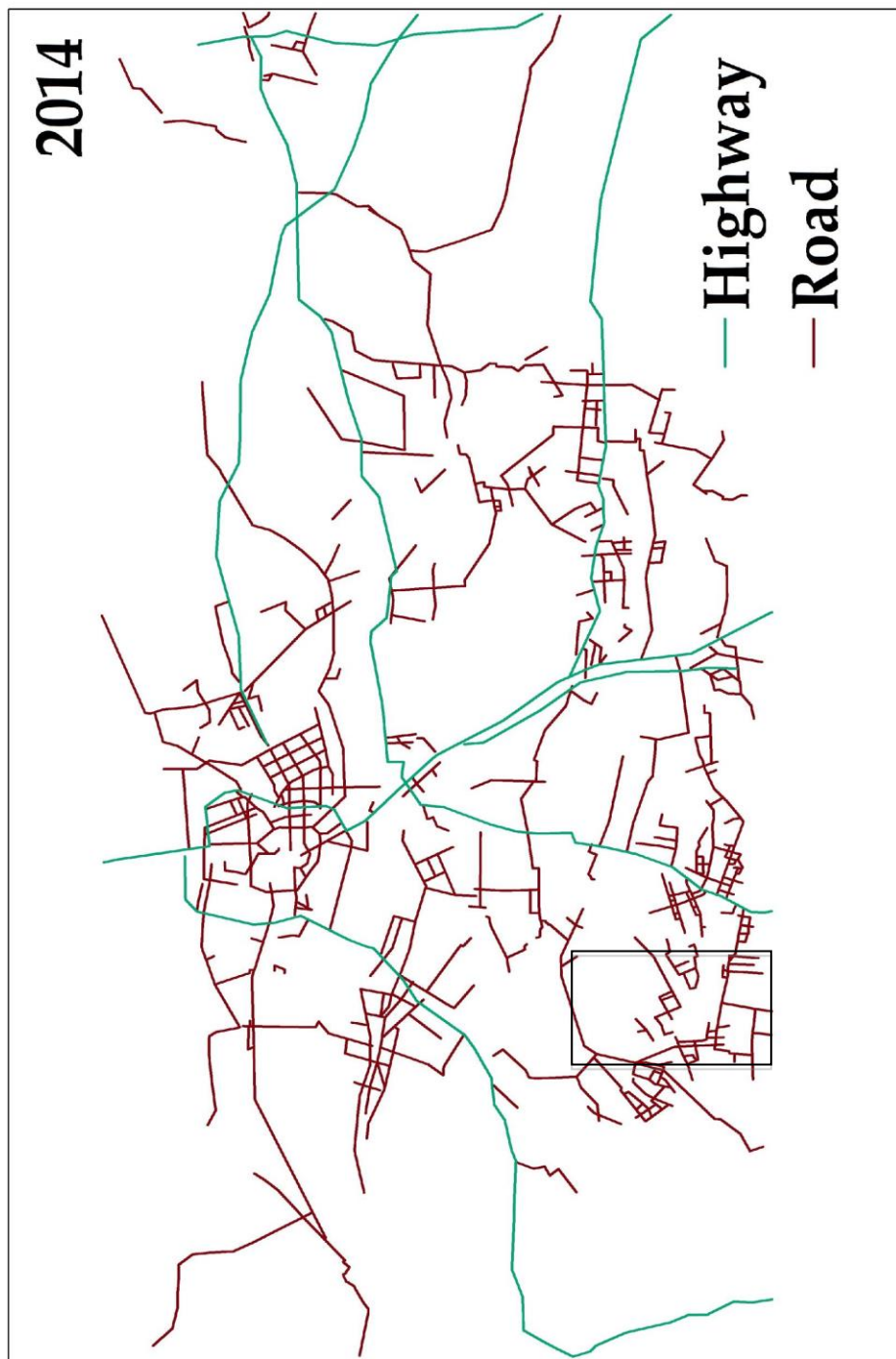


Figure 5.9 Major highway and domestic road network of Kashgar City area
Green is highway, red is domestic road and black rectangle is Yingsar County. Yingar

As Figure 5.9 showed except expressways, the road network also has been increased in the Kashgar Region. Road network development simultaneously with agricultural expansion and urban/built-up land. Many of the land cover changes witnessed by rapid road development in the Kashgar Region. We selected Yingsar County (Figure 5.9 black rectangle area), was calculated by the according to RD formula. The results showed that RD has been increased 27km (23.6%) during 2014. The cultivated land area also expanded over 160ha (7.6%) (Figure 5.11). Increasing road development and expressway network of Kashgar has been linking to the markets. This process stimulated with agricultural and built-up land expansions, remarkably. There are plenty of evidence expansions of cultivated and urban-built up land as Figure 5.12 showed.

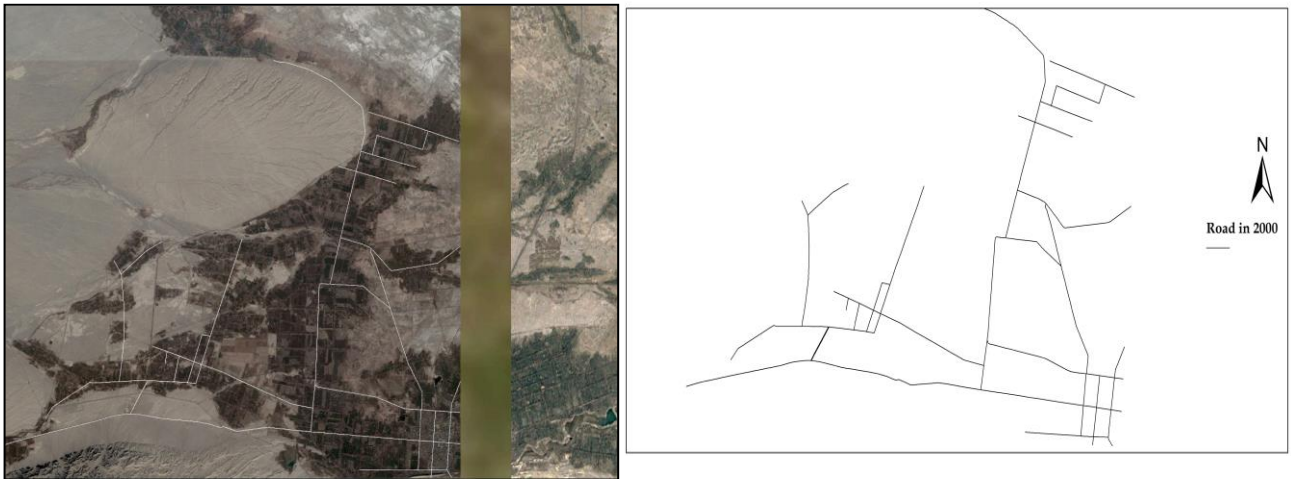


Figure 5.10 High-resolution of Yingsar County of Kashgar Region in 2000 (left) and its road digitization results (right)



Figure 5.11 High-resolution image of Yingsar county of Kashgar in 2014(right) and its road digitization results from 2000 to 2014 (left)

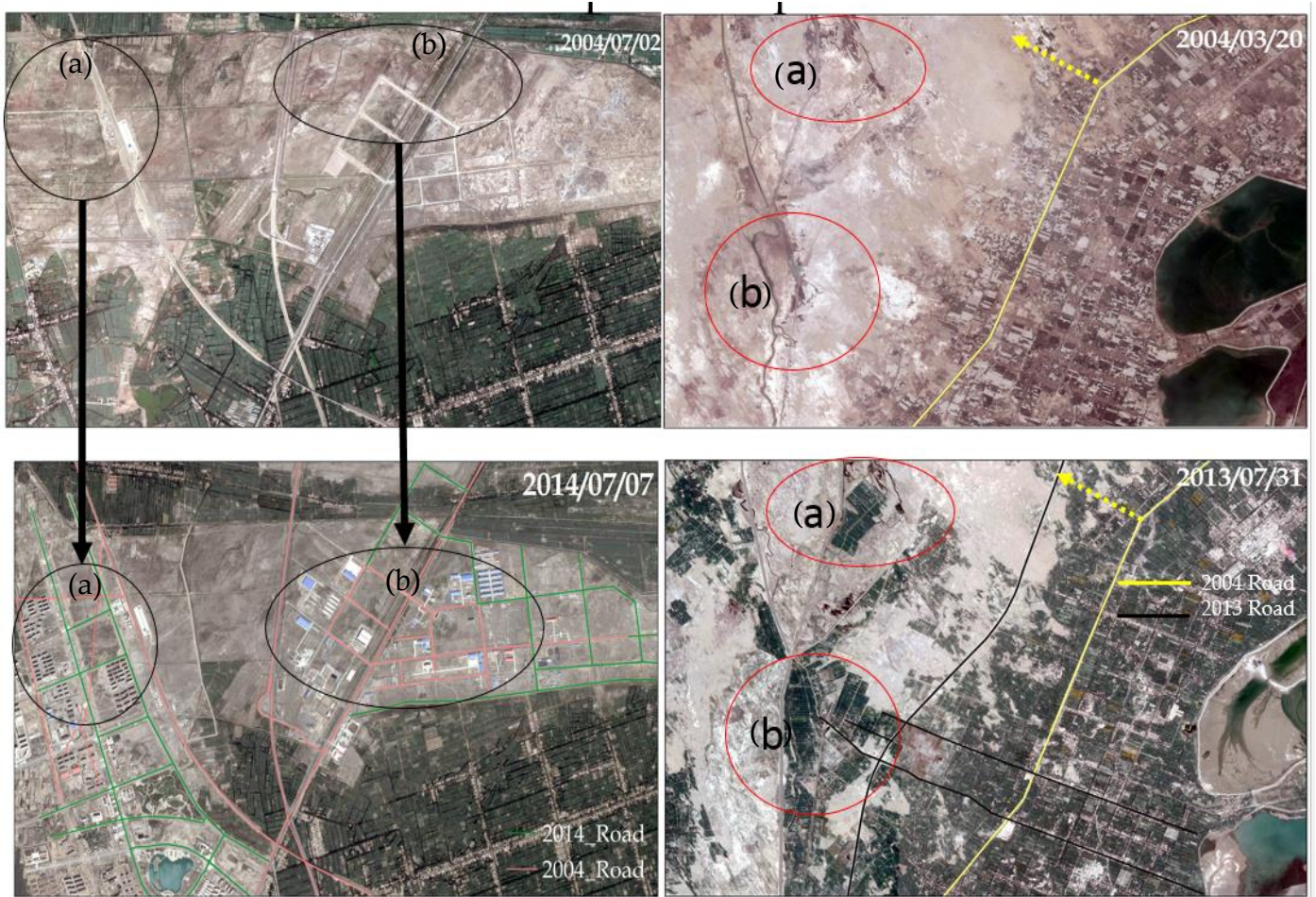


Figure 5.12 Road network development have created agricultural and built-up land expansions of Kashgar Region (local scale)

Both black, red circle with (a) and (b) are bare lands in 2004, paved road and strength road network. Consequence these process, bare land converted to cultivated and urban built-up land.

^(H) Under structural adjustment policies

The rapid economic growth, urbanization and food market development of China have boosted demand for meats, fruits and other non-staple foods, changes that have stimulated sharp shifts in the structure of agriculture (Ji and Scott, 2002). In addition, since China reached the agreements with the U.S. and European Union in November 1999 and May 2000 respectively on China's accession to the WTO (I). In order for China's agriculture to participate in international competition and share the benefits from international trade, China adjusted its structure of domestic agricultural production under the principle of comparative advantage. Under demands of outsiders in regional telecoupling and structural adjustment policies, there has been increased vegetable and melon field to production vegetable and melon towards market requirements from 2006 in Kashgar Region. Figure 5.13 shows melon and vegetable area have been increased remarkably since 2006. These further triggered the expansion of land sown for melon and vegetable cultivation.

China joined WTO, officials considered support measures used in other countries to design measures that would conform to the country's WTO obligations (Lu and Deng, 2011). Moreover, high rates of economic growth and a lower share of agriculture in the economy, the government concerned national food self-sufficiency and rural household incomes, China changed its policy and began instead to subsidize those (Lopez et al., 2017). The consequence, China's support for agriculture has grown by the addition of new programs and extension of coverage to more regions and commodities. Support is focused mainly on rice, wheat, and corn, but it has spread to other crops and livestock. The general input subsidy accounted for most of the growth in subsidy payments to farmers in all localities. In 2004, Gale et al., (2005) found that the direct payment to grain producers was about \$7 per acre and seed subsidies were about the same amount in most places in China including XUAR. A compilation of 2012 subsidy documents from various localities

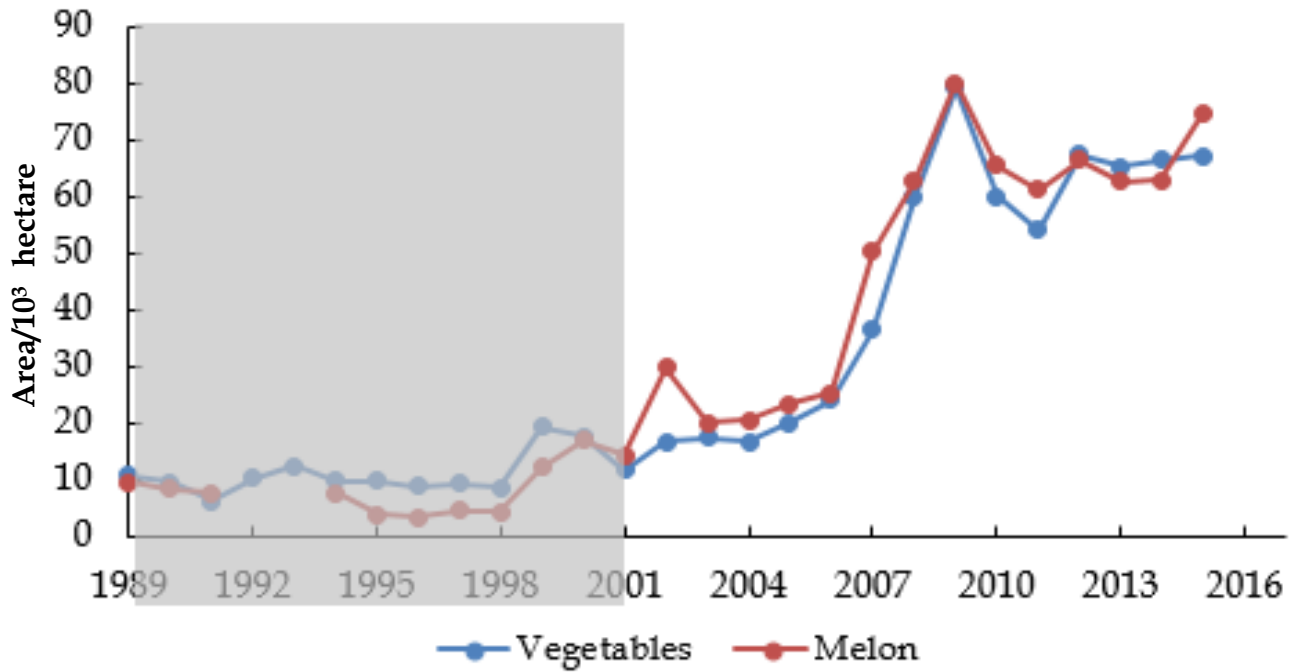


Figure 5.13 Area of vegetable and melon of Kashgar Region

Data from XJSYB. The blue line is a vegetable field area and the red line is melon field area. From 2001, vegetables and melon field area has been increased.

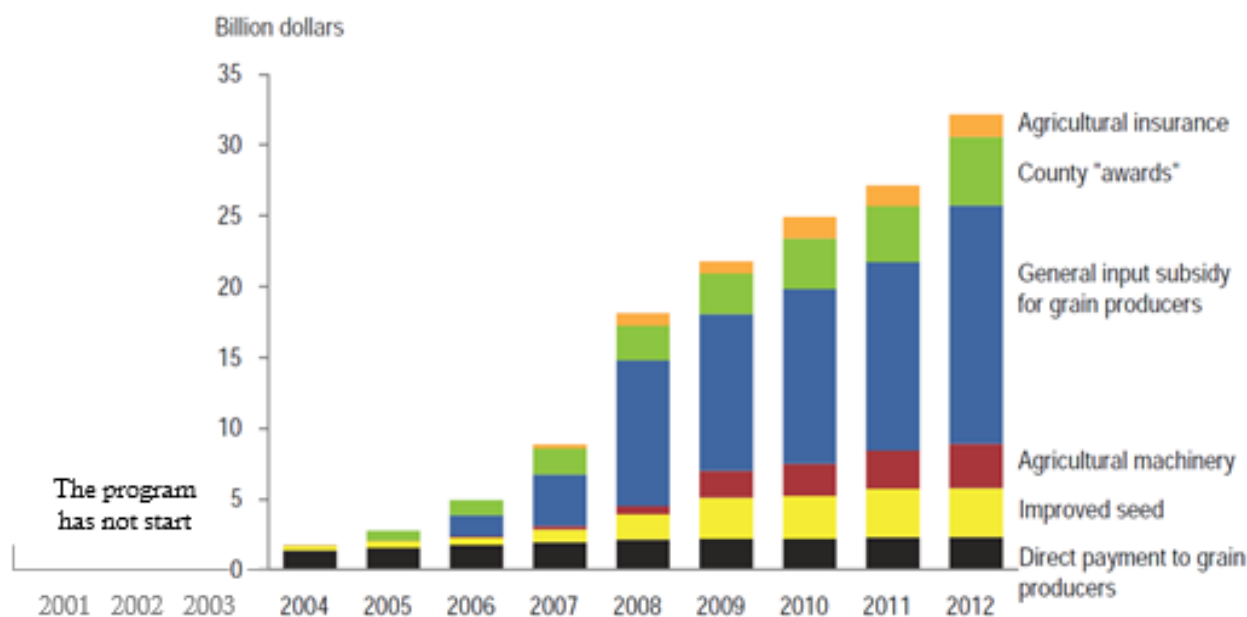


Figure 5.14 Central government expenditures on major agricultural subsidy programs

(data from United States Department of Agriculture)

China joined World Trade Organization (WTO) in 2001 and agricultural subsidy implemented within the WTO rules. Programs initially focused on producers in major grain-producing areas were extended to other commodities and regions. Amounts converted to U.S. dollars at official exchange rates. Source: USDA, Economic Research Service compilation of information from China Ministry of Finance.

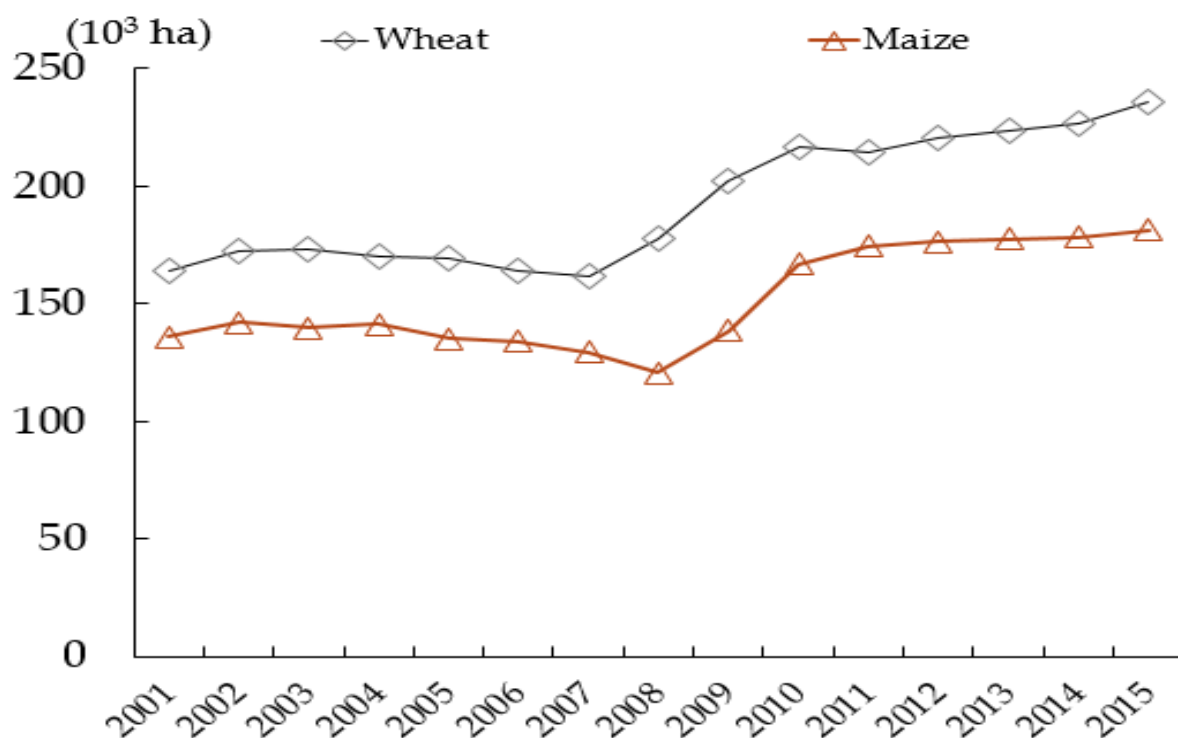
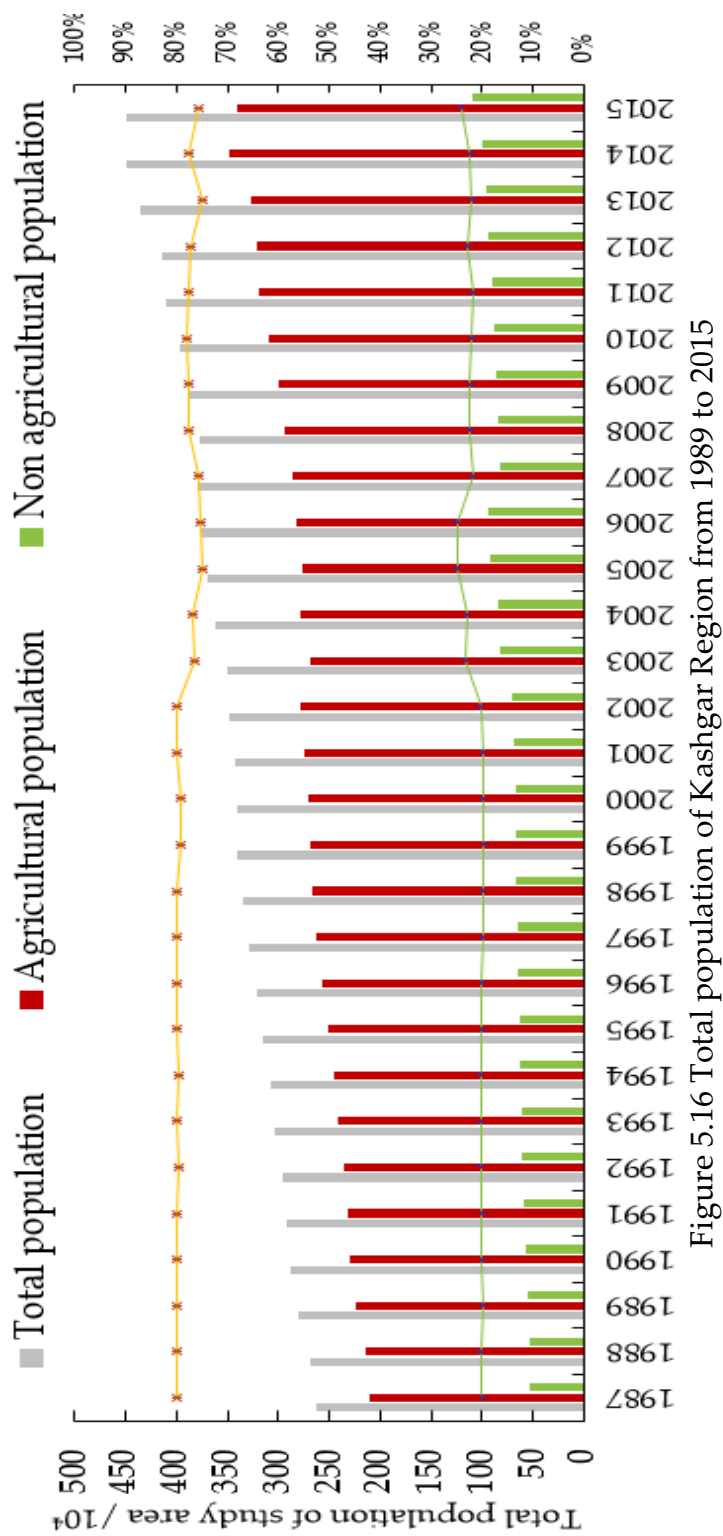


Figure 5.15 Grain area of Kashgar Region from 2001 to 2016
(data from XJSYB)

Agricultural subsidy implemented by government policy in 2004. However, the Kashgar Region agricultural subsidy implemented from 2008, mainly wheat and maize. The consequence of this programme, wheat and maize area expanded, remarkably during the time.

indicates that the combined total of the direct-payment and general-input subsidy now ranges from about \$60 to over \$100 per acre. Programs initially focused on producers in major grain-producing areas were extended to other commodities and regions started in 2004 (Figure 5.14). In the Kashgar Region, agricultural subsidies implemented from 2008. This process caused cultivated land expansions further, especially wheat and maize from 333.73×10^3 ha in 2008 to 456.19×10^3 ha in 2015 (Figure 5.15).

The growth of the population was identified as another cause of agricultural expansions and urban land use changes by Zhou et al., (2003), Zhang et al., (2003), Wang et al., (2008) and Til et al., (2015) for different parts of arid region Northwest China. The overall population trends in the Kashgar Region were increased from 2,745,362 in 1987 to 4,683,114 in 2014 (Figure 5.16), characterized by an increase in agricultural, non-agricultural population and urban population density. Population growth causes a sequence of immediate life-sustaining needs such as resident space, food and shelter (Uusivuori et al., 2002). The bare land and cultivated land were converted to the urban/built-up land, which increased from 40.2 km² in 1972 to 392.8 km² in 2014. The population density of Kashgar city increased from 789 inhabitants per km² in 1990 to 1155 inhabitants per km² in 2000 to 2063 inhabitants per km² in 2014, while population density of other counties also increased remarkably (Table 5.2). Among the total population, especially, 78% of residents of a population in the rural areas belong to agricultural population, where the households are largely depending on land resources for their basic needs and economic desires. Kashgar `s economy is depending on agriculture, which is very important to the economy of the Kashgar Region. Agriculture contributes 45% of gross domestic product (GDP) (Figure 5.17) and over 90% of employment in the country (Figure 5.18). During the 1990s, the development of agricultural production mainly depends on the expansion of cropland due to the low per unit yield of crops, and thus cropland increased slowly. In the meantime, the market economy, a greater area of a cotton plantation that was also stimulated by rising cotton price,



(Data from XJSYB)

The overall population has been increasing during the time, among the total population, especially, 78% of residents of a population in the rural areas belong to the agricultural population.

Consequences caused grassland and forest land to be reclaimed. Since 2001, the price of cotton had been controlled and kept stable (Table 5.1). The land exploitation shifted to the excessive exploitation and focused on improving per unit yield, consequently, per capita cultivated land has been increased (Figure 5.19) and land intensification occurred. Grain production was sufficient for the growing population. Agricultural population provided grain production for themselves and the non-agricultural population (Figure 5.22). A consequence, grain production has been exceeding regional consumptions. The surplus had been increased. Most of grassland and forestland were occupied by cultivated land for satisfying people`s demand for food and economic desires (Table 2.1). As a result, the grassland decreased from 4779.1 km² in 1972 to 2680.6 km² in 2000, and forestland decreased from 3584.5 km² in 1972 to 1344.5 km² in 2014. Population growth resulted from the expansion of cultivated land with reclamation and evident shrinkage of grass- and forestland.

We concluded that an increasing cultivated land of Kashgar Region has the interactions of population growth and a related increase in agriculture labour and surplus, rising cotton demand drove prices, expansion of infrastructure connectivity between distant locations, expansions of railway and highway constructions, adjustment production of cotton and other crops, implementation of direct agricultural subsidies caused agricultural expansion. A consequence, cultivated lands have been shifted land use from small- to large-scale intensive farming occurred. These causes were the primary causes of LUCC in the Kashgar Region. However, significant cultivated land expansion has increased water consumption in the arid region of Kashgar.

Table 5.2 Population density of city and counties of Kashgar Region

Year	1990	2000	2014
City, Counties	Population density (person/km²)		
Kashgar	789	1155	2063
Konashaheer	98	99	82
Yingshahar	110	126	166
Yingsar	56	62	88
Poskam	139	181	223
Yarkant	60	68	93
Karghilq	11	12	17
Makit	16	18	25
Yopurga	36	40	55
Payziwat	41	47	68
Maralbishi	17	20	20
Tashkorgan	1	1.3	1.7

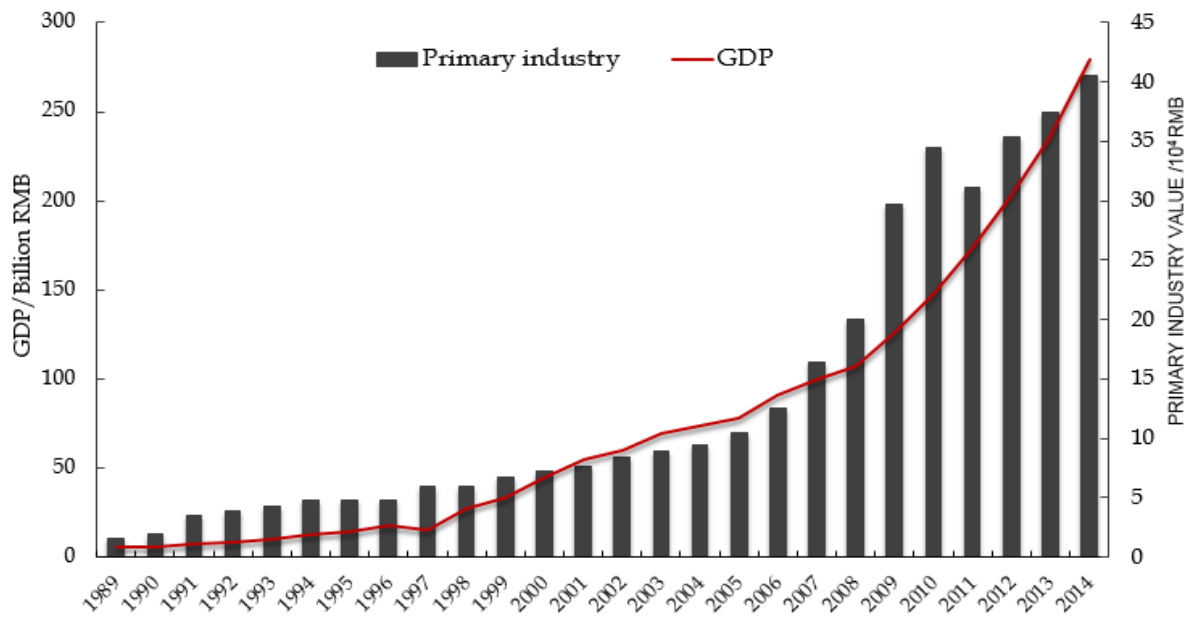


Figure 5.17 Primary industry and GDP of Kashgar Region from 1989 to 2015
(data from XJSYB)

Redline is DGP and the black table is the primary industry of Kashgar Region, Kashgar `s economy is depending on agriculture. Thus, agriculture of the Kashgar Region is greatly contributed to the GDP.

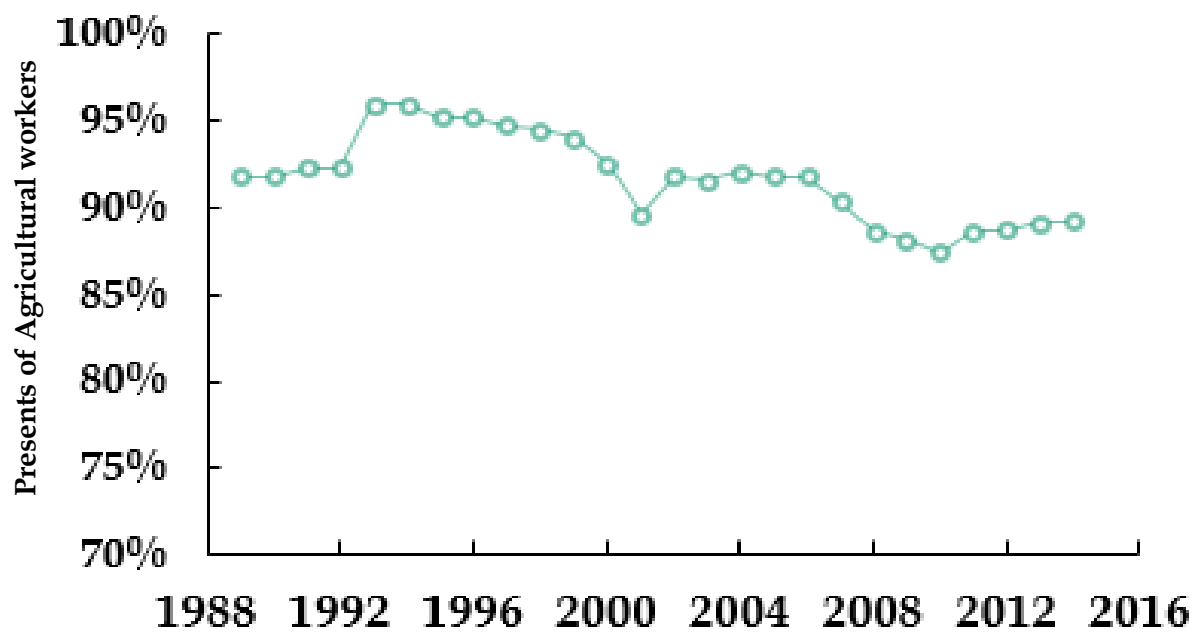


Figure 5.18 Agricultural workers of Kashgar Region

(data from XJSYB)

78% population is agriculture population, the agriculture works of the Kashgar Region accounted for 90%.

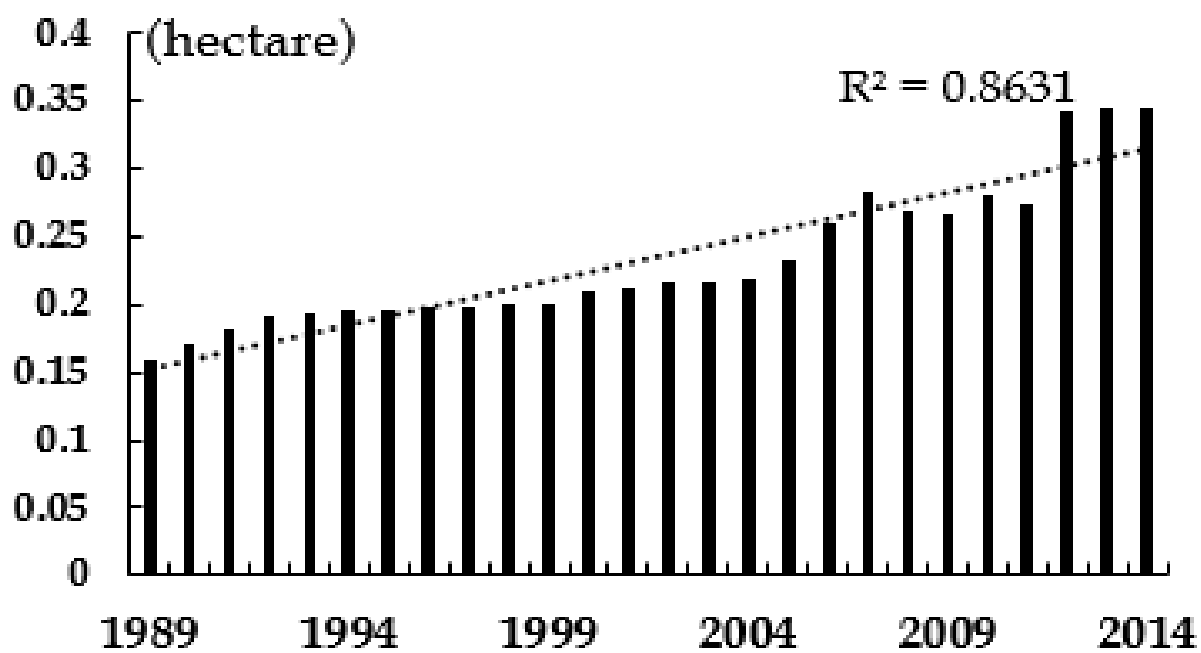


Figure 5.19 Per capita cultivated land area of Kashgar Region
(data from XJSYB)

Per capita cultivated land has been increased during the study period.

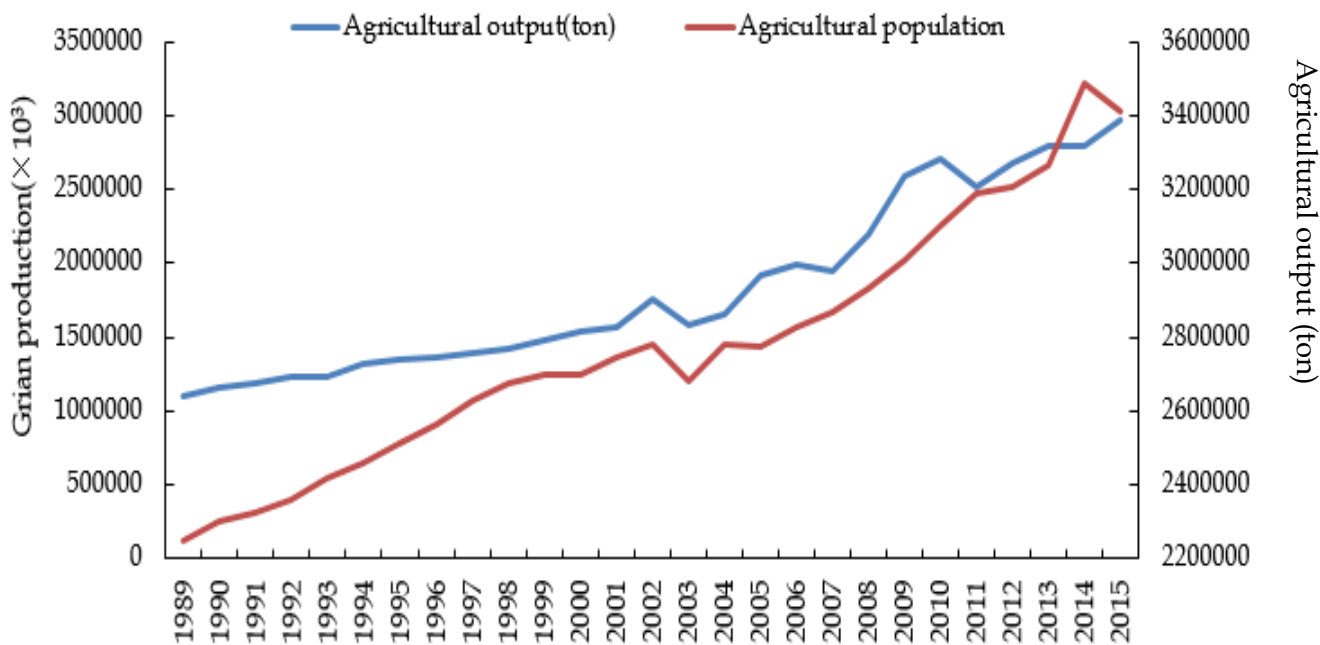


Figure 5.20 Agricultural output and agricultural population of Kashgar Region
(data from XJSYB)

78% of residents of a population in the rural areas belong to the agricultural population, where the households are largely depending on land resources for their basic needs and economic desires. The agricultural population provided grain production to themselves and the non-agricultural population.

Explanations of terms:

AA) sown area:

Refers to an area of land sown or transplanted with crops regardless of being in the cultivated area or no cultivated area. Area of land re-sown due to natural disasters is also included. The indicator can reflect the utilization condition of China. At the present, the sown area of crops mainly includes the following 9 categories: grain, cotton, oil-bearing crops, sugar crops, fibre crops, tobacco, vegetables and melons, medical materials of China.

A) Mutual Aid Group System

In 1954 mutual aid teams were organized with increasing rapidity into agricultural producers' cooperatives, which differed from mutual aid teams in that tools, draft animals, and labour was shared on a permanent basis. Cooperative members retained ownership of their land but secured a share in the cooperative by staking their plots along with those of other members in the common land pool. By 1956 the transformation of mutual aid teams into agricultural cooperatives was nearly complete.

B) Production Cooperative System

A production cooperative, also known as a farmers' co-op, is a cooperative where farmers pool their resources in certain areas of activity. A broad typology of agricultural cooperatives distinguishes between agricultural service cooperatives, which provide various services to their individually farming members, and agricultural production cooperatives, where production resources (land, machinery) are pooled and members farm jointly.

C) People's Commune

The people's commune was the highest of three administrative levels in rural

areas of the People's Republic of China during the period from 1958 to 1983 when they were replaced by townships. Communes, the largest collective units, were divided in turn into production brigades and production teams. The communes had governmental, political, and economic functions during the Cultural Revolution. The people's commune was commonly known for the collective activities within them, including labour and meal preparation, which allowed workers to share local welfare. Though, this also caused the communities of people included in the people's communes to be struck harder by food shortages and face longer hours than under individual labour.

D) Three- year natural disaster's year

Three- year natural disaster's year was a period in the Kashgar Region between the years 1963 and 1966 characterized by widespread famine. Drought and poor weather contributed to the famine, although the relative weights of the contributions are disputed. Estimates of deaths due to starvation range in the tens of millions.

E) Cultural Revolution

The Cultural Revolution, formally the Great Proletarian Cultural Revolution, was a socio-political movement in China from 1967 until 1977. Launched by Mao Zedong, then Chairman of the Communist Party of China, its stated goal was to preserve 'true' Communist ideology in the country by purging remnants of capitalist and traditional elements from Chinese society, and to re-impose Mao Zedong Thought as the dominant ideology within the Party. The Revolution marked Mao's return to a position of power after the Great Leap Forward. The movement paralyzed China politically and negatively affected the country's economy and society to a significant degree.

F) Household Responsibility System (HRS)

The household responsibility system or contract responsibility system was a

practice in China, first adopted in agriculture in 1979 and later extended to other sectors of the economy, by which local managers are held responsible for the profits and losses of an enterprise. This system partially supplanted the egalitarian distribution method, whereby the state assumed all profits and losses.

G) Central government invested 7 billion Yuan for railway and highway constructions

China's \$1 trillion One Belt, One Road (OBOR) infrastructure project has a significant landscape, socio-economic, and political implications in recipient countries. The Kashgar Region is one of the main hubs of China connected with Central Asia. Based on the Transport Department of XJUAR report, the Central government invested 7 billion Yuan for railway and highway constructions (<http://jtnw.sub.xjtt.gov.cn>).

H) Agricultural Structure Adjustment Policy

The central government implemented the Structure Adjustment Policy, the structure of the rural economy has become diversified at several different levels. Firstly, grain production (rice, wheat, maize, millet, soybeans, and root vegetables) has gradually made way for commercial growing (vegetables, fruit, peanuts, oilseed, beetroots, etc.). The second major change was the rapid development of rural industries.

I) China joint WTO

China became a member of the World Trade Organization (WTO) on 11 December 2001. The admission of China to the WTO was preceded by a lengthy process of negotiations and required significant changes to the Chinese economy. It's signified China's deeper integration into the world economy (Wikipedia).

5.2 Impact of LUCC on water resources

Due to the extremely arid climate, with annual precipitation of less than 100 mm, the water supply along the Kashgar Region solely depends on river water and groundwater for irrigation. The ongoing increase in water consumption by the human activities in the Kashgar Region enhancing the competition for water between human needs and nature. This linked to anthropogenic activities and natural ecosystems as both compete for water. We estimated the consequence of LUCC to water consumption. Based on the river discharges in the region, the supply and demand of water resources were analysed. Water consumption of agriculture from four main crops considered, which are cotton, corn, wheat, and oilseed. Their water consumptions were obtained by Shen et al. (2013), they estimated these main crops irrigation water requirement based on the evapotranspiration under the assumption of all area has irrigation. In total 6700 m³ water is needed to irrigate one hectare of cotton per year. 4920 m³ water is needed to irrigate one hectare of corn per year. 4560 m³ and 3520 m³ water are needed to irrigate one-hectare wheat and oilseed per year, respectively. This water consumption of main crops had multiplied by their cultivated land areas.

Domestic and industrial water consumptions were calculated as formula (1), (2). The data for domestic water demand based on government statistical data and water use per capita (urban per capita used 100L/day water and rural per capita used 70L/day). Data for industrial water consumption included industrial output value and industrial production water data were compiled statistical yearbook of Xinjiang Uyghur Autonomous Region. Annual river discharge data from hydrological stations from 1990, 2000 and 2014 were selected for analysing the water supply and demand of Kashgar Region.

Domestic water consumption was calculated as follows:

$$\mathbf{W}_{dwc} = \mathbf{W}_{uwc} + \mathbf{W}_{rwc} \quad (1)$$

\mathbf{W}_{dwc} is domestic water consumption, \mathbf{W}_{uwc} is urban water consumption, \mathbf{W}_{rwc} is rural water consumption (Xia and Liang, 2012).

Urban water consumption (\mathbf{W}_{uwc}) was calculated as follows:

$$\mathbf{W}_{uwc} = P_{\text{urban population}} \times \mathbf{W}_{\text{urban water quota}}$$

$$\mathbf{W}_{\text{urban water quota}} = 100 \text{ L} \times 365 \text{ day}$$

Rural water consumption (\mathbf{W}_{rwc}) was calculated as follows:

$$\mathbf{W}_{rwc} = P_{\text{rural population}} \times \mathbf{W}_{\text{rural water quota}}$$

$$\mathbf{W}_{\text{rural water quota}} = 70 \text{ L} \times 365 \text{ day}$$

Industrial water consumption was calculated as follow (Xia and Liang, 2012):

$$\mathbf{W}_{iwc} = P_{\text{industrial output value}} \times \mathbf{W}_{\text{industrial production water consumption}} \quad (2)$$

The total water demand was obtained by aggregating the agricultural irrigation demand, industrial demand and domestic water demand. With the increase in each type of water demand, there was an upward trend in the total water demand from the 1990, 2000 and 2014 in the Kashgar Region. The total water demand increased from $22.37 \times 10^8 \text{ m}^3$ in the 1990s $40.94 \times 10^8 \text{ m}^3$ in 2000s and $56.92 \times 10^8 \text{ m}^3$ in 2014 (Table 5.3).

Table 5.3 Water consumptions of domestic, cultivated land and industry
 The agricultural irrigation took up more than 90 % of the total water consumption.

Year	Domestic water consumption	Agricultural water consumption	Industrial water consumption	Total water consumption
1990	$0.77 \times 10^8 \text{ m}^3$	$21.26 \times 10^8 \text{ m}^3$	$0.34 \times 10^8 \text{ m}^3$	$22.37 \times 10^8 \text{ m}^3$
2000	$0.90 \times 10^8 \text{ m}^3$	$39.49 \times 10^8 \text{ m}^3$	$0.54 \times 10^8 \text{ m}^3$	$40.94 \times 10^8 \text{ m}^3$
2014	$1.15 \times 10^8 \text{ m}^3$	$54.67 \times 10^8 \text{ m}^3$	$1.09 \times 10^8 \text{ m}^3$	$56.92 \times 10^8 \text{ m}^3$

The water consumptions results showed very obviously that agricultural water consumption occupied more than 90% of total water consumption. As we discussed before the cultivated land of the Kashgar Region has been increased remarkably. A consequence, agricultural water demand has been increased. However, annual river discharges not enough to support an ongoing increase of water consumptions by cultivated land, as Table 5.4 showed, especially after 2000. The runoff of Kashgar Region generated in mountains, and distribution of runoff was unequal during the year, resulting in a relative shortage of water resources. The water stress level also has been increased with 0.44 in 1980, 0.54 in 2000 and 0.62 in 2010 at Yarkant River Basin, 0.54 in 1980, 0.76 in 2000 and 0.69 in 2010 at Kashgar River Basin (Liu et al., 2015). It is evident that the Kashgar Region basin area faced water stress.

The water demand, we only consider water consumptions of four main crops here, in addition, cotton, wheat, corn and oil plants, crop types of Kashgar Region include other crops like soybeans, vegetables, melon, tubers, and these are also needed to water supply from the rivers. Beside from agricultural land, the major natural ecosystems are riparian forest, shrub vegetation and other natural grassland causing a competition for between water those ecosystems.

From the 2000s, cultivated land has been expanded along the alluvial fans of Kashgar Region. The alluvial plains are surrounded by mountains in the north, the west, and the south (Figure 5.21). There is a thick Quaternary loose distributed in the alluvial plain with high porosity and a large amount of leakage supply from the surface water. A series of water-rich areas are formed along the mountain front, providing groundwater with good greasy conditions and big groundwater storage. These alluvial fans particularly important groundwater reservoir, where the place plays are vital to both society and the environment, supporting food production in the Kashgar Region (Hu et al., 2002). Groundwater is supplied mainly surface water by

ice/snow melt water and precipitation from the mountain regions. From the LC results, it is known that large-scale agricultural production was mainly distributed around river banks and alluvial plain with the richest water resources area. The geographic distribution of surface water has changed due to increased human activities for irrigation, which affected the replenishment of groundwater and brought about changes to the table and the quality.

The vulnerability of the Kashgar Region to the impact of changing climate is fundamental importance because the major impact of climate change in this region would be on hydrology, affecting water resources and agricultural economy. Therefore, natural factors as temperature, precipitation, snow cover are attributable in the Kashgar Region. Hence, the next paragraph will consider natural causes of LUCC in the Kashgar Region.

Table 5.4 Comparison water supply and water demand in Kashgar Region

Year	River discharge supply	Total water consumption demand
1990	$28 \times 10^8 \text{ m}^3$	$22.37 \times 10^8 \text{ m}^3$
2000	$49 \times 10^8 \text{ m}^3$	$40.94 \times 10^8 \text{ m}^3$
2014	$50 \times 10^8 \text{ m}^3$	$56.92 \times 10^8 \text{ m}^3$

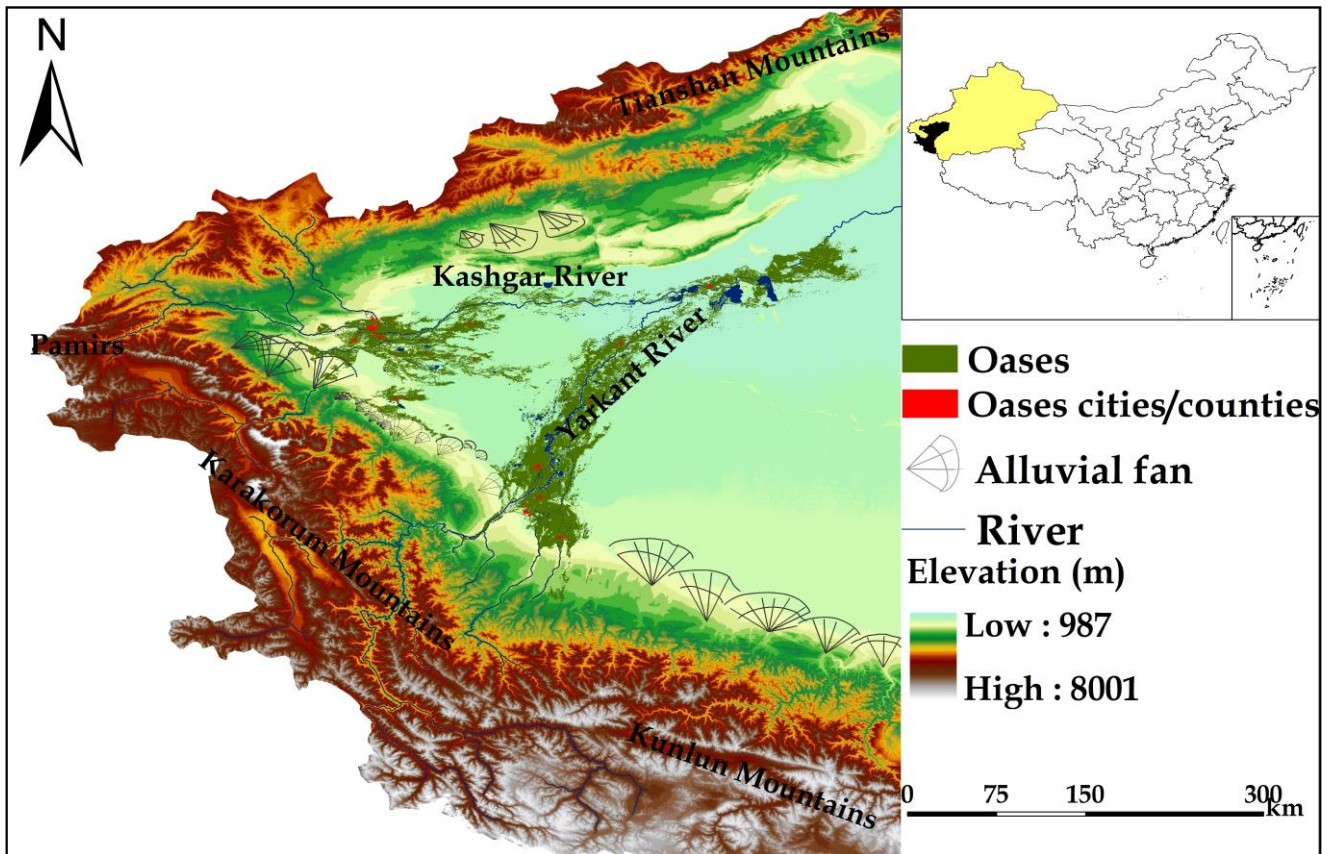


Figure 5.21 Alluvial fan distribution of Kashgar Region

The map showed that three sides of Kashgar Region surrounded high mountains, mountains pass distributed alluvial fans.

5.3 Natural factors

Kashgar Region has covered a vast area, southwest part of the region is high and the northeast part is low. The elevation difference of study area divided into high, low mountains, plain, and desert area. Due to the different characteristics of temperature and precipitation in the mountain, plain and desert, we selected four observation stations, which are Kashgar (1288.7m, at the northern region), Maralbishi (1116.5m, at the east region), Yarkant (1231m, at the south region), and Tashkorgan (3093.7m, on the mountain region). These stations were chosen to investigate the characteristics of climate variables. Table 5.5 shows the results of the MK trend test and all variables were a significant increasing trend ($p < 0.001$). These results indicated that climate exhibited a warm trend during the past 50 years. Other scholars have observed a similar trend in northwest Xinjiang Region over the last 30 years (Xu et al., 2006; Shi et al., 2007; Narama, 2010; Chen et al., 2015).

Table 5.5 Results of Mann-Kendall test for climatic-hydro variables

*Kashgar		*Maralbishi		*Yarkant		*Tashkurgan		+Kaqun		+Karbel		+Kirik		
Zc	β	Zc	β	Zc	β	Zc	β	Zc	β	Zc	β	Zc	β	
T	5.01	0.11	3.14	0.02	4.13	0.03	2.09	0.04	-	-	-	-	-	
P	2.59	0.57	3.05	0.12	3.19	0.46	4.15	0.23	-	-	-	-	-	
R	-	-	-	-	-	-	-	-	0.64	0.11	1.2	0.10	1.19	0.36

*meteorological station; +hydrological station; T-temperature, P-precipitation, E-evaporation, and R-runoff; Z is test statistics of Mann-Kendall; β Kendall slope indicating the magnitude of the monotonic trend; A positive of β indicates an upward trend. Negative value β indicates a downward trend, P <0.001.

In general, temperatures in the plain (Kashgar, Maralbishi and Yarkant) have higher than mountain ranges (Tashkorgan). On one hand, increasing temperature has favourable for agriculture production. Especially, the increasing trends of temperature had favourable for cotton production (Wang et al., 2008). The average yield of cotton production was increased 373.5 kg.hm⁻².10a (p<0.01) from 1990 to 2013 (Abudokerimu et al., 2015). On the other hand, increasing temperature enhance transpiration and evaporation of crop and surface water. Cultivated land have would be led to increasing water consumption from 21.26×10⁸m³ to 54.67×10⁸m³ during 1990-2014 (Table 5.3). Resulted increasing utilization of surface water and groundwater. The LUCC results of surface water decreased from 2762.9 km² to 1062.4 km² (Table 4.1).

In the mountainous area, high elevation precipitation, glacier and snow/ice are provided annual runoff of Kashgar Region (Sorg et al., 2012; Yang et al., 1981).

(1) Snow is a form of precipitation, but it considers differently in hydrology, because of lag between when it falls and when it produces runoff, groundwater discharge and is involved in another hydrological process. In Kashgar Region, seasonal snow meltwater is the main recharge sources to the runoff, which the melting snow occupies 48.2% (Wang et al., 2014; Xu et al., 2010), the seasonal runoff patterns were dominated by winter snow accumulation and spring melts. Generally, snow cover is a seasonal phenomenon and its variability is higher than glaciers. The air temperature is a major index for snow and ice melt process. An increase of 2 °C in air temperature had a much more important effect on snow cover than doubling the precipitation occurring in the snowmelt period (Rango and Martinec, 1994). The increase in temperature on the mountain from 1981 to 2016 can be observed in Figure 5.22 (CRU. 4.01 data). Apart from the increasing trend in annual mean temperature, there has been evidence of differences in warming rate

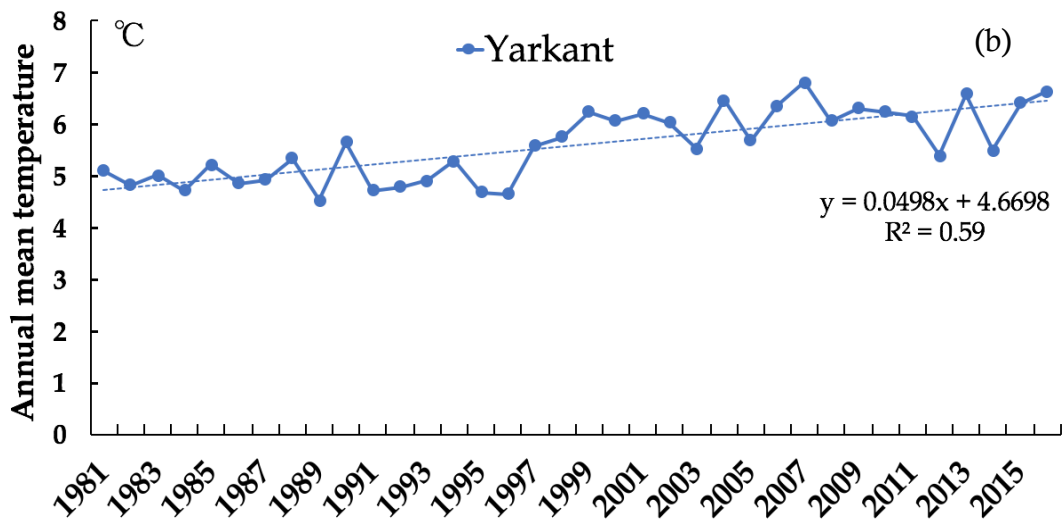
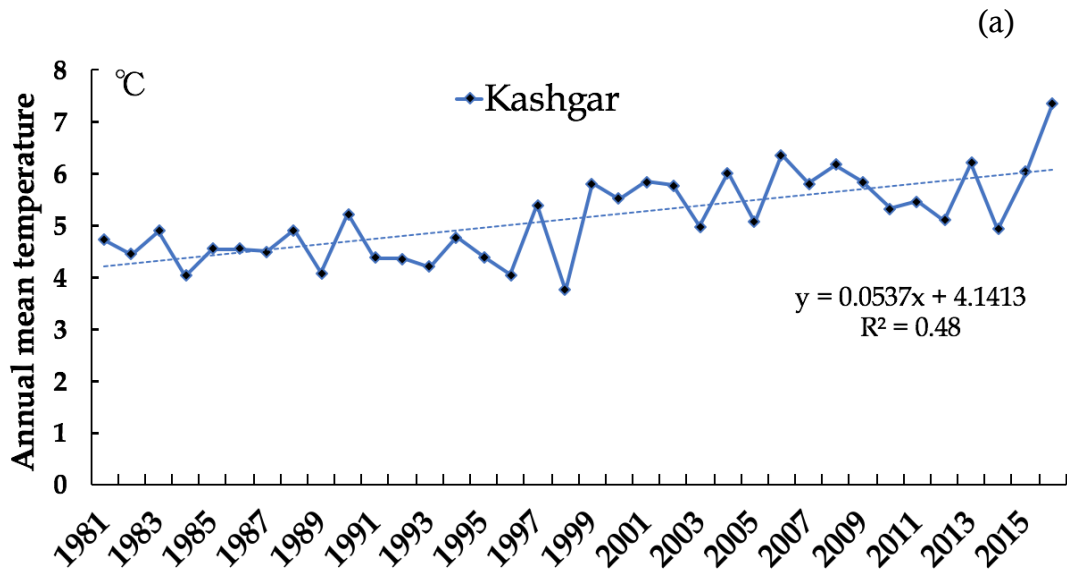


Figure 5.22 Annual mean temperature of Kashgar (a) and Yarkant River (b)
Mountain Area
(CRU. 4.01 data)

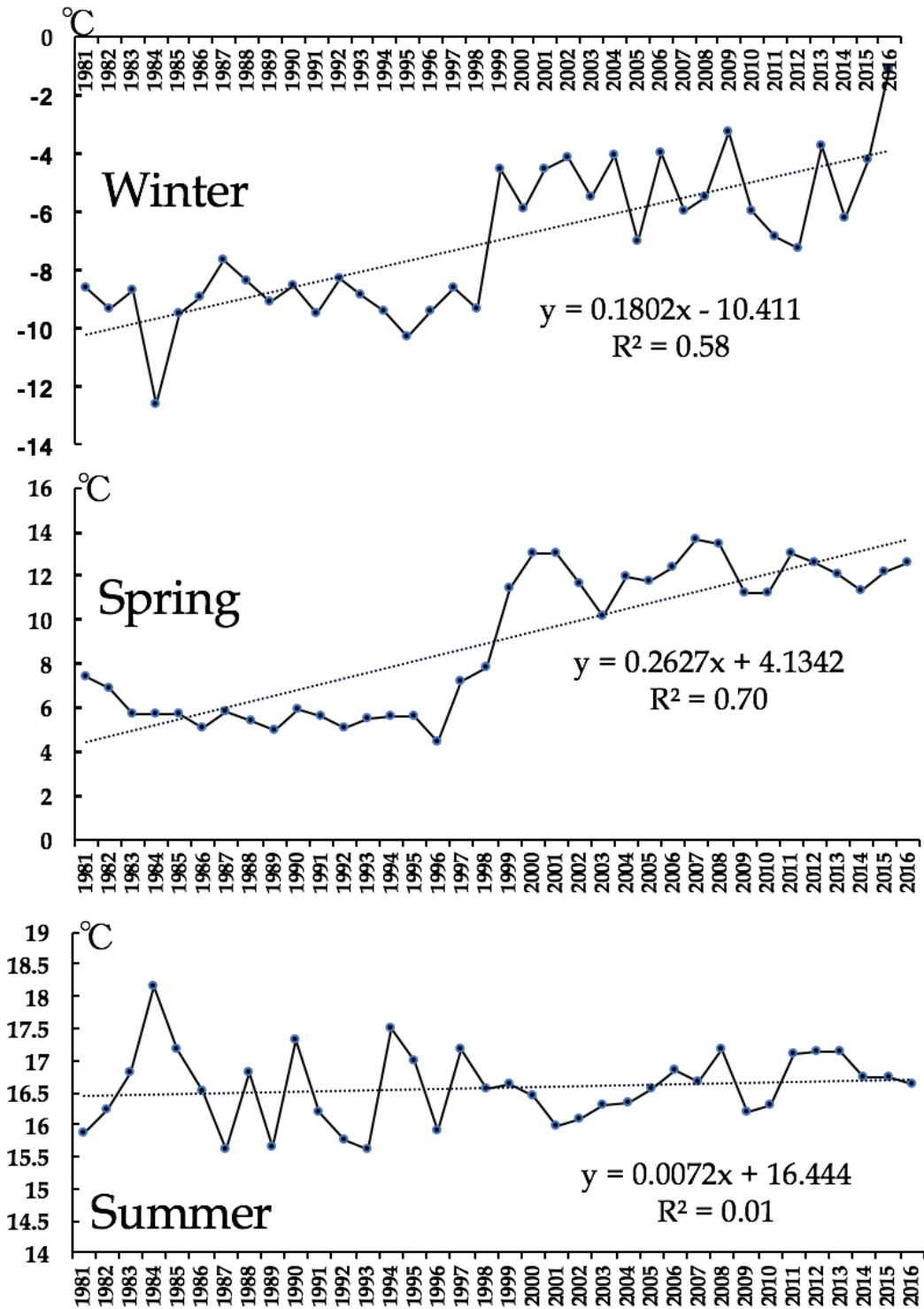


Figure 5.23 Seasonal mean temperature of Kashgar River Area
(CRU. 4.01 data)

Seasonal temperature trends showed that winter, spring and summer temperature has been increased during the observation period.

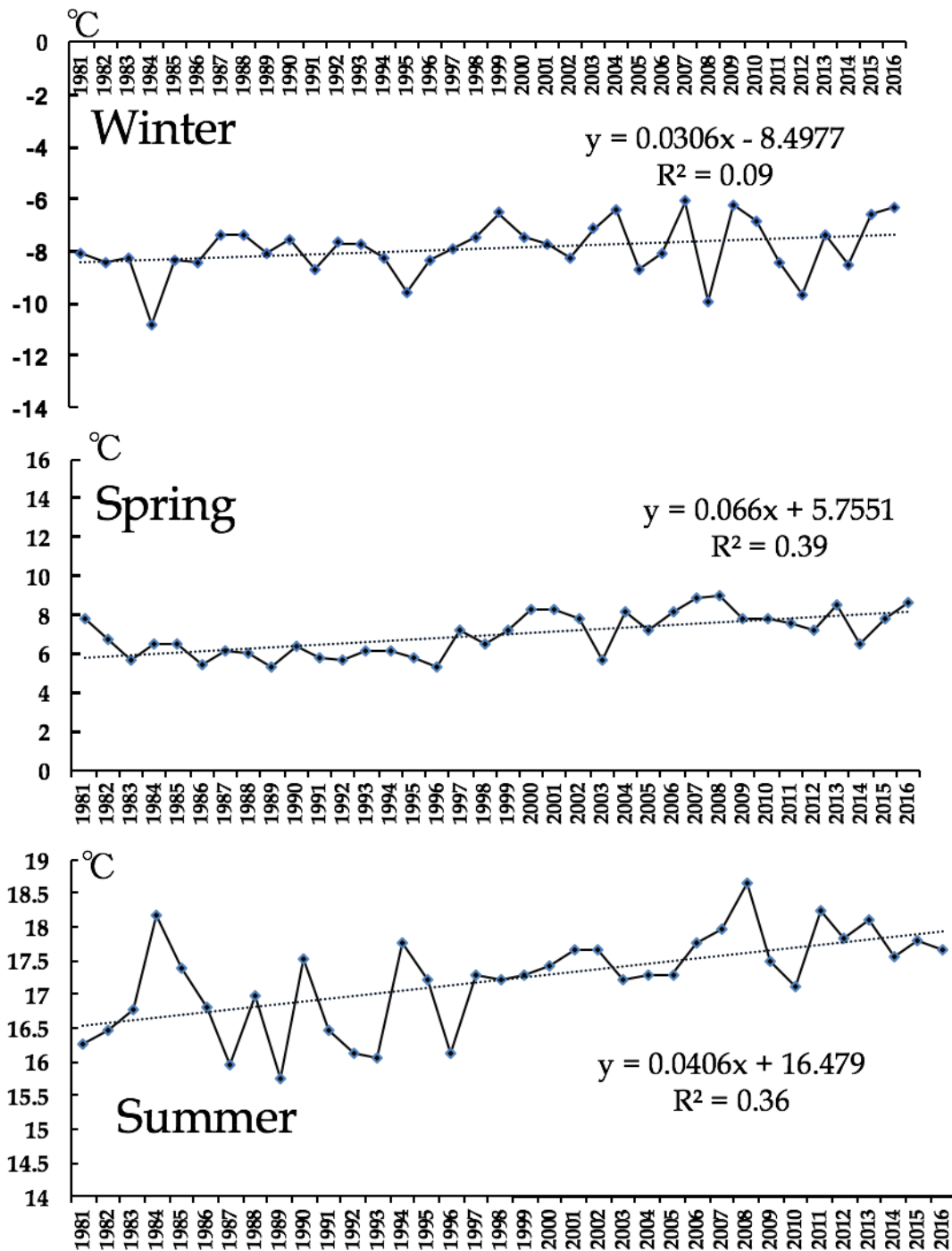


Figure 5.24 Seasonal mean temperature of Kashgar River Area
(CRU. 4.01 data)

Seasonal temperature trends showed that winter, spring and summer temperature has been increased during the observation period.

between seasons at various regional scales. The timing, extent of mountain snowpack and the associated snowmelt runoff, are intrinsically linked to seasonal climate variability and changes. Figure 5.23 and Figure 5.24 (CRU. 4.01data) indicated that the increasing rate of individual season's temperature was even greater in the Kashgar Region, in particular in winter and spring. As temperature rise, more precipitation falls as rain instead of snow leading to smaller snowpack. While rain immediately contributes to strawflower. However, the mountain snowpack serves as a natural reservoir for cold season precipitation storage, releasing water during the spring and summer, for most of the vegetation period. Warmer cold season temperature reduces snow accumulation, as a greater fraction of the precipitation comes as rain (snow to total precipitation (S/P) ratio), while warmer spring temperature hastens snowmelt, thereby shifting the timing of runoff to earlier in the seasons. Li et al. (2018) applied the weather research and forecasting (WRF) model to clarify the spatiotemporal variation of snowfall and the ratio of snowfall to total precipitation over in Xinjiang during the 1979–2015 period. The results showed that the snowfall decreased the Kunlun Mountains (Kashgar Watershed and Yarkant Mountain Area). The results also revealed that the S/P ratio slightly increased during the past decades in Xinjiang. Variations in precipitation amounts determine the total runoff volume, while the seasonality of precipitation affects the fraction stored as snow and therefore the volume of the spring snowmelt.

The MK test results of Table 5.6 and Figure 5.25 were indicated that runoff of the Kashgar Region has an increasing trend. We assumed that the sum of the runoff from a hydrological station in the mountain headstreams represented the runoff generated in the headwater catchment Region after the water had been abstracted for irrigation, industry and domestic uses. Therefore, we separated mountain and plain snow cover, as from the first year of September to the next year August, 36 images were composited

(hydrological year), representing the annual mean snow cover area. The annual mountain snow cover and its seasonal changes have effects on runoff discharging. High snow cover area accumulation recorded in 2005, 2009 and 2012 (Hydrological Year) (Figure 5.26), was attributed to precipitation in a mountain range in the same year (Figure 5.27). The low temperature occurred in 2005 and 2009. A consequence of these process high snow cover accumulated. However, the high temperature occurred in 2007 (Figure 5.28). The annual snow cover area has fluctuated and there is no significant decreasing trend during the fifteen years study period. The time series of fifteen years of data is too short to calculate possible trends of snow-cover characteristics, the results can be used to describe the average snow-cover conditions and compare single years against these values. Moreover, due to the spatial distribution of climatic change and it will be related to the geographic distribution of the area. High snow cover area accumulations and its seasonal changes contributed to an increased runoff in 2005, 2009 and 2012 in short term. Zhou et al. (2013) investigated long term historical archive of snow cover extent using AVHRR satellite images from 1986 to 2008 for the whole Central Asia (including Kashgar Region). The results showed a significant decrease of snow covering days in mountainous regions above 3000 m in the basin with -1.16 days/year in Tianshan and -1.59 days/year in Pamir, respectively, mainly accompanied by earlier snow cover melting date, while snow cover onset date shifted earlier in mid-elevation zone (2000–3000 m) of Pamir, due to the increasing spring temperature. Lyu et al. (2015) obtained snow cover ratio of Tarim River Basin (including Yarkant River Basin) from 8-day SMMR snow cover (MODIS 10A2) for the period 2000 and 2011. The results showed that the snow cover ratio is 18.2%, a slight shrinkage in the snow area. Dietz et al. (2014) also identified possible changes in snow cover season within the last 28 years based on remotely sensed data. The results revealed that an ongoing shift towards earlier snowmelt within the

Pamirs. This process may affect the snow cover and subsequent spring and summer river runoff. In the Kashgar Region, cotton, wheat and maize are the dominated crops, covering 60-80% of the total area (Huang et al., 2018). As the dominant and important crop, cotton, wheat, and maize, their cropping systems were mainly one-season cotton and spring, winter wheat and summer corn in this region due to abundant heat resources. Their monthly distribution of irrigation water demand was also different and two water demand peaks occurring in May and August (Shen et al., 2013). Winter wheat in the Kashgar Region gradually entered to the jointing and heading stage, irrigation water demand increased rapidly on May. While, the cotton is at the seedling stage, resulting in the first peak occurred. Due to the increasing temperature (Figure 5.25 and Figure 5.26), less precipitation falls as snow and melting of snow occur earlier in spring. A consequence, there is would be a seasonal water shortage in the Kashgar Region due to the inconsistent seasonal distribution of the runoff and irrigation water requirement. In June, wheat is harvested, irrigation water demand is reduced. After June, water demand was mainly due to the cotton and summer corn. Cotton was in the flowering and boll stage in August (Huang et al., 2018). Meanwhile, the summer corn also entered the key water demand period, and consequence, the irrigation requirement occurred again in August (Shen et al., 2013). Snowmelt runoff shifted earlier which also may lead to less water released in summer when irrigation water demand is also higher. However, during summer, glacier melt, and liquid precipitation provides water resources (Aizen et al., 1996). Therefore, variability of temperature, snow cover and runoff will change the stability of the water cycle system of the Kashgar Region. The atmospheric water vapour content, with increased in the 1990s, together with intensified water cycle caused by global warming could further have strengthened the stream flow variability (Chen et al., 2008). Streamflow runoff changes presumably reflect a complex.

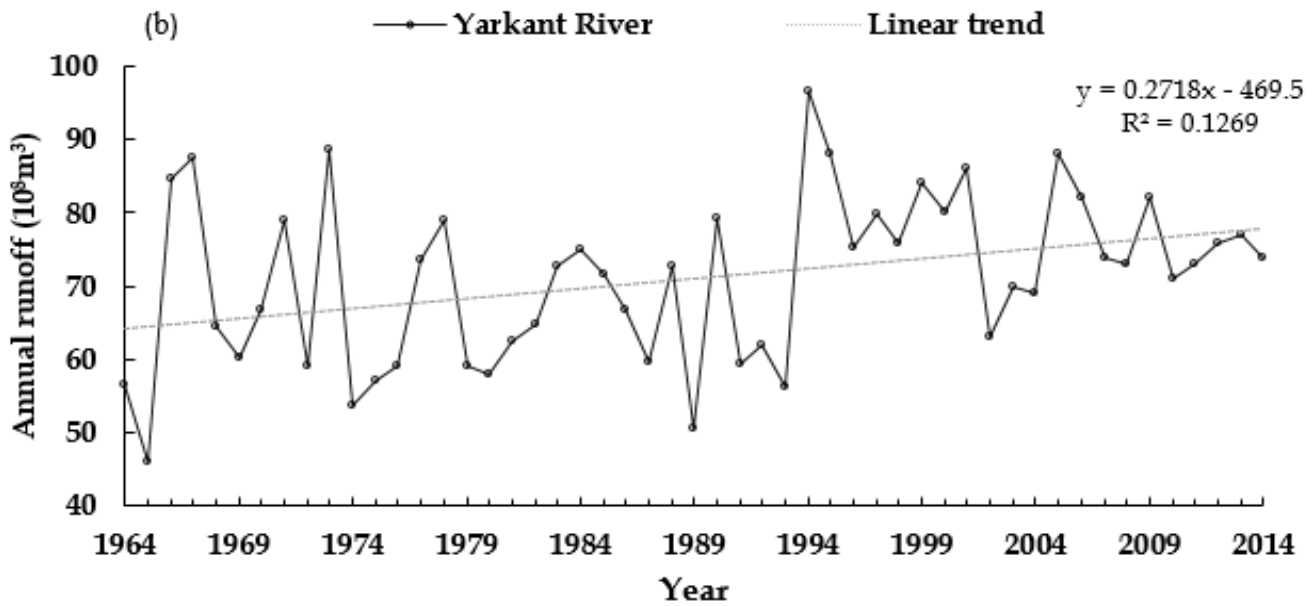
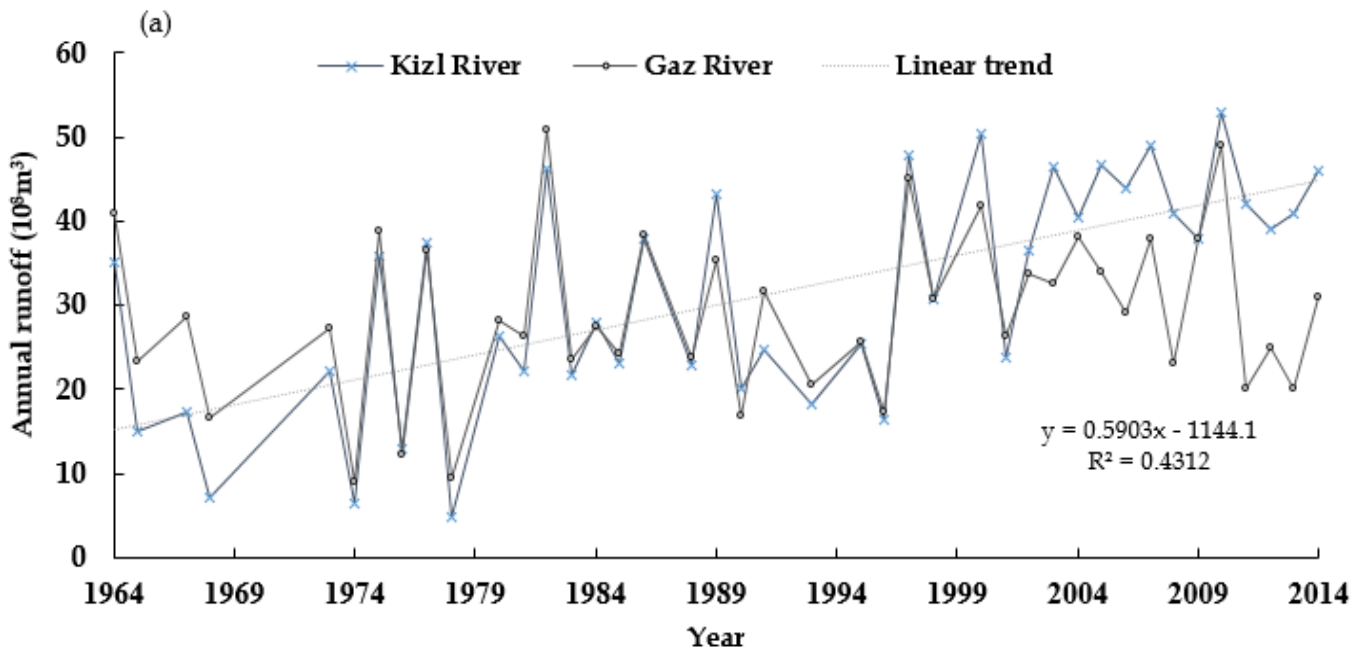


Figure 5.25 Annual mean runoff variation of Kashgar River (a) and Yarkant River (b)
(data from hydrological station of Kashgar Region)

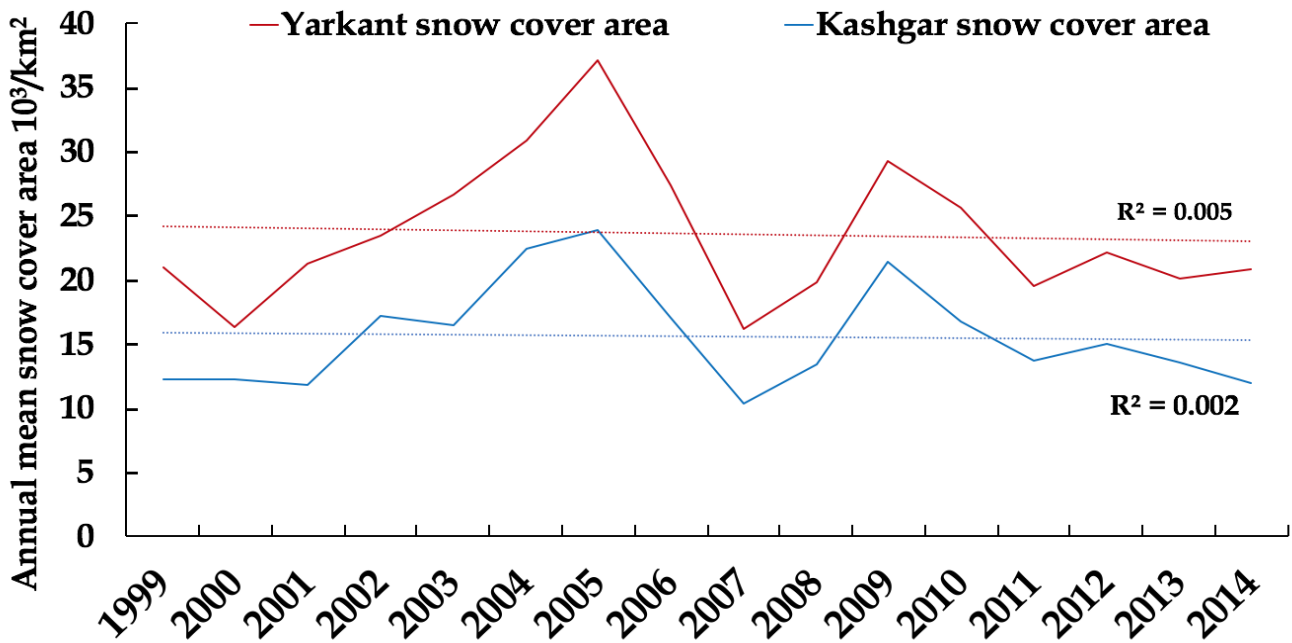


Figure 5.26 Annual mean snow cover of Kashgar Region mountain area from 1999 to 2014 (hydrological year)

Redline is snow cover area of Yarkant Mountain, green is snow cover area of Kashgar Mountain area. Yarkant Mountain snow cover area is bigger than Kashgar Mountain snow cover area. They have the same high snow cover area accumulation in 2005 and 2009.

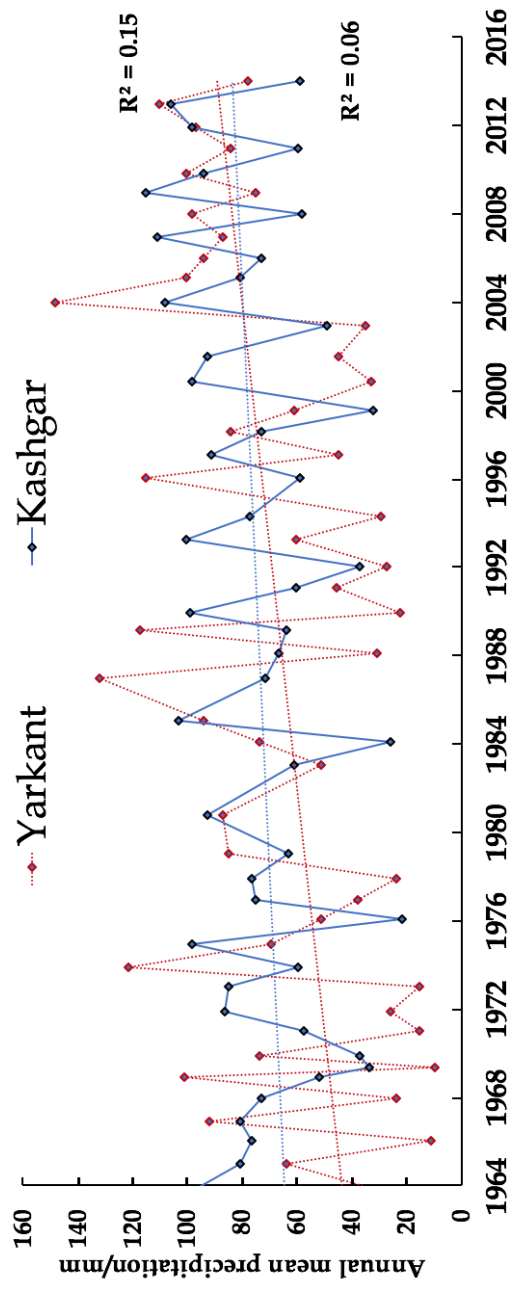


Figure 5.27 Annual mean precipitation of mountain area of Yarkant and Kashgar
(data from meteorological station)

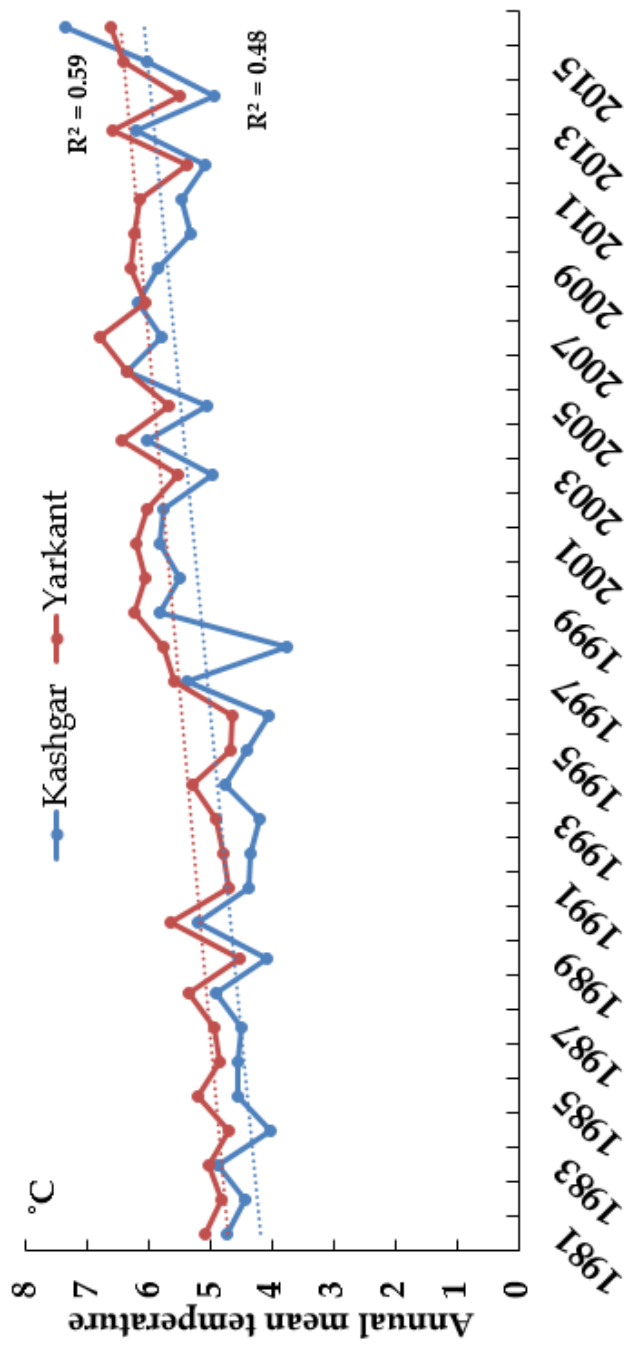


Figure 5.28 Annual mean temperature of mountain area of Yarkant and Kashgar
(CRU. 4.01 data)

(2) Glacier-besides, snowmelt and glacier melt water also provided water for runoff discharge. According to first and second China Glacier Inventory (CGI) data, there are 3070 glaciers in the Kashgar Region with a total area of 5894.86 km² and a total volume of 690.25×10^9 m³ for first CGI, and 3503 glaciers, with a total area of 5113.27 km², and total volume of 592.19×10^9 m³ for the second CGI (Liu et al., 2015), glaciers occupied 12.6% of the watershed drainage area. From 1960 to 1995, the ratio of glacier melt water to total runoff in Yarkant River increased from 50 % to 80% (Shi, 2005). The magnitude of glacier contribution to the natural runoff is much less than snowmelt runoff in short-terms. However, a long-term effect of temperature and precipitation changes on the physical characteristics of glacier of study area was addressed by Dong et al. (2009). An increase in air temperature during the study period (1960-2000), the glaciers in Yarkant River and Kashgar River basin retreated by 7.9 % and 6.1 % and overcome the effects of increased precipitation on the glacier mass balance, due to the regional climate changes that enhanced glacier ablation.

These runoffs from melting snow have played an important role to the recharge of groundwater infiltration and its storage. The total natural recharge of groundwater is 89.3×10^8 m³/year in Kashgar Region (Nian et al., 2001). Mansure et al., (2011) showed that groundwater decreased remarkably of Kashgar Region by 5.63 ± 1.79 m. The replenishment by precipitation is not much significant to the groundwater in arid climate of this study area. However, the geographical distribution of runoff has changed due to increased human activities, the water area has consistently decreased from 2762.9 km² in 1972 to 1062.4 km², which may have affected the replenishment of groundwater and changes to the ground water table. In addition, the natural runoff determines the size of oases and affects human societies for economic development by irrigation and fresh water supply. Rising temperature caused seasonal variation in melt water; result in lead to

increasing runoff. Meanwhile, increased temperature directly affected evaporation and transpiration of cropland and surface water, induced to increasing of water utilization.

Mountain basins shoulder the task of supplying fresh water for downstream rivers. Since stream flow is substantially influenced by the climate change, the variability of stream flow and snowmelt runoff can be important indicators for climate change. Climate change will further exacerbate the uncertainty of the water supply and increase extreme hydrological events in this region, such as floods and droughts (Guo et al., 2016). Among the existing climate modelling studies in Northwest China with focus on Tarim River Basin (including Kashgar Region). Gao et al. (2001, 2003) apply a nested approach combining the regional climate model RegCM2 and the global coupled ocean- atmosphere model CSIRO R21L9 to simulate the climate for double CO₂ content. Their results indicated that annual temperature would increase by 2.7 °C, and annual precipitation would increase 25%. Guo et al. (2016) simulate future climate change trends using latest CMIP5-RCP future climate scenarios from 2016-2045. The results showed that from month scale, the temperature shows an increasing trend all seasons, which is more significant in the summer and winter and the most significant in July. Further increases in temperature negatively impacted snow cover area, inducing snow cover reduction or early melting. Without snow cover in summer, surface albedo will be much lower, leading to shrinking or ablation of glaciers. As a consequence, continued snow cover decrease, and glacier shrinkage will affect quantity and seasonal distribution of regional water supply. Therefore, variability of temperature, snow cover and runoff will change the stability of water cycle system of Kashgar Region. Current study period, social factors primary causes of LUCC. However, natural factors (snow cover, precipitation and runoff) will be restricting factor of LUCCs of Kashgar Region in the future.

Chapter 6. Conclusion

The regional-based case study has a key component of the Global Land Project (GLP) of the land system science community. In order to better contextualize individual case studies and identify generic pattern across case studies, meta-analyses are conducted. Case study as quantify, map, understanding cause and publish the global researchers can engage in crossie synthesis to assess geographic biases and global knowledge gaps across their case studies collection by meta-analysis. Case studies are providing concepts of current understand feedbacks between social-environmental systems between distant world regions. Valuable for others with similar geographic conditions and globally similar environments around the world. Therefore, we selected the Kashgar Region as a case study in this research.

The main objectives of this study were to map, detect, and quantify spatiotemporal changes in LUCCs; to understand the interrelationship between LUCC and its social and natural factors; to investigate the consequences of LUCC on water resources in arid environments of Kashgar Region, China, where characterized by mountain-alluvial fan-oasis-desert landscape with low precipitation (less than 100 mm) and high evaporation (more than 2000 mm) in the oases area, under the control of the typical inner-continental climate. Water resources are a crucial factor in ecological stability and socio-economic development. Snow and ice meltwater in the high mountains provide fundamental water resources to discharge river and groundwater for the development of oasis in the study area. We combined multi-scale and multi-temporal remotely sensed images to investigate the spatial and temporal dynamics of LUCCs over the last 42 years. Statistical data on social and natural factors were employed to identify the causes of resulted changes.

The results and conclusion in this study are as follows:

Major land use changes over last 42 years from 1972 to 2014 were obtained, and results showed that cultivated land is made up of the largest part of the total area, with its area from 3.6 % in 1972 to reach 10% in 2014 and most changed land cover types. We found significant differences indicating new cultivated land expansions within the observation period. The spatial expansion of cultivated land occurred peripheral extension of the existing oases in 1972, after distributed mainly in middle parts of Kashgar and Yarkant Rivers in 1990, due to smooth topography in the upper and middle reaches of rivers and not necessary to build the complicated water conservancy project for irrigation, only a few simple channels were needed to draw the runoff into the oases. Continued expansion of cultivated land and their spatial distribution have caused higher water consumption of the rivers. The most significant changes from the 2000s, cultivated land had been expanded along the alluvial fans below the mountains, where have been suitable sites for the expansion of cultivated land. The mountain pass of Kashgar region has distributed alluvial fans in the north, west and south. Mountain-front recharge through highly permeable alluvial fans can be an important source of groundwater recharge. A series of water-rich areas are providing water with good porosity conditions and big groundwater storage. Therefore, these areas have been favourable conditions for agricultural land expansions due to its rich groundwater resources. The results of LUCC demonstrated that geographic characteristics of Kashgar Region, as a mountain – alluvial fan- oasis-desert landscapes have controlling LUCCs.

An increase in the cultivated land of the Kashgar Region from 1972 to 2014 has been very remarkable. This is a result of the interaction of vast population growth and a related increase in agricultural labour. The growing human population from 2,745,362 in 1988 to 4,683,114 in 2014, twice the rate of population increases during the observation period. The agricultural

population is accounted for 78% of the total population. Employment in agriculture was still a 90% high level. Not only the growth of the population but also the number of 78% people depending on agricultural for their livelihood that have a strong impact on agricultural land. Consequence, per capita cultivated land increased. Results, the agricultural population led to an increase in grain surplus. Grain production exceeds local consumptions. Kashgar Region grain production has increased from 392 kg per capita in 1989 to 660 kg per capita in 2016 (government standard per capita was 500 kg). The agricultural production enough support for a rapidly growing population. Consequences, grain production shifts from food crops to commercial crops. Due to the increase of world cotton consumption and cotton price, the central government designated the Xinjiang Uyghur Autonomous Region (XUAR) for building a national cotton base area in China. Because, physical conditions of XUAR with abundant radiation and heat resources, suitable for cotton production. A consequence, increased in profitability of cotton cultivation, triggering the reclamation of more land. Local land use changes of Kashgar Region are increasingly triggered by demands for cotton products that are part of global supply chains involving a large geographic distance of the telecoupling. Strengthening in this telecoupling process of Kashgar Region, where became the main cotton production area of XUAR, contributed its 43% of the cotton production (XUAR accounted for 79 % of the cotton production of China).

However, Kashgar Region located at a special geographic position and the relatively backward transport is a disadvantage its distribution and export of agricultural products. Without the highway and railway, agricultural products of Kashgar cannot be shipped out of the region smoothly, and logistics costs will remain high. Moreover, the textile industry is mainly distributed coastal regions of China. Since 2000, a surplus of grain production had occurred. The Central government has invested to improve Kashgar's

transportation networks. Railway and expressway have been paved. Increasing railway and expressway network of Kashgar to open up market opportunities for agricultural products transport and provides the best supply chain for regional agricultural trade. Increasing socioeconomic and environmental interactions of telecoupling and connections towards the over distance outside, globalized markets of cotton are influence regional land use decisions. These telecoupling process stimulated with agricultural land expansions further.

Rapid economic development in China has led to a change in consumption pattern and diet of Chinese consumers. Due to the increasing demand of outside and in order to attain the proper balance between cotton and other crops, county governments have made the decision to conduct strategic adjustment in agricultural production, considering the physical condition of each county of Kashgar. While, expansions of railway and highway network from Kashgar to inner cities of China (west to east connection), closed to market and enhance connections of between Kashgar to outside in telecoupling. As a result, there has been increased vegetable and melon field to production vegetable and melon. These processes further triggered the expansion of cultivated land for melon and vegetable cultivation.

As a high rate of economic growth in China, however, a lower share of agriculture in the economy. The government implemented subsidy-based support to agriculture land expansions within the WTO rules. China's support for agriculture has new programs after becoming a member of the world trade organization (WTO). Support is focused mainly on agricultural production (wheat and corn). The general input subsidy accounted for most of the growth in subsidy payments to farmers in all localities. This agricultural supplement policy led to cultivated land expansions constantly. Resulted, we found by LC maps to bring shifts in land use in large-scale and intensive farming become apparent.

The continuing expansion of cultivated land and their spatial distribution caused higher water consumption. The results of agricultural water consumptions showed that the water consumption of cultivated land increased remarkably occupied 90% of the total water consumptions. The river runoff is not enough to support an ongoing increase in water consumptions by cultivated land. Groundwater provided a major water supply sources of the Kashgar Region. Along mountain pass of Kashgar region distributed alluvial fans, which serves as important groundwater reservoirs in Kashgar Region. The alluvial fan groundwater in the Kashgar Region plays an important role in agricultural expansion.

Groundwater and river discharge are mainly supplied from the mountain area (recharge zone by snow, ice meltwater). The results of climatic factors indicated an increasing trend in both temperature and precipitation in the mountain during 1964-2014. The snow cover investigation results showed it has strong interannual changes and high snow cover area accumulated in 2005, 2009 and 2012 (hydrological year), its seasonal short-term changes contributed to the increase in runoff in the same year. Although, the precipitation increased at a rate of 8.11 mm/10 year, an increase of precipitation was very small and regular. However, the annual snow cover area has fluctuated and not clearly significantly decreasing trend for 15 years observation period. Besides, the temperature increased at a rate of 0.72 °C/ 10 year, especially winter and spring temperature increased remarkably, which impacts on changes in snow and snow cover extent. Temperature rises as results of global climate change; the snow cover area decreases in magnitude as the ratio of liquid and solid precipitation shifts in favour of liquid precipitation in response to increased temperature. This process may affect the snow cover accumulation and subsequent spring and summer river runoff, this process also may lead to an increase in spring runoff or shifts peak runoff discharges. The consequence, reduction in summer snow cover,

surface albedo will much lower, its impact on glacier led to shrinking or ablation. These changes will produce serious impacts on water resources, even intensify the shortage of water resources and the contradiction between supply and demand. These processes will be reducing the stability of the water supply and oasis expansions in the future.

Major conclusion:

The mountain-alluvial fan-oasis-desert are the main geographic landscape features of an inland river basin in Kashgar Region. Oases are an essential part of the Kashgar Region, where major human activities and economic development zone are existing in a desert background. Their scale, location, and development depend on the carrying capacity of the water resource. Water resources originate from the mountains are located in the upper reaches of the Kashgar Region and is mainly composed of mountain ice snow melt water. Flow at mountain pass created groundwater and surface runoff supplies water consumption of oases. Kashgar Region's agriculture had focused on food grains for the reason of rapid population increase at the beginning, among the total population number of 78% people depending on agricultural for their livelihood that have a strong impact on agricultural land, per capita cultivated land had been increased. A consequence, the agricultural population led to an increase in grain surplus. The surplus shifts from food crops to commercial crops. Kashgar Region is still an agricultural based economy. At the same time, the telecoupling process as cotton demand of the world, rising cotton price and strong increase in cotton profitability are triggered cotton cultivation. Increasing grain surplus and cotton production requires transport to a large market or another demand area. Therefore, improved transportation in the Kashgar Region by supporting the central government. A consequence, strengthening connectivity between distant location by railway and highway, to open up market opportunities for agricultural products have been accelerated the increase of areas sown to grain crops and cotton. Moreover, in order to further promote increase agricultural economy and demand of the outside for other agricultural

production, the agricultural subsidy has been implemented by government agriculture policy within the WTO rules, which are stimulated increase agricultural area continually. These social interactions of cultivated land expansions combined with the regional geographic characteristic of the Kashgar Region are primary causes of LUCCs. While, natural causes, changes to the temperature, snow cover and runoff as a facilitator of implementing social cause during current study periods.

The contribution of this study:

From the current study, we have known that the regional geographic characteristics of the Kashgar Region controlled LUCCs. Understanding the causes of LUCC is not only responding socio-economic context but also geographical conditions, in which adapting to environment situations. Regional geographic features of Kashgar Region practical and economic importance to the cultivated land expansion, however, its changes and expansions determined natural conditions of the area. Our comprehensive results revealed that land-use change, influenced by complicated interactions between socio-economic and natural conditions. Understanding the causes of LUCC not only responding socio-economic context but also geographical conditions, in which adapting to environment situations.

The oases are a natural landscape of the Kashgar Region. Over the past decades, there had been rapid population growth and economic development lead to modification of the natural ecological process by human activities. Currently, the socio-economic context combined with the regional geographic characteristics is the primary causes of LUCCs. However, water resources originated from the mountain area, where is very sensitive to global climate change. Climate change will exacerbate hydrological fluctuations and water uncertainty of oases expiations in future. Thus, climate change will be the main cause of LUCCs in the Kashgar Region in the future. These findings are valuable in the Kashgar Region for design sustainable development through stakeholder engagement and through the concept of land governance.

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