西北农林科技大学

硕士学位论文

乌兹别克斯坦的植被变化与归因

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CHANGES AND ATTRIBUTION OF VEGETATION IN UZBEKISTAN

ABSTRACT

Arid zones are very vulnerable to climate change and vegetation is considered central part of vegetation-climate change research studies. Since Uzbekistan's location is arid zone, vegetation-climate relationship analyses play important role in country's agricultural, social-economic life. Several scientific research studies have been conducted with respect to vegetation change and its responses to climate variables in regional scale, i.e. over the whole Central Asia. Scientific research studies related to vegetation change and its attributes in Uzbekistan has not so far been conducted as country scale individually in time series.

In order to determine vegetation change and its relationship with climate variables, trend analyses have been conducted by Mann-Kendall and Sen's slope estimator for NDVI and climate variables. Three climate variables, i.e. precipitation, solar radiation, temperature have been selected since vegetation is mostly determined by water and energy. Also, seasonal NDVI and climate variables have been checked for trend analyses. In order to determine abrupt point change in NDVI, Mann-Kendall test for abrupt change has been applied and based on this, study time period was split into two sub-periods for further analyses in terms of trend analyses, correlation analyses, and regression analyses. Pearson correlation has been applied to detect relationship of NDVI versus climate variables. In order to check dependence of NDVI on climate variables, single-factor regression and multiple-factor regression have been used. Based on the developed vegetation-climate equation for the first period, contribution of human activities and climate variables on vegetation have been determined and the following results have been obtained:

1. Trend analysis of vegetation. NDVI did not significantly change in the period of 1982-2015, but summer NDVI and autumn NDVI significantly decreased during this time period. NDVI insignificantly increased (Z=1.205) during the first time period (1982-2009) and insignificantly (Z=-0.413) decreased during the second time period (2010-2015).

2. Trend analysis of climate change. Among climate variables, only temperature significantly increased between 1982-2015, whereas solar radiation and precipitation insignificantly increased. All seasonal temperature significantly increased in the period of 1982-2015 while all seasonal solar radiation values insignificantly increased. Except summer precipitation, spring and autumn precipitation insignificantly increased, and summer precipitation insignificantly decreased. Precipitation insignificantly increased during both sub-periods, i.e. 1982-2009 and 2010-2015. Solar radiation insignificantly decreased for both time periods. However, temperature significantly increased in the first period and insignificantly increased during the second time period. It can be concluded that the significant increasing of temperature during 1982-2015 is due to significant increase in the first period.

3. Attribution of vegetation change. NDVI versus precipitation has significant negative correlation, whereas NDVI versus solar radiation and NDVI versus temperature have significant positive correlation in the period of 1982-2015. In the first period also this correlation phenomenon remained, but negative correlation of NDVI versus precipitation strengthened in the second time period. Positive correlation of NDVI versus solar radiation and NDVI versus temperature also strengthened during the second time period. Multivariate regression analyses released that NDVI mostly dependent on climate variables than human actions. According to analyses based on the developed vegetation-climate equation, climate change dramatically influenced (90%) on vegetation while human activities constituted 10% in Uzbekistan.

Key words: vegetation change; climate change; Uzbekistan; attribution of vegetation; temporal change of vegetation and climate variables.

乌兹别克斯坦的植被变化与归因

摘要

干旱地区非常容易受到气候变化的影响，植被是植被 - 气候变化研究的核心部分。乌兹别克斯坦地处干旱地区，分析植被 - 气候关系对农业、社会经济发展有重要意义。关于植被变化及其对区域尺度气候变化的响应，在整个中亚地区已进行了若干科学研究。但乌兹别克斯坦的植被变化及其归因研究尚不多见。

为了确定植被变化及其与气候变量的关系，使用 Mann-Kendall 方法对 NDVI 和气候变量进行了趋势分析。由于植被生长主要由水和能量决定，选择了三个气候变量即降水、太阳辐射和温度。为了确定 NDVI 的突变，应用 Mann-Kendall 进行突变检验，并在此基础上将研究时间段分为两个子时期，基准期和变化期，进一步进行趋势分析、相关分析和回归分析。使用 Pearson 相关分析检测 NDVI 与气候变量的关系。为了研究 NDVI 对气候变量的依赖性，使用单因素回归和多因素回归方法。根据基准期的植被 - 气候方程，计算了变化期人类活动和气候变量对植被的贡献。得到了以下结果：

1.植被变化趋势分析。NDVI 在 1982 - 2015 年期间没有显著变化，但夏季和秋季 NDVI 显著下降。在基准期（1982-2009）NDVI 不显著增加（Z = 1.205），而变化期（2010-2015）NDVI 不显著降低（Z = -0.413）。

2.气候变化趋势分析。气候变量中，1982 - 2015 年温度显著增加，而太阳辐射和降水量则不显著增加。1982 - 2015 年所有季节的气温均显著增加，而所有季节的太阳辐射均未显著增加。除夏季降水外，春季和秋季降水量不显著增加，夏季降水量不显著减少。在两个时期即 1982 - 2009 年和 2010 - 2015 年，降水量均不显著增加，太阳辐射都不显著下降。然而，温度在第一阶段显著增加，在第二时间段期间不显著增加。1982-2015 年，温度的显著升高是由于第一期的显著增加导致的。

3.植被变化的归因。NDVI 与降水量显著负相关，而 NDVI 与太阳辐射和 NDVI 与温度的关系在 1982 - 2015 年显著正相关。在第一阶段，这种相关现象仍然存在，但 NDVI 与降水的负相关性在第二阶段得到加强。在第二阶段，NDVI 与太阳辐射和 NDVI 与温度的正相关性也得到了加强。多元回归分析发现 NDVI 主要依赖于气候变化而不是人类活动。根据建立的植被 - 气候方程，气候变化对植被变化的影响很大（90％），而人类活动只占 10％。

关键词：植被变化; 气候变化;乌兹别克斯坦; 植被归属; 植被和气候变量的时间变化。

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CHAPTER I

1.1 INTRODUCTION

Uzbekistan is very sensitive to global climate change since it is located in arid zone. According UNEP aridity index which spans from 0.05 to 0.65 in Uzbekistan is classified as an arid zone and this is sensitive to soil erosion, degradation and climate change.[1]

In the globalized world every country strives for its interests. On this way they, especially poor and transition economies, pay much attention to the economic growth rather than reducing greenhouse CO_2 emissions (Motel, 2015) and from this point of view they are considered potential carbon emitters globally, and these countries suffer more from bulk of climate change damages (Mendelsohn and Williams, 2006). Because agriculture is dominant sector in economic least, developing countries or in countries with transition economy and this sector is very susceptible to climate change and its consequences. Global industrial revolution in the 20th century caused global surface temperature increase than ever before and consequently, during the second half of the 20th century anthropogenic activities caused rise of surface temperature 0.2 degrees Celsius annually in the northern Hemisphere, whereas it was 0.1 degree Celsius annually for 900 years before the twentieth century (Smith et al., 2015). Year after year, the climate change risk level and the number of risks increase, we can recognize this potential risk from annual publications entitled *Global Risks Report* by World Economic Forum in Davos. 2016 report emphasized the "failure of climate change mitigation and adaptation" as the top risk (Dolsak and Prakash, 2018), and 2017 report placed three of top five potential risks related to climate change, i.e. "extreme weather events" (second), "major natural disasters" (fourth), "failure of climate change mitigation and adaptation" (fifth) (*ibid*). These evidences explain the importance of establishing and running climate change mitigation and adaptation strategies. Having realized this concept, prior to 2016, Paris agreement was signed by world leaders, the agreement that targeted to reduce carbon emission with specific assigned national determined contributions. Up to now 184 countries have signed and ratifies the Paris agreement, while 12 countries only have signed without ratification (as the case in March 2019).

Uzbekistan is dependent on agricultural sector and about 14% of annual GDP belong to agriculture. Most arable land for agriculture is irrigation-dependent (approximate 4.3 million ha). Annual formation of water resources inside the country constitute about 23.06 cubic kilometer, but annual consumption of water resources is about 112.38 cubic kilometer (MAWR)[2]. This means that 15-20% of consumed water resources in Uzbekistan forms inside the country and other 80-85% forms in Tajikistan and the Kyrgyz Republic (Khamidov and Hamidov, 2017). Moreover, economic sectors in developing countries primarily depends on climate vulnerable sectors such as agriculture and technological development in these countries is quite low than developed countries (Mendelsohn and Williams, 2006).

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[1] *http://www.uz.undp.org/content/uzbekistan/en/home/presscenter/pressreleases/2016/07/21/a-step-forward-in-strengthening-uzbekistans-readiness-for-access.html*

[2] Ministry of Agricultural and Water Resources of Uzbekistan

There are few studies about vegetation response to climate variables, relationship between vegetation change and climate variables, and impacts of climate change (Bobojonov and Aw-Hassan, 2014) at sub-national levels. However, some papers inform of response regularity of vegetation to climate extremes is uncertain in Central Eurasia including Central Asian countries (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) (Lioubimtseva et al., 2005; Xu et al., 2017, 2016; Zhou et al., 2015) and impacts of climate change on farm income in Central Asian countries (Bobojonov and Aw-Hassan, 2014). Vegetation is considered as a sensitive indicator of climate change occurrence (Liu et al., 2018) and vegetation monitoring via remote sensing is crucial to better understand processes related to agricultural change in sub-humid to semi-arid ecosystems (Yin et al., 2012). Understanding how global vegetation cover responds to climate change in temporal and spatial scales is very important to form future projections for ecosystem dynamics and adaptation of ecosystem to global climate change (Xu et al., 2014). Many scientific works related to climate change and its impact on vegetation growth, climate variables change in worldwide and regional and either in spatial or temporal scale have been done. For example, (Pang et al., 2017; Peng, 2017; Wang et al., 2012; Xu et al., 2014 etc.) in China, (Lioubimtseva et al., 2005; Xu et al., 2017; Zhou et al., 2015) in Eurasian and in Central Asia, (Jong et al., 2013; Wu et al., 2015) in worldwide, (Gocic and Trajkovic, 2013) in Serbia, (Atta-ur-Rahman and Muhammad, 2016) in Pakistan and other scientific observations devoted to climate change and vegetation growth and its response to climate change have been studied.

1.1.1 Uzbekistan: geographical location, climate conditions, economic-social attributes

1.1.1.1 Geographical location, natural climate and ecological condition

Uzbekistan is located in the middle of Central Asia which spans from the Caspian Sea in the West to China in the East (foothills of the Tian Shan and Pamir mountains) and from Afghanistan in the South to Siberia in the North and is considered double-landlocked country to go to sea ports. The country borders with other four Central Asian countries (Kazakhstan in the north and northwest, Kyrgyz Republic in the east, Tajikistan in the south-east, Turkmenistan in the south-west) and Afghanistan in the South (Figure 1).

Figure 1 Central Asian countries bordered with Uzbekistan

Local climate of Uzbekistan is continental with low precipitation that is annual 100-200 mm in the plains of northern-western part of the country and up to 1200 mm in mountainous regions. Most of the annual precipitation falls during March-April. The year seasons characterize with long hot dry summer and cold winter. The vegetation of Uzbekistan is divided into four main ecosystem zones and the main for division of vegetation into ecosystem zones is the change in hydrothermal conditions (Belolipov et al., 2013). These zones cause form a chain that as elevation increases precipitation increases too (*ibid*). These zones are the chul (arid plain, desert) zone, the adyr (lowlands and foothills) zone, the tau (mid-mountain) zone and the yailau (high mountain) zone (*ibid*). Desert zones occupy most of the territory of the region. Desert so-called **Kyzylkum desert** located among Kazakhstan, Turkmenistan, and Uzbekistan is considered the largest one in Central Asia. The desert is the 16th largest one in the world. Its location is in the doab of two large rivers in Central Asia – Amudarya and Syrdarya. The territory consists of mostly extensive plain at an altitude up to 300 m with a number of foothills. Indigenous people of Kyzylkum desert utilize large part of the area as pasture for their livestock. The desert is well known for its large number of deposits of gold, uranium, copper, aluminum and silver, natural gas, and oil.

Livestock sector is the leading branch of agriculture in Uzbekistan, producing 45% of the gross national agricultural product. Main pattern of the sector is that the most contribution of livestock sector is *dehkhan* farms and private households. Livestock is one of the main income base for rural population of the country. Production growth of the livestock output – meat and milk are basic food products. Private households and *dehkhan* farms are potential contributors to the development of the livestock production that breed majority of cattle. Having obtained independence the government endowed capital to the development of the livestock sector. If during the Soviet Union time only agricultural enterprises – kolkhozes and *sovkhozes* were available, after independence those enterprises were mitigated and new entities - livestock breeding farms emerged, which either owned their private cattle or operated in a form of specialized livestock breeding farms sharing collective properties. The beginning of 2008, there were around 10,000 livestock breeding farms and 148 livestock companies operating. Totally, the herd number of all entities was 7.5 million heads by the end of 2007, including 3.1 million cows, 12.6 million sheep and goats. According to data 2007, 1.2 million tons of meat (live meat), 5.1 million tons of milk, and 22,500 tons of wool were produced. Most volumes of meat and milk are produced in Samarkand, Tashkent, and Kashkadarya regions. Sheep and goat breeding are widespread in Kashkadarya, Navoi, Samarkand, and Surkhandarya regions. **Grazing** and **overgrazing of vegetation by livestock** along roadsides and ditches are widespread. Grazing livestock on community pastures, including by hired shepherds, is not common due to lack of rangelands. In Uzbekistan pastures situation is rather complex. In 1991, the control of pastures (about 92%) was under Ministry of Agricultural and Water Resources (MAWR) of Uzbekistan. Over time, the coverage of pastures decreased up to 40% and was not done reclamation practices.

(Aw-hassan et al., 2016) stated the Karakalpakstan Republic, Bukhara, and Syrdarya regions are subject regions in the country for land rehabilitation, i.e. they need ecological restoration. Not only these regions, but also Kashkadarya, Khorezm, Jizzakh region also demand ecological restoration. Since Karakalpakstan, Bukhara, Khorezm regions are located close to the shrunk Aral Sea, ecological condition is in high-attention-demanded level, i.e. salt particles from the shrunk sea are delivered to these regions by wind and further cause soil salinity, environment pollution, air pollution, etc.

1.1.1.2 Center of Hydro-meteorological Service of Uzbekistan (Uzhydromet)

Center of Hyd-rometeorological Service (Uzhydromet) is the only state organization to inform current and future weather forecasts in Uzbekistan. Meteorological, hydrological, and agro-meteorological observation have been carried out since 1921 in the territory of Uzbekistan. The ecological observations of condition of water bodies, air and soil have been carried out since 1972.The objectives of Uzhydromet are:

- the improvement of service system of hydrometeorological observations;
- hydro-meteorological provision of sectors of economy, state administrative bodies, population and armed forces of Uzbekistan with the necessary hydro-meteorological information;
- creating and keeping state hydro-meteorological, environment pollution, accounting of surface water bodies fund of data;
- coordinating and controlling all activities related to creating and keeping state water inventory;
- systematic observations of air, soil, surface water bodies, as well as appearance and strengthening of disastrous hydro-meteorological phenomena;
- conducting scientific research activities for improvement of short-term and long-term weather forecasts, water availability of rivers, and climate change observations in the territory of Uzbekistan.

Uzhydromet has established relationships world renowned organization - World Meteorological Organization (WMO) which its main target is weather and climate observation, cooperation for collection and exchange of meteorological, hydrological and other observations of environment conditions data. In the zone of Uzhydromet mother than 400 stations exist for weather and climate observation targets.

1.1.1.3 Agricultural, economic attributes

After collapsing of the Soviet Union the country obtained its independence on the 31st of August, 1991. Uzbekistan is the most population-density-high country in the region constituting more than 33 million people (in January 2019).[3] The highest density of the population is in Samarkand regions (SCS, 2019).

In 2016, the new President and the new Government opened the door of Uzbekistan and began new waves reforms in all sectors. A new launched program by the new Government of Uzbekistan is directed to market-oriented reforms that unprecedented in the new history of the country (World Bank). The economy of the country is agricultural-based and its annual share in the total annual GDP is about 14%.[4] During the independence years Uzbekistan has actively collaborated with international renowned organizations such as

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[3] State Committee of the Republic of Uzbekistan on Statistics. The next referred as SCS

[4] Annual report of the first president of Uzbekistan to the Parliament

World Bank, Asian Development Bank, Islamic Development Bank, International Fund of Monetary and so on. The World Bank has launched overall 74 projects with Uzbekistan and out of them 12 projects in Irrigation and Drainage, 6 projects Agricultural Extension, Research, and Other Support Activities, 6 projects in other Agriculture, Fishing and Forestry, 6 projects in water supply and in other sectors.[5]

The foreign trade of the country in 2018 (January-December) amounted approximately 34 billion USD and increased, comparing to the same with previous year, by 27.3%. Exports amounted more than 14 billion USD (growth rate - 13.6%), and imports - about 20 billion USD (growth rate - 39.6%) (SCS, 2019). Main import products of Uzbekistan are machines, equipment, chemical products, food and metals. Main import partners of the country are Russia, South Korea, China, Germany and Kazakhstan.[6] About 95.9% exported products from Uzbekistan were imported by Switzerland (29.4%), China (27.5%), Russia (12.6%), Kazakhstan (10.0%), Turkey (9.4%) and other countries.[7] These exported products from Uzbekistan are gems, precious metals, mineral fuels including oil, cotton, copper, fruits and nuts, vegetables and other goods (*ibid*).

1.1.2 Current forestry condition and State Forestry Committee in Uzbekistan

Forests are unevenly distributed over the country and forest are was 1.9 million ha, 3.2 million ha, and 3.3 million ha in 1990, 2000, and 2005, respectively (Vildanova, 2006). In Uzbekistan, forest use is followed by temporary and permanent forest use targets. Temporary forest use consists of two forest use period, i.e. short term and long term. Short term can be up to 3 years while long term is up to 10 years and permanent forest use is permanent tenure agreement for forestry organization and entities. Forest use in Uzbekistan is performed by State Forest Fund (SFF). The first law related forestry management, forest resources and utilization of forest resources so-called 'Law on Forest' was accepted in 1994. According to the law, forests are state property and national wealth, subject to rational use and protection by the state. 11.144 million ha land resources are under the SFF lands and out of this, 9.02 million ha in sandy deserts, 1.78 million ha in mountains, 0.22 million ha in valleys, 0.11 million ha in floodplains.

Land use patterns of Uzbekistan in 2018 describes as in the Table 1 and total land resources of the country is just under 45 million hectare. According to the Table 1, current forest area of Uzbekistan is about 7.66% out of the country, i.e. totally 3.4 million ha, out of this 54 thousand ha area is n irrigated lands and forest resources of the country is for only nature protection (Vildanova, 2006). State Forest Fund of Uzbekistan (SFA) comprised that about 600 thousand ha of forests were artificial plantations. Forest resources and biological diversity is given in the Box 1.

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[5] Source: http://projects.worldbank.org/search?lang=en&searchTerm=&countrycode_exact=UZ

[6] https://tradingeconomics.com/uzbekistan/imports

[7] http://www.worldstopexports.com/uzbekistans-top-10-exports/

Table 1 Land use patterns (2018)[8]

Land use patterns		Size (thousand ha)
Total land resources	Total	44892.4
	Irrigated lands	4311.5
Arable lands	Total	4026.4
	Irrigated lands	3271.7
Lands for perennial trees	Total	391.6
	Irrigated lands	371.7
Fallow land	Total	80.8
	Irrigated lands	47.8
Hayfields and pasture	Total	21115.2
	Irrigated lands	43
Types of agricultural lands	Total	25614
	Irrigated lands	3734.2
Households and garden vegetable unified lands	Total	703.9
	Irrigated lands	522.9
Meliorative construction lands	Total	71.9
Forests	**Total**	**3442.7**
	Irrigated lands	**54.4**
Lotes	Total	152.7
Others	**Total**	**14907.2**

Box 1 Bio diversity and forest resources of Uzbekistan[9]

In Uzbekistan, the following definitions have been adopted during the USSR and since that time:
- The area of the State Forest Fund is termed forest land and includes land for afforestation, and non-forest land, where afforestation requires additional reclamation activities for site preparation;
- Forest lands includes such categories of lands as forest covered area that they are non-closed-up artificial (young) plantings, sparse crops, sparse forests, fire-sites, perished stands, cut sites, and glade abandoned sites;
- Non-forest lands include arable land, hayfields, pastures, marshes, sands, glaciers and other lands.

Biological diversity of Uzbekistan includes more than 27,000 species, with more than 15,000 breeds of animals and a total number of plant species, mushrooms and algae of approximately 11,000 species. The flora of Uzbekistan includes 4,800 species of vascular plants, which relate to 650 genera and 167 families. The number of endemic species is relatively low, in the

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[8] Source: State Committee of Land Resources, Geodesy, Cartography and Cadastre of Uzbekistan as in case of 2018

[9] Main Department for Forestry of Uzbekistan

range of 8% (or about 400 species) of the total species richness. Relict endemic species include 10-12% of all endemics. 305 flora representatives are included in the Red Book of the Republic of Uzbekistan.

The basic forest forming species of forest stands in desert like plains is saxaul (Holoxilon persicum Bge. And H. aphillum Hjin.). Large areas are also covered by saltwort (Salsola Richterii Kar., S. paletzkiana Litv.), kandyms (Calligonum), and tamarisks (Tamarix). Most of the forest stands under desert conditions are of low-density (i.e. 0.3-0.4) reaching rather low growing stocks of wood: for **saxaul** stands up to 60 cubic meter/ha, **saltwort** stands up to 30 cubic meter/ha, and **tamarisk** stands up to only 3-4 cubic meter/ha.

By their composition, mountain forests are divided into juniper (*archa), pistachio tree, almond tree,* walnut tree, apple tree, hawthorn and mixed ones. The main forest-forming species in the valleys are the poplars (*Populus), the ash trees (Fraxinus), the maple (Acer), the plane trees (Platanus), the* elm trees (*Ulmus) and the other quick-growing, fruit- and nut-bearing species.*

The forest-forming species in flood-plain tugai forests are the Asiatic poplar (*Pópulus diversifolia), the Bukhara Dschidda* (*Elaeagnus angustifolia), various species of the willow (ш.) and the Tamarix sp.*

Vegetation of mountain territories has zonal character and distinctions are made between desert-like and dry steppes, meadow steppes, bushes, deciduous and coniferous (juniper) forests, and subalpine and alpine meadows. Although relatively small in terms of area, the mountain forests of Uzbekistan are diverse by species composition.

More than 100 tree and shrub species can be found here. Based on the composition, the mountain forests can be divided into various types such as juniper, pistachio, almond, nut-tree, apple-tree, hawthorn, mixed forests, and shrubbery.

1.1.2.1 Forest administration and management

It is noteworthy to emphasize the management of forest resources in Uzbekistan, because the management regulation changes regularly, i.e. which organization obeys which higher-level-status state organization, or their functions and priorities are exchanged among state organizations regularly over time. Management of forestry resources is managed by several state organizations including Cabinet Ministers of Uzbekistan, local state bodies, Ministry of Agriculture and Water Resources, State Committee of Uzbekistan on Nature Protection. But as main state organization to manage forestry sector Main Department of Forestry affiliated by Ministry of Agriculture and Water Resources was turned into from Uzbekistan SSR State Forestry Committee which was established on February 12, 1991. This main organization practiced till May 11, 2017 and State Forestry Committee was reestablished on this day again. During 2000-2017 time period Main Department of Forestry managed about 91.7% of the total SFF land resources (Vildanova, 2006).

1.1.2.2 Forest legislation and policy

Destruction of forests in pre-revolutionary Turkestan reached such a scale that in 1897 the "Regulations on Forest Protection" were issued before independence. Furthermore, the "Law on nationalization of lands and forests" was adopted in 1918. In compliance with this law, all forests in the Turkestan Republic became part of the State Forest Fund. Having obtained its independence Uzbekistan issued the law on "Nature Protection" in 1992 and "State Committee (SFC) of the Republic of Uzbekistan on Nature Protection" was established in 1996. In 1997 "Protection and Use of Flora", in 2004 the law on "Protected Natural Territories", and in 1999 Forest Act were accepted by the government. Moreover, on September 4, 2001 the Cabinet Ministers of Uzbekistan issued Resolution 163 "On Classification of Forests in the Republic of Uzbekistan by Protection Categories". To meet further needs of population for construction wood and pulp, in 1994 the Cabinet Ministers of Uzbekistan accepted a resolution on creation of industrial plantations of poplars and other fast-growing species. However, due to the lack of water resources for irrigation, the survival rate of planted trees was law, which resulted in a decrease of the area of poplar plantations. In 2009, with technical support of FAO[10] national forest policy on reforestation and afforestation was issued, however, still no **Sustainable Forest Management Concept** has been formed by the government. In recent years, Uzbek government and state forestry committee (SFC) have been trying to mitigate the effects of deforestation (especially, illegal felling of trees for burning energy in the suburbs, out of cities, and illegal encroachment of bare lands) by adjusting legislation and articles. As well as, the government and state forestry committee are formulating legal framework based on international standards and FAO guidelines. FAO branch and SFC are subject to remain the current forest resources in a good manner, because Uzbekistan is one of the countries with less forest covered area, i.e. about 7% of overall territory of the country is covered by forests. So keeping the current level of forestry is a promising result. FAO is seen as critical organization for the engaging in activities against deforestation, forest degradation, and desertification control with its specific projects till 2016 (FAO, 2018) at the regional level and SFC as the state head organization had not implemented sustainable forest management framework indicators as national level and had not integrated any legislation or jurisdiction document into practice in terms of sustainable forest management although concept of indicators for sustainable forest management was developed at the Earth Summit in 1992. Furthermore, REDD is a package of efforts tend to reduce emissions from deforestation and forest degradation (REDD). This is primarily for encouraging developing countries to reduce emissions and enhance halting greenhouse gas emissions via forest management options, as well as to provide financial and technical support for these efforts. During the 16th meeting of the Conference of the Parties (COP) affiliated by United Nations Framework Convention of Climate Change (UNFCCC) a decision was made to include conservation, sustainable management of forests and the enhancement of forest carbon stocks - the “+” activities – hence, “REDD+” has been used (ENFCCC, 2010) and we can call this as 'climate change mitigation measure'. However, Uzbekistan has not showed any interest on this concept and the country is not available in the list of countries with REDD+ concept in terms of sustainable forest management. REDD+ concept and its activities are able to provide with promise results relative to deforestation reduction, depletion of emission level, desertification control, etc. in the country. But, community, also, need to be involved in decision-making process and people should see with their naked eyes the consequences of deforestation, desertification, forest degradation. Moreover, the relative forestry organizations and committee should work collaboratively with

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[10] Food and Agriculture Organization

local people, but this aspect of the process is not available in any normative documents in Uzbekistan. Because, all orders are accepted by state government and committees. However, society and indigenous people are owner the environment and natural resources. State forestry related organizations should formulate framework how to work together with community members.

1.2 Target, objectives, hypothesis

Main target of the thesis is detecting vegetation change and its attributes with climate variables (precipitation, solar radiation, temperature) in order to identify the contribution of climate change and human activities in vegetation change over time. Vegetation change occurs in space and time due to intervention of human activities and because of climate change. Human activities include afforestation, deforestation, urbanization, grazing and overgrazing, changing of land uses and other activities and these activities are considered human factor on vegetation change. Main climate factors are rainfall and energy, thus precipitation, solar radiation, and temperature as factors by climate change so that detect its relationship with vegetation change. Here are the objectives that were put in front of the thesis procedures:

- to perform the trend analysis of vegetation and climate variables (precipitation, solar radiation, temperature) and identify their significance, i.e. realizing their changes over time and check significance;

- to check abrupt point change in vegetation and its significance to know whether there is a sudden change in vegetation. If yes, to analyze the next steps based on the abrupt point data, if there is not any abrupt point change in vegetation, the next analyses are performed for overall time period;

- to determine the correlation levels between NDVI versus climate variables. In our case, abrupt point change happened in significant levels, so correlation analysis were performed based on two time periods between NDVI and climate variables;

- to run regression analysis to determine relationship between NDVI and climate variables and improve equation of this relationship. Regression analyses have been performed along two directions, i.e. for single-factor regression and multiple-factor regression analyses. Single factor regression analyses show the relationship of NDVI versus single climate variable while other two climate variables are seen constant. Via the single-factor regression analysis we can know the relationship between NDVI and one of the climate variables. Multiple-factor regression analyses show relationship of NDVI versus all climate variables. Multiple-factor regression analyses show the overall relationship between NDVI and all climate variables. Moreover, the equation of multiple-factor regression is improved;

- to determine various factors on vegetation based on improved equation of multiple-factor regression analyses between NDVI and climate variables. In this case, human activities and climate change are involved in as factors in vegetation change. Formulas are developed in order to determine the contribution of each factor in vegetation change.

There is not any specific program directed to improvement of vegetation or afforestation programs in Uzbekistan. Thus, it can be hypothesized that vegetation change (if significantly occurred over space and time) can be influenced mostly by climate factor. Final analyses can show how the vegetation has been changed and the contribution of the factors in percentage. These aforementioned analyses are very helpful for state programs directed to improvement of vegetation in the future.

1.3 Structure of the thesis

The first chapter is referred as introduction and devoted to information about Uzbekistan including geographical location, site-specific conditions of the country, agricultural and economic attributes, forestry condition, forest administration and management, forest policy and other attributes about the country.

Main analyses are performed from the second chapter. Each chapter is devoted to specific target and methods including data collection and analyses, results and discussion are included in that relative chapter. The second chapter is devoted to the trend analyses of vegetation change. The methods section includes all methodological approach and results, and discussion section is engaged in results of the analyses. Methods section includes collecting and processing the NDVI data in time series, Maximum Value Composite (MVC) method, Mann-Kendall test and Sen's slope estimator tests. Since Mann-Kendall and Sen's slope estimator tests are explained in this section these methods are not included in the next chapter. However, these two methods are applied for trend analyses of climate variables in the next chapter. All analyses for vegetation trend change including abrupt point change detection are described in the second chapter.

The third chapter includes the trend analyses of climate variables, i.e. precipitation, solar radiation, temperature. Methods section includes collecting and processing of climate data in time-series and delta-downscaling framework. Results and discussion of climate trend analyses are given in the results and discussion section.

The last chapter (the fourth chapter) consists of attribution of vegetation with climate variables. Correlation analyses between NDVI and climate variables, single-factor and multiple-factor regression analyses, and analyses of the contribution of human activities and climate variables are included in this chapter.

Discussion part is devoted to overall discussion of the thesis based on the results of all analyses.

CHAPTER II TREND ANALYSIS OF VEGETATION

2.1 Methods

2.1.1 Collecting and processing data

Vegetation indices are radiometric measures of photosynthetically active radiation absorbed by chlorophyll in the green leaves of vegetation canopies and are therefore they are considered good surrogate measures of to show the physiologically functioning surface greenness level of a region (Figure 2).

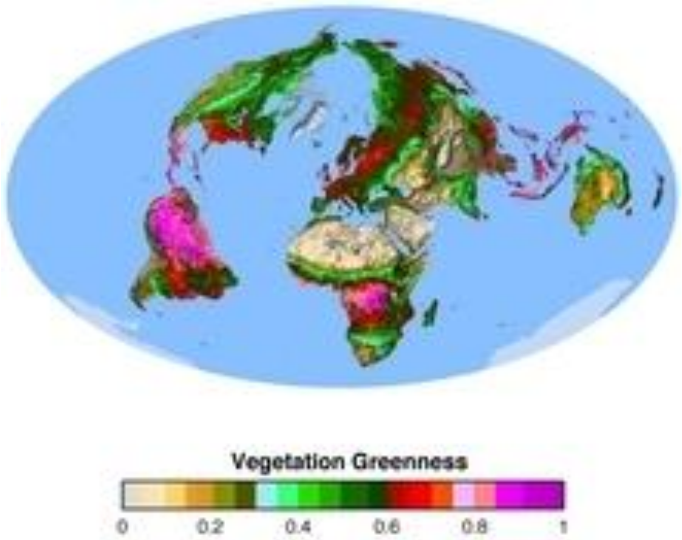

Figure 2 Vegetation greenness[11]

The NDVI data is obtained from https://nex.nasa.gov/nex/projects/1349/, and can directly be downloaded from https://ecocast.arc.nasa.gov/data/pub/gimms/ web page. General data description is given in the **Box 2**. Normalized Difference Vegetation Index 3rd generation (NDVI3g) data which has been generated from NOAA's Advanced Very High Resolution Radiometer (AVHRR) has become important in recent decades and can be used to map land cover and monitor vegetation changes and desertification at continental and global scales (Pinzon and Tucker, 2014; Tucker et al., 2005, 1985; Zhuang, 1999). In the past 30 years NDVI time series have been generated in the framework of Global Inventory Monitoring and Modeling System (GIMMS) project and the latest version of the GIMMS NDVI data set spans the period July 1981 to December 2011 and is termed NDVI3g (third generation GIMMS NDVI from AVHRR sensors). Furthermore, the latest updated version, 3g.v1 has been placed and spans the period from July 1981 to December 2015. The NDVI3g version is a long-term data record which has been produced so that study vegetation photosynthetic capacity for land surface vegetation, non-stationary trend analysis and this dataset is the first one in its kind that is compatible for time-series analysis of land surface trends in vegetation

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[11] https://nex.nasa.gov/nex/projects/1349/

in photosynthetic capacity, seasonality or phenology, and climate-vegetation trends (Anyamba et al., 2014).

Box 2 AVRHH NDVI3g general data description

README 2014 March 2014

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1. DESCRIPTION
2. FILE NAMING CONVENTION
3. GRID PARAMETERS
4. DATA FORMAT VI3g
5. FLAGS

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1. DESCRIPTION

This dataset is an inverse cartographic transformation and mosaicing of the GIMMS AVHRR 8-km Albers Conical Equal Area continentals AF, AZ, EA, NA, and SA to a global 1/12-degree Lat/Lon grid.

Continent demarcation and pixel selection is predetermined with an ancillary NDVI-3G based land-water mask.

2. FILE NAMING CONVENTION

geo[year][month][period].n[sat][-[VI][version]g

where

year	2-int	2 digit year
month	3-char	abbr. lower case month name
period	3-char	alphanum period: bimonthly 15[ab]
sat	2-int	satellite number
version	n-int	version number (3)

For example,

geo09jan15a.n17-VI3g

3. GRID PARAMETERS

grid-name: Geographic Lat/Lon
pixel-size: 1/12=0.0833 degrees

```
   size-x: 4320
   size-y: 2160

   upper-left-lat: 90.0-1/24
   upper-left-lon: -180.0+1/24
   lower-right-lat: -90.0+1/24
   lower-right-lon: 180.0-1/24
   *coordinates located UL corner of pixel

4. DATA FORMAT - VI3g
   datatype: 16-bit signed integer
   byte-order: big endian
   scale-factor: 10000
   min-valid: -10000
   max-valid: 10000
   mask-water: -10000
   mask-nodata: -5000
   *values include embedded flags (see full NDVI-3G documentation - in preparation)
5. FLAG VALUES
   Each NDVI data set (ndvi3g) is an INT16 file saved with ieee-big_endian
   it ranges from -10000->(10000->10004)
   with the flagW file added to the ndvi values as follows:
   ndvi3g = round(ndvi*10000) + flagW - 1;
   flagW ranges from 1->7
   to retrieve the original ndvi  and flagW values
   flagW = ndvi3g-floor(ndvi3g/10)*10 + 1;
   ndvi = floor(ndvi3g/10)/1000
   The meaning of the FLAG:
   FLAG = 7 (missing data)
   FLAG = 6 (NDVI retrieved from average seasonal profile, possibly snow)
   FLAG = 5 (NDVI retrieved from average seasonal profile)
   FLAG = 4 (NDVI retrieved from spline interpolation, possibly snow)
   FLAG = 3 (NDVI retrieved from spline interpolation)
   FLAG = 2 (Good value)
   FLAG = 1 (Good value)
END
```

NDVI (Normalized Difference Vegetation Index) is the ratio of subtraction of visible red band from the near infrared to sum of visible red band and the near infrared (Equation 1):

$$NDVI = (p_{NIR} - p_{red})/(p_{NIR} + p_{red}) \qquad \text{Equation 1}$$

Where, p_{NIR} and p_{red} are the near infrared and the red spectral reflection values, respectively.

The NDVI dataset which has been used in the research spans from 1981.7-2015.12, covers the globe, 15-day a NDVI data, and the spatial resolution of the data is 8 km. Having downloaded the NDVI dataset, the **maximum value composite (MVC)** technique was used to obtain monthly NDVI series from the 15-day NDVI dataset. MVC method is described in the next passage. Besides, the data was extracted using a rectangular box including the study area. The time period will span from 1982.1-2015.12, 34 full years.

Having finished all of the aforementioned steps, Mann-Kendall and Sen's Slope estimator tests were used in order to check the magnitude of change and significance of change of NDVI and climate variables (precipitation, solar radiation, temperature). The results of Mann-Kendall and Sen's Slope estimator tests will be given in the form of tables and spatial demonstration of the maps (in our research: Uzbekistan) in the results passage of the current chapter. Since the data covers time-series dataset and this is a large scale one we needed multi-functional computer-based software so as to perform all analysis properly, so **MATLAB 2014a** version was used in our research investigation. For performances of all steps of analysis, personal codes of MATLAB were used.

2.1.2 Maximum Value Composite (MVC)

MVC method which is a procedure based on pixel-by-pixel basis and obtains the highest NDVI value for each pixel and requires a series of multi-temporal satellite dataset to be processed into NDVI images (Holben, 1986) and this method has been adopted in several research works (Jue et al., 2001; Lee, 2014; Li et al., 2017; Pinzon and Tucker, 2014; Tucker et al., 2005; Wu et al., 2015; Xu et al., 2017; Zhuang, 1999 etc.) to minimize cloud contamination, remove atmospheric noise and convert 15-day dataset to monthly NDVI data. In our research also Maximum Value Composite (MVC) method was applied so that get monthly NDVI data from 15-day NDVI data of AVHRR NDVI3g dataset. MATLAB 2014a version was applied to perform all analysis and personal MATLAB codes were used in the processes. However, to get Maximum Value of NDVI data from a dataset ArcMap computer based software can be used too. MVC method can be applied by using 'Cell Statistics' tool (under 'Local' tool unit) under 'Spatial analyst Tools' toolbox.[12] When 'Cell Statistics' tool is clicked on 'Cell Statistics' box appears. Having input all rasters or constant values, 'Maximum' option is selected in the 'Overlay Statistics (optional)' box and the desired results can be taken.

According Julian date, in our case, 15-day NDVI data consists of 1982.01.12 and 1982.01.27 for January 1982, 1982.02.11 and 1982.02.26 for February 1982 and this finishes with 1982.12.23 for one-year (1982) of NDVI data. By using MVC method, monthly NDVI data is taken from two 15-day NDVI dataset.

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[12] ArcToolbox > Spatial Analyst Tools > Local > Cell Statistics

2.1.3 Mann-Kendall test

The non-parametric Mann-Kendall trend test (Kendal's tau test or Man -Kendall trend test) was used in the research to check the significance of the change trend at the 95% confidence level. The distribution-free Mann-Kendall method has been widely applied in the time series agro-meteorological and hydrological time series analysis (Atta-ur-Rahman and Muhammad, 2016; Blain, 2013; Gocic and Trajkovic, 2013; Hamed, 2009; Li et al., 2012; Liu et al., 2015; Peng et al., 2017b; Shadmani et al., 2012; Wang et al., 2012). The advantage of distribution-free tests is that their power and significance are not influenced by the actual distribution of the data (Hamed, 2009). Furthermore, the MK test does not demand the normality of time series and is considered less sensitive to outliers and missing values, so the method is recommended by the World Meteorological Organization to conduct change trend analysis in hydro-meteorological data (Liu et al., 2015).

To operate the Mann-Kendall trend test the data values of the dataset are evaluated as ordered sequence time series and each data value is compared to all other data values. The first value of the Mann-Kendall statistic, S, is seen as 0 (i.e., no trend). If a data value of later time is higher than the data value from the earlier time, then S is incremented by 1. Also, if the data value of a later time period is less than the data value of the earlier time, then S is decremented by 1. The final result of S is the calculations of all these increments and decrements.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \qquad \text{Equation 2}$$

where *n* is the number of data points, x_j and x_i are the data values in time-series i and j (j>i), respectively and $sgn(x_j - x_i)$ is the sign function as in the Equation 3:

$$sgn(x_j - x_i) = \begin{cases} +1, if\ x_j - x_i > 0 \\ 0, if\ x_j - x_i = 0 \\ -1, if\ x_j - x_i < 0 \end{cases} \qquad \text{Equation 3}$$

The computation of the variance is as in the Equation 4:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \qquad \text{Equation 4}$$

where *n* is the number of data points; *m* is the number of tied groups; t_i is the number of ties of extent *i*. A tied group denotes a set of sample data having the same value. If the sample size exceeds 10 (n>10), then the standard normal test statistic Z_S is calculated by the Equation 5:

$$Z_S = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, if\ S > 0 \\ 0, if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, if\ S < 0 \end{cases} \qquad \text{Equation 5}$$

Positive Z_S values indicate increasing trend and negative Z_S values mean decreasing trend. The significance level of the increasing and decreasing tend is checked at specific significant α level. When $|Z_S| = Z_{1-\alpha/2}$ the null hypothesis (H_0) can be rejected, so a significant increasing or decreasing trend exists. $Z_{1-\alpha/2}$ is taken from the standard normal distribution table. In the current study, significant α level is α=0.05 was used. At 5% significant level, the H_0 which means no trend is rejected if $|Z_S|$>1.96.

In our study NDVI and climate variables (precipitation, solar radiation and temperature) were checked by Mann-Kendall and Sen's Slope estimator tests. In generally, Mann-Kendall test is used to identify the significance of the trend in time series analysis while Sen's Slope estimator test is used to show the magnitude of the change trend in time series.

2.1.4 Sen's Slope estimator test

The non-parametric Sen's slope estimator was used in this study to check magnitude of the changes in the NDVI and climate variables (precipitation, solar radiation, temperature) (Sen, 1986) and lots of research studies applied the test to check the magnitude of meteorological time series trend (Atta-ur-Rahman and Muhammad, 2016; Gocic and Trajkovic, 2013; Peng et al., 2017b, 2017a; Wang et al., 2012). The magnitude of trend change in this study is based on monthly data aforementioned above. (Sen, 1986) improved the non-parametric trend test for estimations of the slope of the trend and each of the magnitude NDVI trend, the magnitude of precipitation trend, the magnitude solar radiation trend, and the magnitude of temperature trend is calculated by the SSE.

$$f(t) = Qt + B \qquad \text{Equation 6}$$

Q denotes slope, B is a constant (in the Equation 6). Firstly, the slope values of the entire time series data are calculated so that obtain the slope estimation (Q) (Equation 7):

$$Q_i = \frac{X_i - X_j}{j - k} \qquad \text{Equation 7}$$

where i=1,2,3,...,N, at time j and k (j>k) and X_j and X_k indicate the values of data pairs, correspondingly. The median of N values of T_i has been expressed as SSE as expressed in the Equation 8:

$$M_{med} = \begin{cases} Q_{[(N+1)/2]}, & if\ N\ is\ odd \\ \dfrac{Q_{[N/2]} + Q_{[(N+2)/2]}}{2}, & if\ N\ is\ even \end{cases} \qquad \text{Equation 8}$$

So, the final SSE depends on the N, i.e., if N is odd, then SSE is calculated as Equation 9, while if N is even, then SSE can be expressed as in the Equation 10:

$$Q_{med} = \frac{T(N+1)}{2} \qquad \text{Equation 9}$$

$$Q_{med} = \frac{T(N/2) + T(N+2)}{2} \qquad \text{Equation 10}$$

(Atta-ur-Rahman and Muhammad, 2016)

2.2 Results and discussion

2.2.1 Spatial distribution of NDVI

Monthly NDVI spans from Northwest to eastern part of the country (Figure 6). The highest NDVI is in around the east part of the country including Andijon, Ferghana. Sirdaryo and Tashkent city and NDVI in these areas constitute 0.23, 0.2, 0.2, and 0.2, respectively (Table 1) and these regions' territory is 3.66% of the whole country. In other word, 3.66% area of the country took [0.2-0.4] NDVI values in the period of 1982-2015 (in (Li et al., 2017) NDVI is classified into five types as T1 (0-0.2), T2 (0.2-0.4), T3 (0.4-0.6), T4 (0.6-0.8) and T5 (0.8-1.0)).

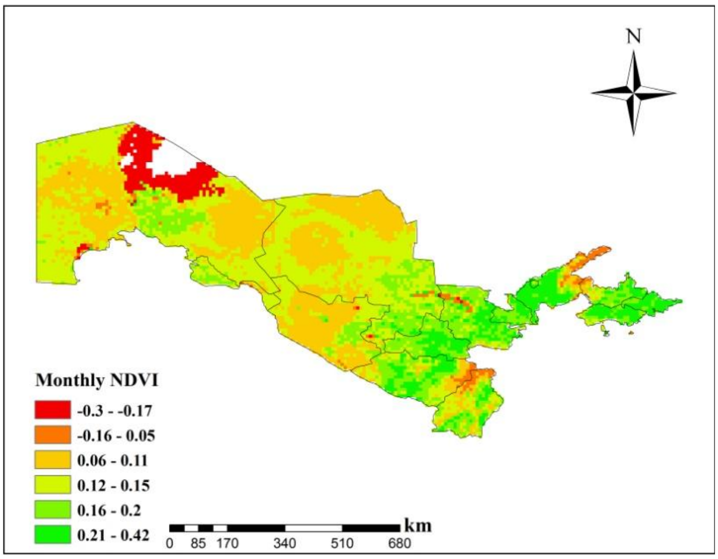

Figure 3 Spatial demonstration of mean monthly NDVI over 1982-2015

Other regions can be indicated with the NDVI type of T1 (0-0.2) or about 96% of the total country was covered with low vegetation types. The most sparse vegetation is in the north part of Uzbekistan, around the desiccated Aral Sea (the red area in the Figure 3).

Table 2 Description of the regions. Mean monthly NDVI over 1982-2015

ID	Regions	Area (km^2)	NDVI
1	Andijon	4,200	0.23
2	Bukhara	39,400	0.11
3	Ferghana	6,800	0.20
4	Jizzakh	20,500	0.17
5	Karakalpakstan	165,600	0.06
6	Kashkadarya	28,400	0.17
7	Khorezm	6,300	0.13
8	Namangan	7,900	0.17
9	Navoi	110,800	0.12
10	Samarkand	16,400	0.19
11	Sirdaryo	5,100	0.20
12	Surkhandarya	20,800	0.14
13	Tashkent City	300	0.20

14	Tashkent	15,000	0.17

2.2.2Trends in NDVI

Figure 6 shows the geographic distribution of the magnitude of trend for monthly NDVI for the whole country in the period of 1982-2015. Table 4 shows no significant trend in monthly NDVI for all regions in the period of 1982-2015. An insignificant decreasing trend is observed in Andijan, Karakalpakstan Republic, Navoi, and Sirdaryo regions, these regions constitute 63.84% of the country and magnitude of insignificant decreasing trend ranges from -0.216/10 year to 0.145/10 year with a mean of -0.0028/10 year. Other regions (about 36.16%) shows insignificant increasing trend ranges from -0.166/10year to 0.098/10 year with a mean of 0.0051/10 year in the zone with insignificant increasing trend (Table 4). Temporal trend of mean annual NDVI is not showing fluctuations in the period of 1982-2015 over the country (Figure 4).

Mann-Kendall test has been carried out to check whether there is an abrupt change in mean annual NDVI over 1982-2015 over the entire country and the results are showing the abrupt change in 2010 (Figure 5). The horizontal red lines indicate significance level at the 95%, if the intersection point is located in the these upper and lower level of significance level abrupt change is considered significant, but if the point is outside the significance level, then the result is insignificant (Li et al., 2016), thus there is a significant abrupt change in mean annual NDVI in 2010.

This abrupt point detection was carried out to explore whether there is a sudden increasing or decreasing change after 1991, because Uzbekistan obtained its independence in this year. However, the abrupt point change is occurring in 2010. This is not explainable with policy regimes after independence. However, slight fluctuation in annual mean NDVI can be explained with increasing of land resources for one farmer for utilization in the period of 2000-2016 (Table 3). There is a sharp increase in total land utilization for farmers from 2000 to 2005, i.e. from more than 888 thousand ha in 2000 to 3.8 million ha 2005. This dramatic increase till 2005 is more than 4 times higher than in 2000. Moreover, abrupt increasing in utilization of land resources for farmers occurred in the period of 2005-2010, from 3.8 million ha to almost 5.5 million ha (1.43 times higher in 2010). However, we do not have data that in what expense these increases of transformations for utilization of land resources for crop production occurred, i.e. from grasslands, forest lands, shrub lands, etc.

Table 3 Distribution of land resources

Years	Number of farmers	Average land per farmer
2000	43756	20.3
2005	125668	30
2010	66134	82
2015	96081	60.6
2016	132356	43.9

Source: State Committee of Uzbekistan on Statistics

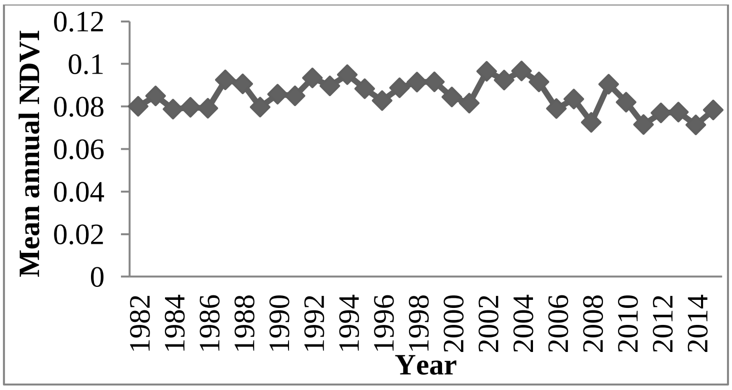

Figure 4 Temporal trend of mean annual NDVI

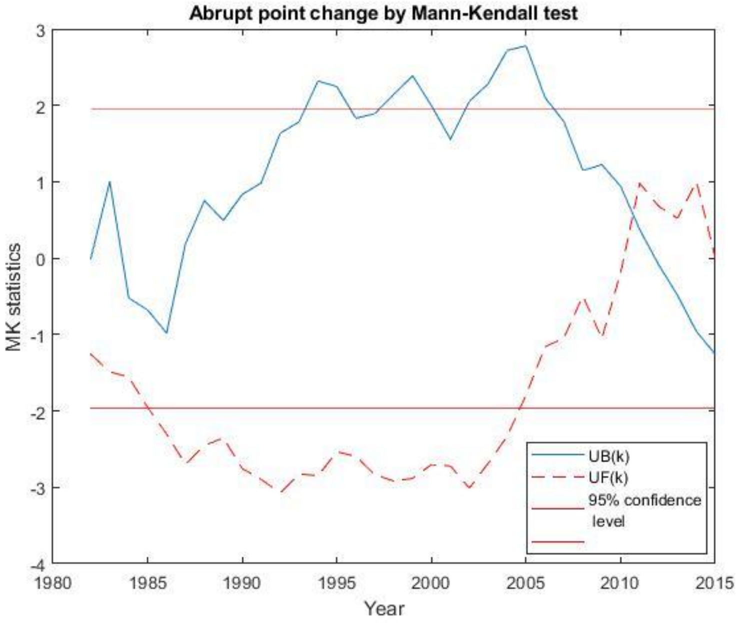

Figure 5 Abrupt point change in annual NDVI

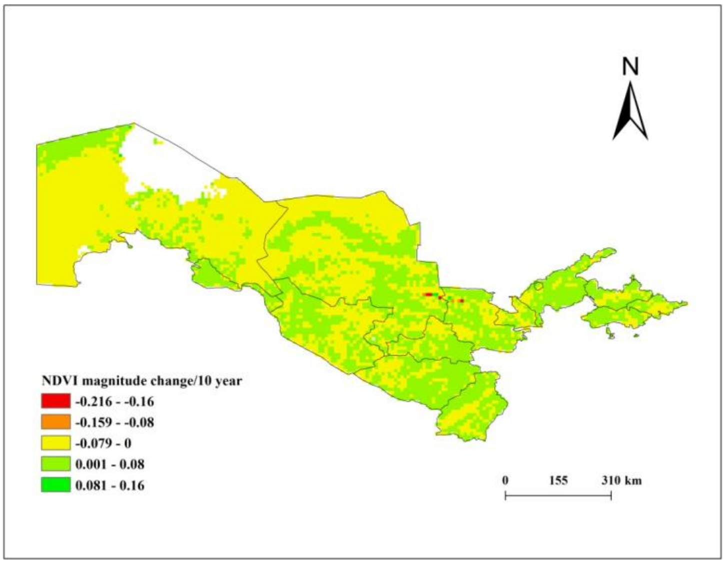

Figure 6 Geographic distribution of the magnitude of trend for monthly mean NDVI across regions in the period 1982-2015

Table 4 Distribution of the magnitude of trend for monthly mean NDVI and significance of magnitude change across regions in the period 1982-2015

	Region	Min	Max	Range	Mean	Significance
1	Andijon	-0.019	0.02	0.039	-0.0006	-0.16
2	Bukhara	-0.028	0.028	0.056	0.0002	0.2
3	Ferghana	-0.015	0.029	0.044	0.0057	1.00
4	Jizzakh	-0.166	0.098	0.264	0.0034	0.39
5	Karakalpakstan	-0.061	0.091	0.152	-0.0059	-1.6
6	Kashkadarya	-0.047	0.045	0.092	0.007	0.76
7	Khorezm	-0.016	0.052	0.068	0.0075	1.62
8	Namangan	-0.019	0.036	0.055	0.0049	0.76
9	Navoi	-0.216	0.145	0.361	-0.0016	-0.40
10	Samarkand	-0.033	0.037	0.07	0.0042	0.66
11	Sirdaryo	-0.024	0.012	0.036	-0.0031	-0.67
12	Surkhandarya	-0.054	0.049	0.102	0.0042	0.61
13	Tashkent City	-0.003	0.015	0.018	0.0046	1.04
14	Tashkent	-0.031	0.038	0.07	0.0099	1.42

2.2.3 Seasonal trends in NDVI

Seasonal temporal change in mean annual seasonal NDVI variability during spring and autumn seasons (Figure 7). Annual spring mean NDVI values have been under summer period mean NDVI till 2002, and there is a change in annual spring mean NDVI after that over summer NDVI till 2012. After this year, again spring mean NDVI tend to lower under summer mean NDVI. Autumn mean NDVI showed gradual decreasing trend over the study period time for the whole country.

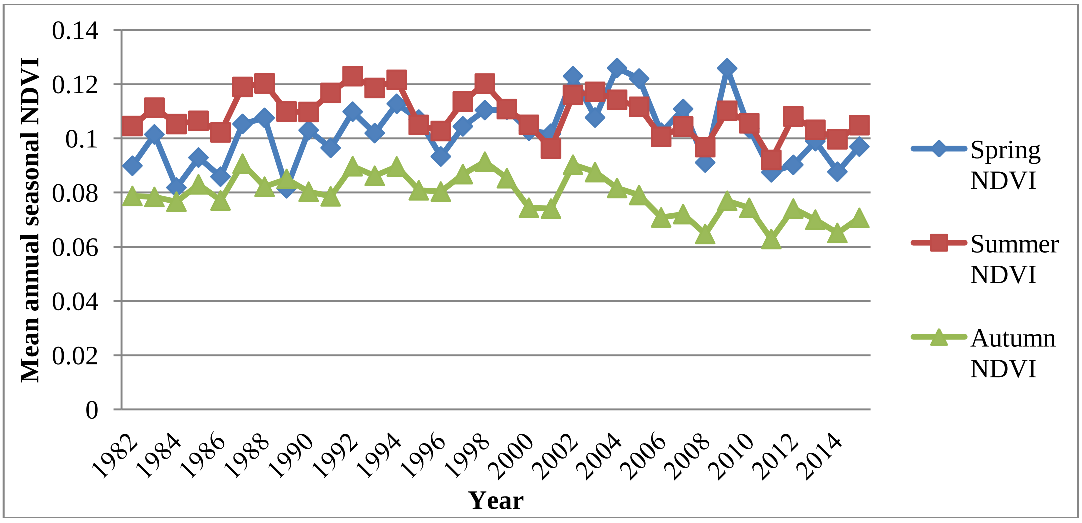

Figure 7 Temporal trend in seasonal mean annual seasonal NDVI in the period of 1982-2015

Furthermore, Mann-Kendall and Sen's slope estimator tests have been applied to detect significance and magnitude of trend change in mean annual seasonal NDVI data. The Mann-Kendall test is showing insignificantly increasing (Z=1.01) trend in mean annual spring NDVI over 1982-2015(Figure 8). Annual seasonal mean NDVI is the average of monthly NDVI for that season of each year, i.e. spring mean NDVI in 1982 is average of monthly March, April, May NDVI in 1982 excluding winter NDVI. These analyses were done in growing season which is mean temperature is positive (>0) and monthly NDVI is larger than 0.0 (>0.1). In Uzbekistan spring and summer periods are green and growing season and irrigation for crops starts from March in some areas, April in some parts of the country and lasts till August. The reason of showing Autumn mean NDVI and climate variables is to show how the changes are occurring after growing season.

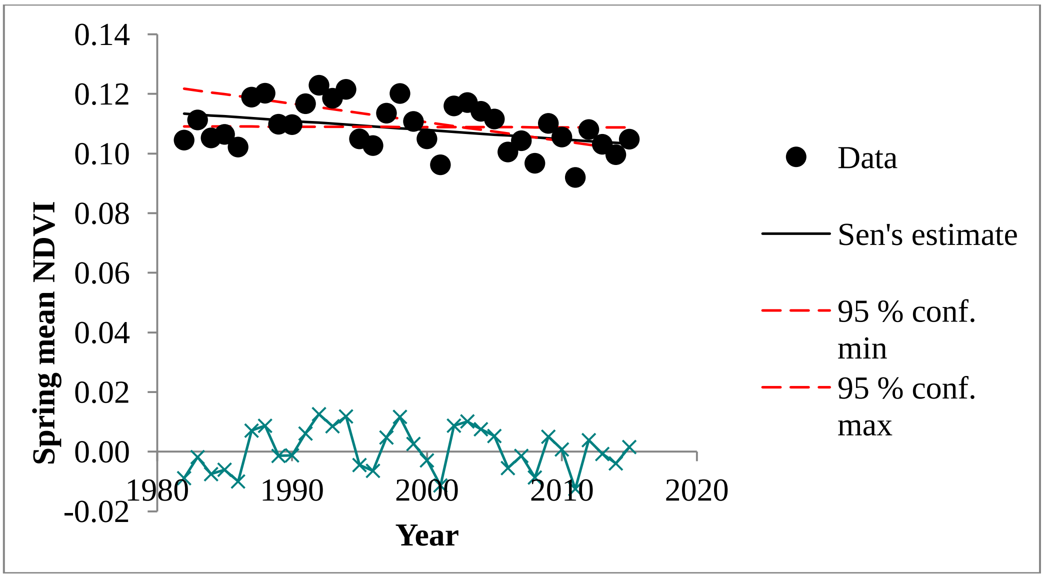

Figure 8 Chart demonstration in mean annual spring NDVI by Mann-Kendall and Sen's slope estimator

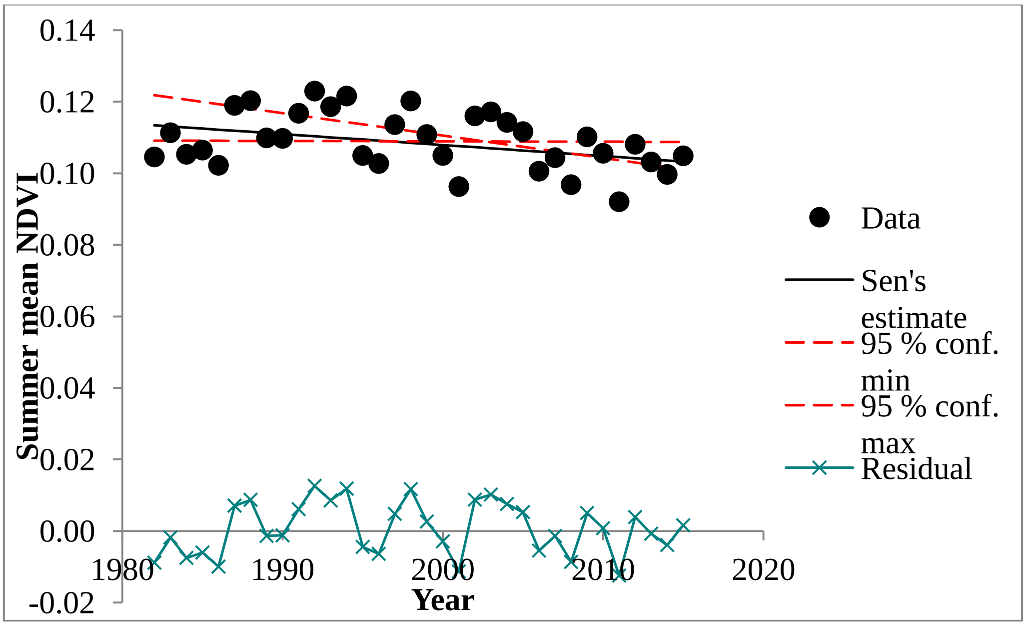

Figure 9 Chart demonstration in mean annual summer NDVI by Mann-Kendall and Sen's slope estimator

But the test is showing significant (Z=-2.08) decreasing trend in summer mean NDVI (Figure 9) and in autumn mean NDVI over 1982-2015 for the country (Figure 10). The reason of upward trend of mean spring NDVI over mean summer NDVI after 2002 can be connected with significant decreasing trend in mean summer NDVI. Also, the test is showing strong significant (Z=-2.96) decreasing trend in mean annual autumn NDVI (Figure 10) over 1982-2015 for the country.

Abrupt change point in mean annual NDVI (Figure 5) is showing that since 2010 there is a sudden change in mean annual NDVI. The next analysis is to check the trend in mean annual NDVI and its significance for time periods, i.e. 1982-2009 and 2010-2015. These sorts of analyses are performed for climate variables so that identify the trends of them and their significance too.

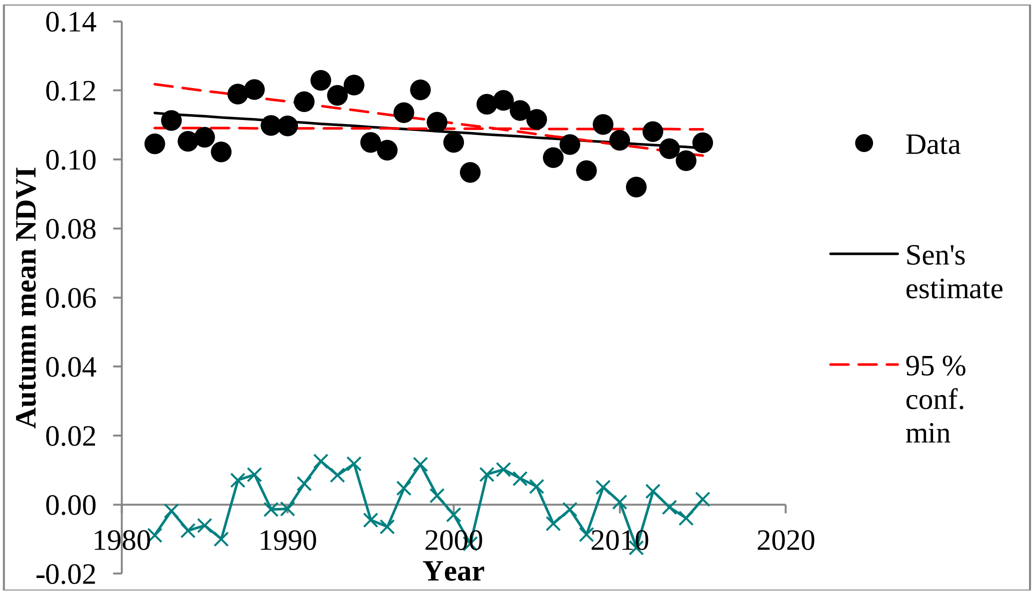

Figure 10 Chart demonstration in mean annual autumn NDVI by Mann-Kendall and Sen's slope estimator

The abrupt point intersection in mean annual NDVI was in 2010, thus the time slap was divided into two periods, i.e. 1982-2009 and 2010-2015. The next step is to process the Mann-Kendall test to check significance of trend analysis for these two time periods. Mean annual NDVI trend results of Mann-Kendall test for two time periods are given in this chapter and Mann-Kendall test results for climate variables' trend results for two time periods are given in the next chapter. These results indicate how NDVI and climate variables over time in these two time slaps.

In the first time period (1982-2009), NDVI increased insignificantly (Z=1.2), but insignificantly decreased (Z=-0.41) in the second time period (2010-2015).

CHAPTER III Trend analysis of climate change

3.1 Methods

3.1.1 Collecting and processing data

The Climate Research Unit (CRU) Time Series (TS) data are produced by the Climatic Research Unit at the University of East Anglia and passed to the Centre for Environmental Data Analysis (CEDA) for long-term archival and distribution purposes. CRU TS 4.01 version was released to CEDA archival in September 2017. The climate data can be obtained from CRU TSv.4.01 https://crudata.uea.ac.uk/cru/data/hrg/, this dataset spans from 1901.1-2016.12, covers the globe, monthly data, spatial resolution is 0.5° (~55km). (Harris et al., 2014) can be used as a guide to the new process being used for CRU TSv4.xx releases. The climate data includes most six independent variables that are mean temperature, diurnal temperature range, precipitation, wet-day frequency, vapor pressure and cloud cover (Harris et al., 2014). In this research, monthly total precipitation and mean temperature were used. Solar radiation data was obtained from worldclim.org web page, its resolution is 8 kilometer. Having downloaded the climate dataset, the data was extracted by using a rectangular box including study area and this data spans from January 1982 to December 2015. For next research analysis, Delta downscaling framework was used so that downscale the climate data variables from 55 km to 8 km. Since CRU TS climate dataset is low-resolution, the high-resolution (5 minutes about, about 8 km) climate so-called WorldClim dataset was used. Further information about this is described in Delta downscaling framework section. After all of these processes Mann-Kendall and Sen's Slope Estimator tests were used in order to investigate the magnitude of trend change of climate variables and their significance. Mann-Kendall and Sen's Slope Estimator tests were described in the previous chapter II.

3.1.2 Delta downscaling framework

"Downscaling" is the process of turning the native-scale global climate model (GCM) results of global climate responses to changing global atmospheric composition and postprocessing those via additional ***dynamical or statistical (non-dynamical, empirical, simple)*** models to create a set of results at finer spatial scale which is more meaningful in the context of local and regional impacts (Brekke et al., 2013). According to (Brekke et al., 2013), a challenge with dynamical downscaling approach is the computational requirement of regional climate model (RCM) implementation, which challenges the feasibility of an effort featuring many projections.

The Delta method requires either low-resolution time series data and high-resolution climate variables as inputs, where high-resolution climate variables must contain a physically representative, fine-scale distribution of the meteorological variable (Mosier et al., 2014). The purpose of using Delta method rather than interpolating low spatial resolution data to higher spatial resolution is that the Delta downscaling framework method incorporates high-resolution orographic effects which do not exist in the low-resolution to the data(*ibid*) and may reduce uncertainties in the raw data (Peng et al., 2017b). The Delta method has been applied to numerous scientific studies (Mosier et al., 2014; Peng et al., 2017b, 2017a).

The current climate data is derived from low-resolution time series (from CRU 0.5° time-series: monthly total precipitation and monthly mean temperature) and high-resolution climatology by using Delta downscaling method. In this study as low-resolution data CRU TSv4.01 dataset was extracted with 0.5° (~55 km) and as high-resolution data WorldClim dataset was downloaded from the linked web-page.[13] The WorldClim version 2 dataset has average monthly climate data for minimum, maximum and mean temperature (°C), monthly precipitation (mm), monthly solar radiation (kJ m^{-2} day^{-1}), wind speed (m s^{-1}), and water vapor pressure (kPa) in the period of 1970-2000. The spatial resolution spans from 30 seconds (~1 km^2) to 10 minutes (~340 km^2). For a high-resolution climatology dataset, WorldClim dataset is the only source with 30 seconds (~1 km^2) spatial resolution for all global land surface (Mosier et al., 2014). This 'WorldClim version 2' high spatial-resolution-interpolated monthly climate data for global land areas has been created by using data from 9000 to 60000 weather stations and this version is refined and expanded version of 'WorldClim version 1 database' (Fick, 2017).

The process of steps of delta downscaling using CRU 0.5° time series and high resolution climatology datasets is well described in (Peng et al., 2017b, 2.3 section and Figure 2).The first step is the construction of 0.5° climatology for each month for each variable (monthly precipitation and monthly mean temperature) from the CRU 0.5° time series dataset. In this study, time series spans from 01.01.1982 to 31.12.2015. A 0.5° anomaly for precipitation and mean temperature is calculated. The anomaly for precipitation is the ratio of time series element to the relative low-resolution climatology, and the anomaly for mean temperature is the difference between time series element and climatology (Peng et al., 2017b). The calculated anomaly is then interpolated to the 5' WorldClim data through spatial interpolation. Finally, the delta method is transforming the high-resolution anomaly back to an absolute surface by scaling it using WorldClim climatology for the relative month (*ibid*). All of these steps are done via Matlab 2014a version by using personal codes.

Having finished the aforementioned processes, the non-parametric Mann-Kendall and Sen's Slope estimator tests were applied to detect the significance and magnitude of climate variables, respectively. Since application processes of the Mann-Kendall and Sen's Slope estimator tests were described in the previous chapter (2.1.3 and 2.1.4 sections) they are not included in this chapter.

3.1.3 Schematic mapping the data

Having downloaded the climate variables from CRU (Climate Research Unit) dataset, the data is extracted using rectangular box including study area and spatially interpolated. Climate variables (precipitation, solar radiation, temperature) data are obtained from point observation via meteorological stations in a space over time. Generally, acquisition of data for every point over an area is impossible, thus predicted values of data can be assigned to all other locations based on observed values. For this purpose, interpolation methods are used. Spatial interpolation functions create a continuous (or prediction) surface from observed point values. These functions can predict from observed values for all locations in a raster

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[13] The high spatial resolution climate dataset was downloaded from this page: http://worldclim.org/version2

dataset, whether a measurement has been taken or not. The reason why interpolation is used for this is that, predicted values of all other locations which measurements have not been taken are close to those observed values which measurements have been taken around that location. Several spatial interpolation methods exist such as *IDW (Inverse Distance Weighted) and Spline* that are called *'Deterministic models'*, *Kriging* interpolation method that is referred to *'Geostatistical model'*. These counted interpolation models are commonly used in spatial analyses in GIS. The interpolation methods in ArcGIS can only use point observations as inputs. Interpolation methods in ArcMap can be done via Spatial Analyst Tools in the ArcMap ArcToolbox: Spatial Analyst Tools>Interpolation>Interpolation methods (*IDW, Kriging, Natural neighbor, Spline*).

3.1.4 Extracting data in the study area

Having done interpolation processes in the rectangular areas including study area, the data in of the country is spatially mapped in ArcMap. For this purpose, shape file of the boundary of the country is needed. By using Spatial Analyst Tools the data can be extracted across boundary of the country: Spatial Analyst Tools>Extraction>Extract by Mask. Furthermore, data for region can be shown as table using Zonal Statistics as Table tool in the Spatial Analyst Tools: Spatial Analyst Tools>Zonal>Zonal Statistics as Table. This table for each region is converted from zonal statistics table to Excel: Conversion Tools>Excel>Table To Excel. After all these processes the data can be shown as thematic map and as table across regions.

3.2 Results and discussion

3.2.1 Mean monthly data evaluation

Figure 11 shows geographic distribution of climate variables over 1982-2015. Temperature (°C) is in mean monthly scale, solar radiation (MJ/m2) and precipitation (mm) are in monthly scale. High values of monthly precipitation belong to Bukhara, Kashkadarya, Samarkand, Surkhandarya and Tashkent City regions indicating 32.64 mm, 40.3 mm, 36.31 mm, 43.11 mm, and 32.36 mm , respectively (Table 4). Monthly precipitation in other regions was a little lower. Mean monthly temperature ranges from -5.67°C in Karakalpakstan Republic to 1.75°C in Sirdaryo region. And monthly solar radiation ranges from 1420.9 MJ/m2 in Andijon region to 2015.06 MJ/m2 in Surkhandarya region.

Table 5 Distribution of mean monthly climate variables across regions. Temperature is in monthly average, solar radiation and precipitation are monthly in the period 1982-2015

	Regions	**Area (km²)**	**Monthly precipitation, mm/month**	**Mean monthly Temperature, °C**	**Monthly solar radiation, MJ/m2**
1	Andijon	4,200	10.19	-0.38	142.09
2	Bukhara	39,400	32.64	-0.24	184.85
3	Ferghana	6,800	4.92	0.35	147.98
4	Jizzakh	20,500	24.06	0.63	177.02
5	Karakalpakstan	165,600	6.93	-5.67	154.13
6	Kashkadarya	28,400	40.30	0.85	198.38

7	Khorezm	6,300	11.61	-3.37	168.61
8	Namangan	7,900	10.22	-1.10	147.15
9	Navoi	110,800	23.82	-2.28	167.31
10	Samarkand	16,400	36.31	0.77	190.20
11	Sirdaryo	5,100	21.09	1.75	171.49
12	Surkhandarya	20,800	43.11	1.29	201.51
13	Tashkent City	300	32.36	1.34	161.78
14	Tashkent	15,000	29.29	-2.21	157.77

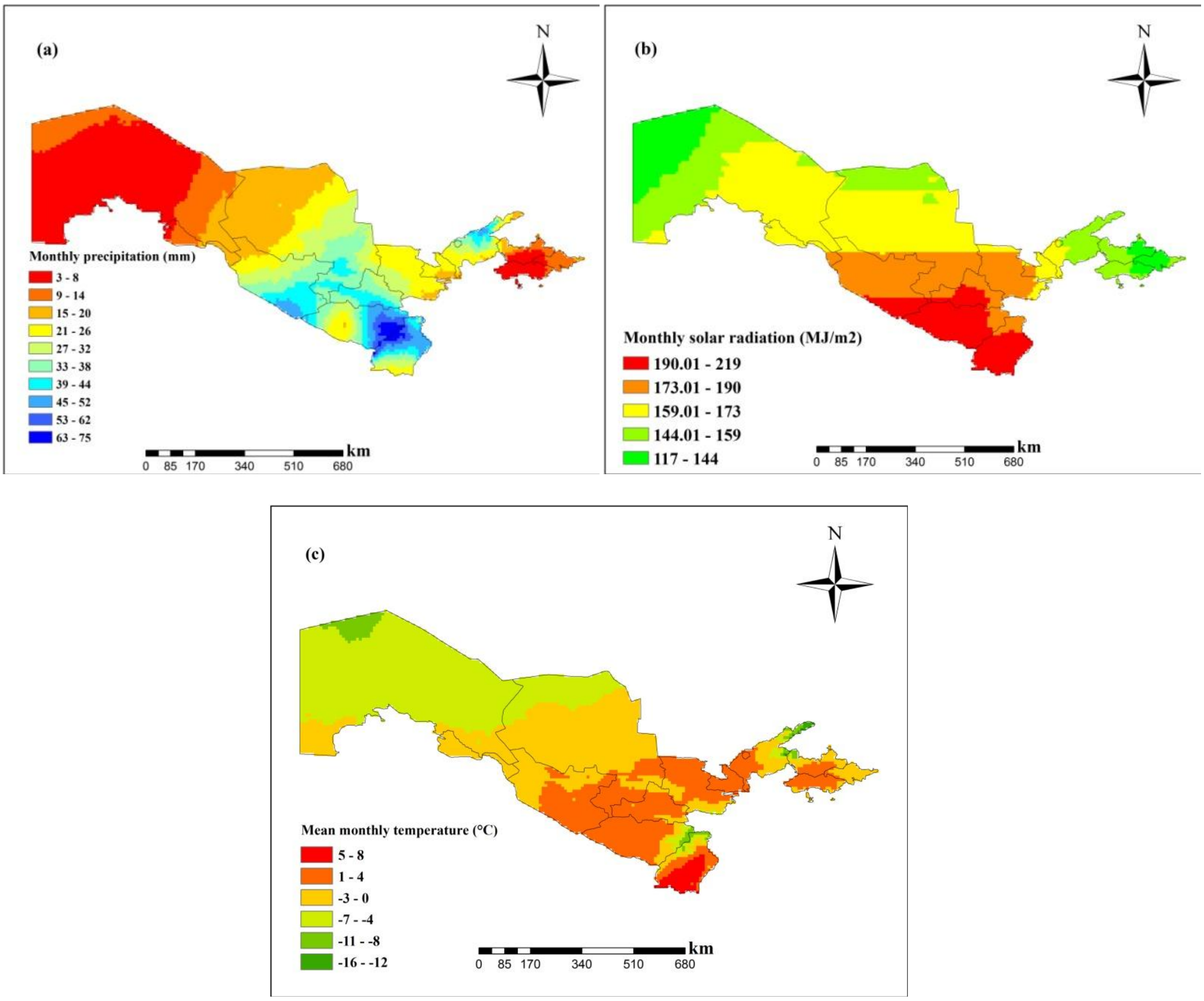

Figure 11 Geographic distribution of climate variables in the period 1982-205. (a) is monthly precipitation (mm), (b) is monthly solar radiation (MJ/m2), (c) is mean monthly temperature (°C)

3.2.2 Trends in monthly precipitation

Figure 12 shows geographic distribution of the magnitude of trend for monthly precipitation in the period of 1982-2015 (34-year span). Among regions of the country only Kashkadarya region has significant increasing trend over 1982-2015 (Table 7). In this region, monthly precipitation ranges from 3.61 mm/10year to 55.88 mm/10year with a mean of 28.71 mm/10year (Table 6).

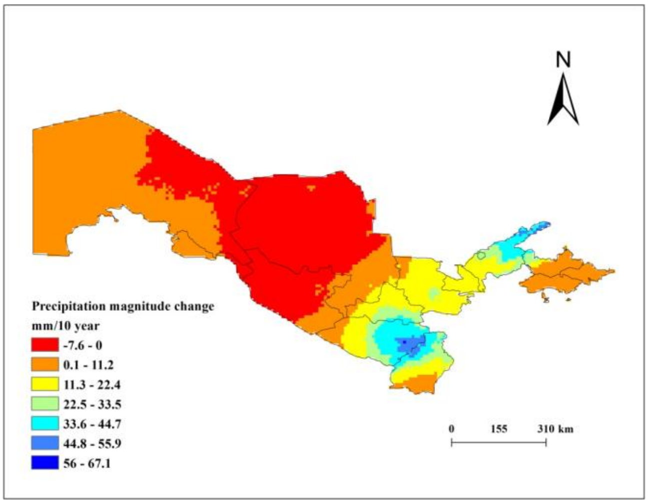

Figure 12 Geographic distribution of the magnitude of trend for monthly precipitation in the period 1982-2015

This region's territory is 6.34% of the total study area. Other regions have insignificant trend in monthly precipitation. Samarkand and Surkhandarya regions have a slight insignificance that magnitude of monthly precipitation ranges from 6.33 mm/10year to 38.22 mm/10year with a mean of 20.68 mm/10year and from 3.89 mm/10year to 49.87 mm/10year with a mean of 22.59 mm/10year, respectively, while other regions are strong insignificant.

Table 6 Distribution of the magnitude of trend for monthly precipitation across regions in the period 1982-2015 (mm/10year) by Sen's slope estimator test

	Region	**Min**	**Max**	**Range**	**Mean**
1	Andijon	2.2	5.33	3.13	3.6
2	Bukhara	-4.78	8.56	13.34	-0.89
3	Ferghana	1.86	5.41	3.55	3.53
4	Jizzakh	5.06	24	18.94	17.5
5	Karakalpakstan	-3.75	10.5	14.25	2.56
6	Kashkadarya	3.61	55.88	52.27	28.71
7	Khorezm	-1.61	8.83	10.44	3.64
8	Namangan	2.63	38.35	35.72	11.15
9	Navoi	-7.62	17	24.62	-1.27
10	Samarkand	6.33	38.22	31.89	20.68
11	Sirdaryo	15.41	22.23	6.82	18.65
12	Surkhandarya	3.89	49.87	45.99	22.59
13	Tashkent City	23	27.27	4.27	24.97
14	Tashkent	13.55	50.5	36.95	29.09

3.2.2.1Trends in annual and annual mean seasonal precipitation

Temporal trend of annual precipitation is very variable over country in the period of 1982-2015 (Figure 13), i.e. annual precipitation fluctuated evidently from 1982-2015 by showing no gradual increasing or decreasing trend. A sharp decrease the annual precipitation from 1994 to 1995 constitutes 213 mm/year and 128 mm/year for each year, correspondingly. But beside the year that showed the highest level of annual precipitation, there is no dramatic increasing or decreasing trend, and the most amount of annual precipitation was in 2003 constituting 283 mm/year over the entire country.

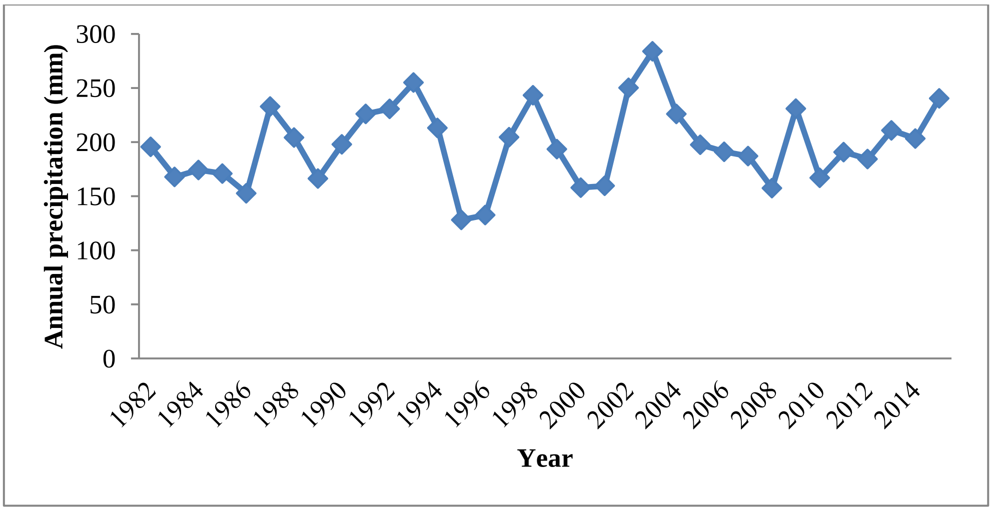

Figure 13 Temporal trend of annual precipitation (mm/year)

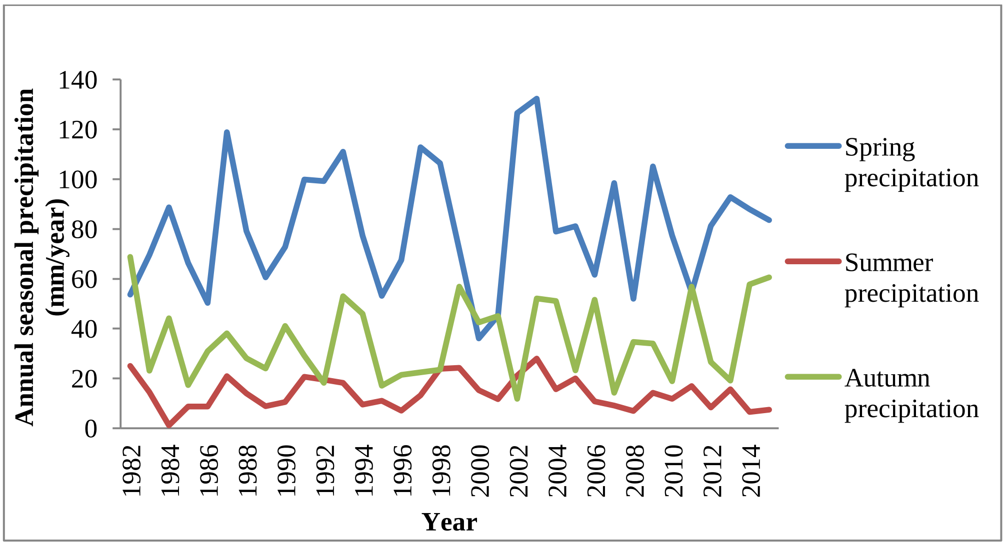

Figure 14 Temporal trend of annual seasonal precipitation

Also, in 2002 there is high rainfall intensity constituting 250 mm/year. Annual seasonal precipitation is sum of monthly precipitation for that season of each year, i.e. spring precipitation in 1982 is sum of monthly precipitation of March, April, May in 1982. But for mean temperature and solar radiation, mean of monthly data was included in that season of each year. Figure 14 shows that most annual precipitation fell during the spring period, summer and autumn rainfall are much lower than spring precipitation. There is a dramatic increase in spring precipitation in the period of 2001-2002 spanning from 45 mm to 126 mm, respectively. In this high rainfall intensity year almost 63 mm precipitation fell in April and this kind of high precipitation intensity is typical in Uzbekistan.

Furthermore, while Mann-Kendall showed no significant trend in monthly precipitation in the period of 1982-2015, this test showed no significant trend in annual seasonal precipitation over the entire country too. Z value is giving 0.77 in spring precipitation indicating no significant trend in annual spring precipitation in the period of 1982-2015 (Figure 15). As annual precipitation is very variable, all annual seasonal precipitation values tend to variable.

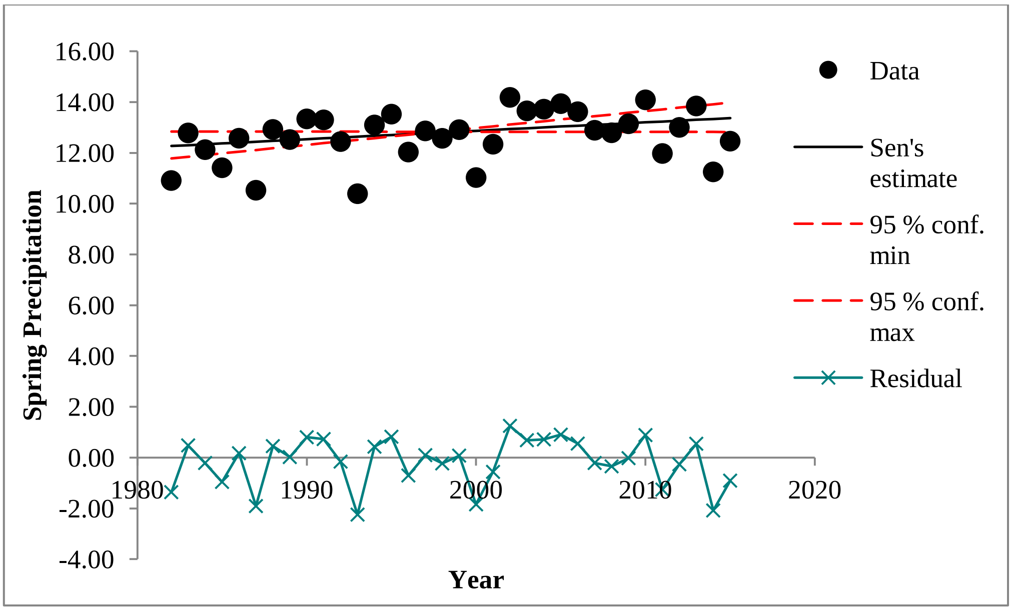

Figure 15 Chart demonstration in annual spring precipitation by Mann-Kendall and Sen's slope estimator

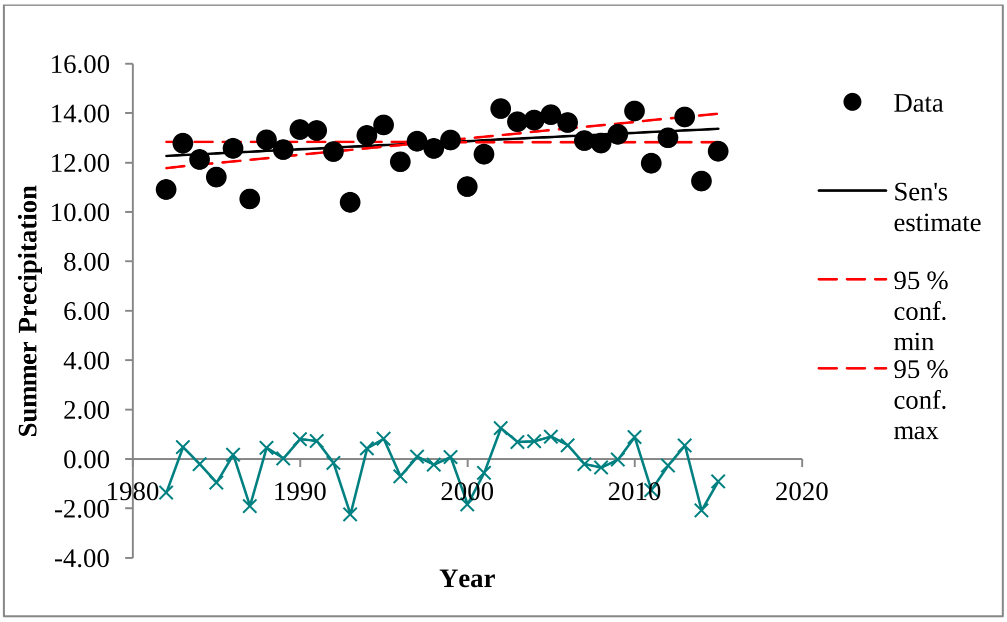

Figure 16 Chart demonstration in annual summer precipitation by Mann-Kendall and Sen's slope estimator

Trends in annual summer (Figure 16) and autumn precipitation (Figure 17) are showing insignificant trends over the country in the period of 1982-2015. Z values for annual summer and autumn precipitation are -0.62 and 0.68, respectively.

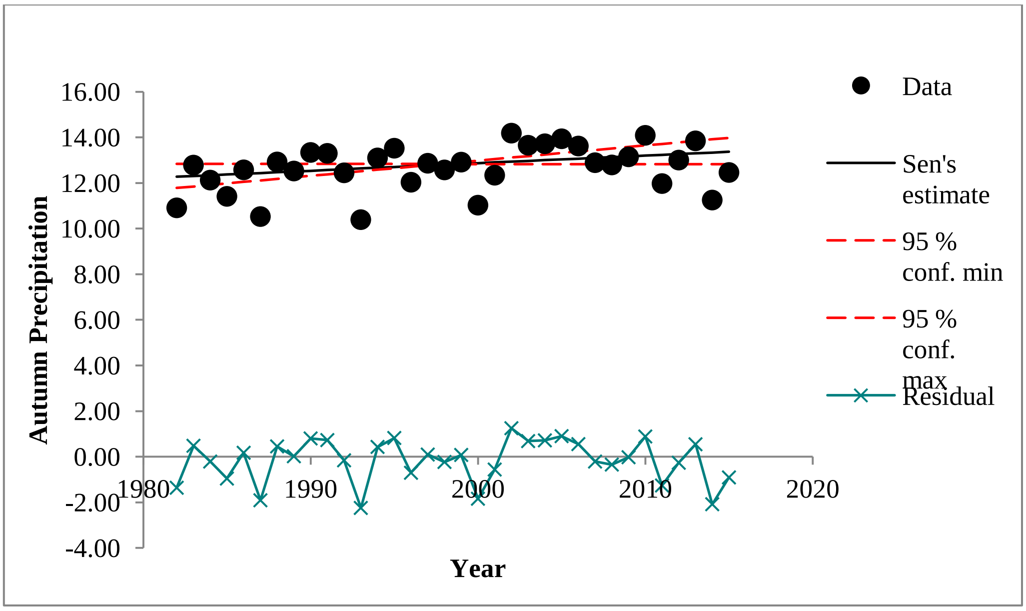

Figure 17 Chart demonstration in annual autumn precipitation by Mann-Kendall and Sen's slope estimator

Summarizing monthly, annual and annual seasonal precipitation trend of precipitation, none of them showed significant increasing or decreasing trends either over the country or in regional scale in the period of 1982-2015. Most rainfall volume was in April in high rainfall intensity years and spring precipitation showed dominance over summer and autumn precipitation during the study years. Moreover, annual autumn precipitation overcame from annual summer precipitation.

Table 7 Significance of change trends of climate variables by Mann-Kendall test over 1982-2015

	Region	Precipitation	Solar radiation	Temperature
1	Andijon	0.41	-0.33	3.74
2	Bukhara	-0.18	0.18	2.83
3	Ferghana	0.61	-0.03	3.5
4	Jizzakh	1.19	-1.13	3.19
5	Karakalpakstan	0.46	1.37	2.58
6	Kashkadarya	2.39	-1.48	3.01
7	Khorezm	0.57	0.61	2.49
8	Namangan	0.88	-0.53	3.54
9	Navoi	-0.35	1.08	2.87
10	Samarkand	1.61	-0.86	3.15
11	Sirdaryo	1.47	-1.01	3.29
12	Surkhandarya	1.71	-1.64	2.79
13	Tashkent City	1.5	-0.36	3.23
14	Tashkent	1.49	-0.49	3.37

3.2.3 Trends in monthly solar radiation

Geographic distribution of the magnitude of trend for monthly solar radiation in the period of 1982-2015 is given in Figure 18. The Mann-Kendall test shows no significant trend at the 95% confidence level for monthly solar radiation over 1982-2015 over the entire country (Table 7 and Table 8). Andijon, Ferghana, Jizzakh, Kashkadarya, Namangan, Samarkand, Sirdaryo, Surkhandarya, Tashkent City, and Tashkent regions have insignificant decreasing trend while Bukhara, Karakalpakstan Republic, Khorezm, and Navoi regions have insignificant increasing trend.

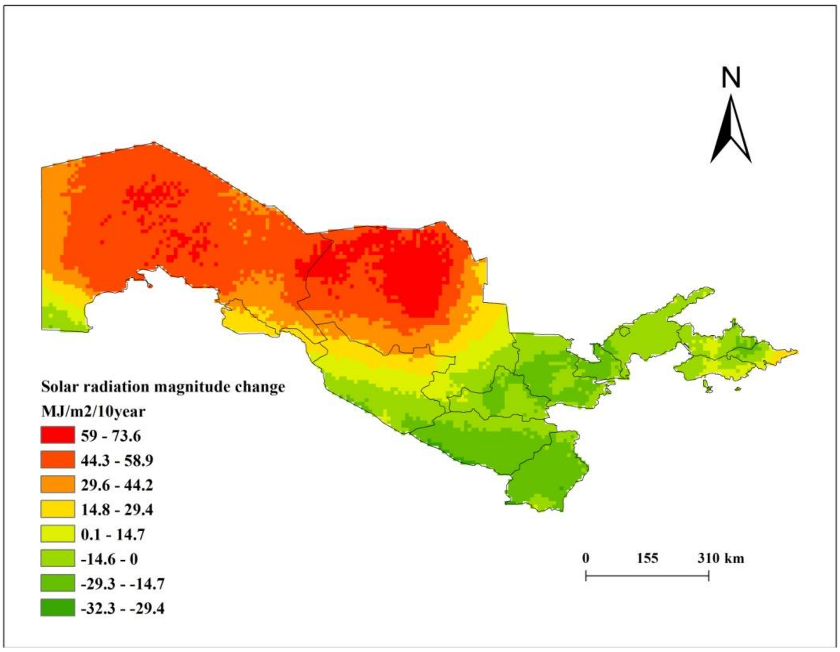

Figure 18 Geographic distribution of the magnitude of trend for monthly mean solar radiation in the period 1982-2015

Table 8 Distribution of the magnitude of trend for monthly mean solar radiation across regions in the period 1982-2015 MJ/m^2/10 year

	Region	Min	Max	Range	Mean
1	Andijon	-18.14	22.33	40.48	-1.22
2	Bukhara	-20.1	42.8	62.9	6.81
3	Ferghana	-11.5	13.8	25.3	-0.02
4	Jizzakh	-25.67	0.23	25.89	-14.45
5	Karakalpakstan	-14.75	66.33	81.08	46.66
6	Kashkadarya	-32.29	-5.33	26.95	-19.34
7	Khorezm	6.73	38.5	31.77	23.33
8	Namangan	-17.43	3.85	21.28	-5.05
9	Navoi	-21.52	73.6	95.15	42.3
10	Samarkand	-29.21	1.65	30.86	-11.46
11	Sirdaryo	-20.87	-9.77	11.1	-16.34
12	Surkhandarya	-31.25	2.11	33.36	-20.08
13	Tashkent City	-8.78	-3.57	5.21	-5.54
14	Tashkent	-17.06	1.89	18.94	-7.32

3.2.3.1 Trends in mean annual and mean seasonal solar radiation

Trends in mean annual solar radiation indicate average of monthly solar radiation per square meter annually (from January to December) and how it is changing over time in the study period, i.e. 1982-2015. Temporal analyses are showing fluctuations in mean annual solar radiation (Figure 19). 2002 and 2014 can be emphasized as years with the lowest and highest mean annual monthly solar radiation volumes constituting 424 MJ/m2 and 464 MJ/m2, respectively.

Among mean annual seasonal solar radiation trends mean summer solar radiation is the highest than the mean spring and autumn solar radiation (Figure 20). There are no dramatic changes and fluctuations in mean summer solar radiation and mean autumn solar radiation volumes over the study period. Mean spring solar radiation starts fluctuating since 1996 and there is a sharp increase from 2003 (439 MJ/m2) to 2004 (519 MJ/m2).

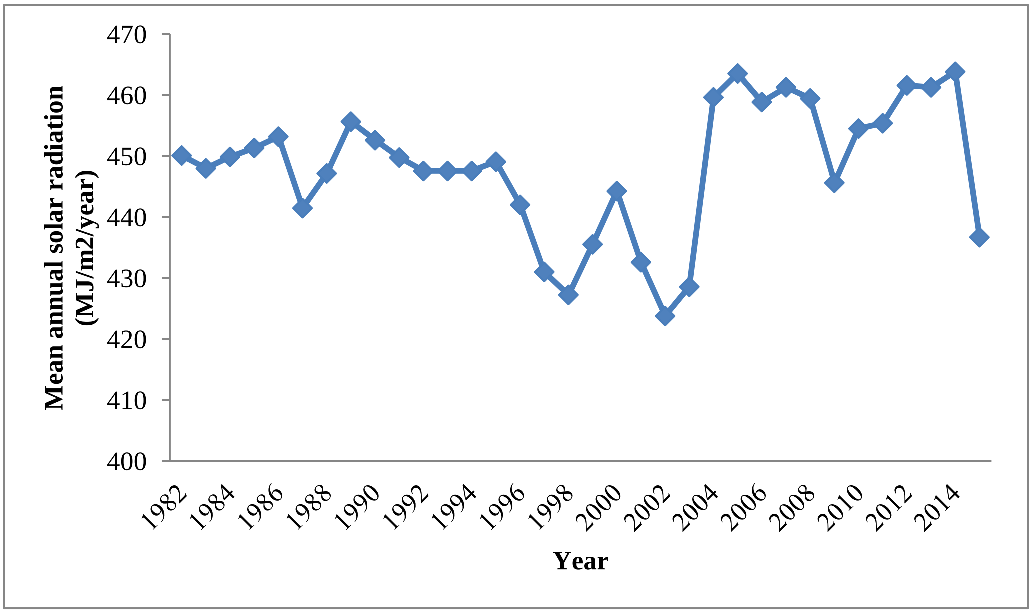

Figure 19 Temporal trend of mean annual solar radiation (MJ/m2/)

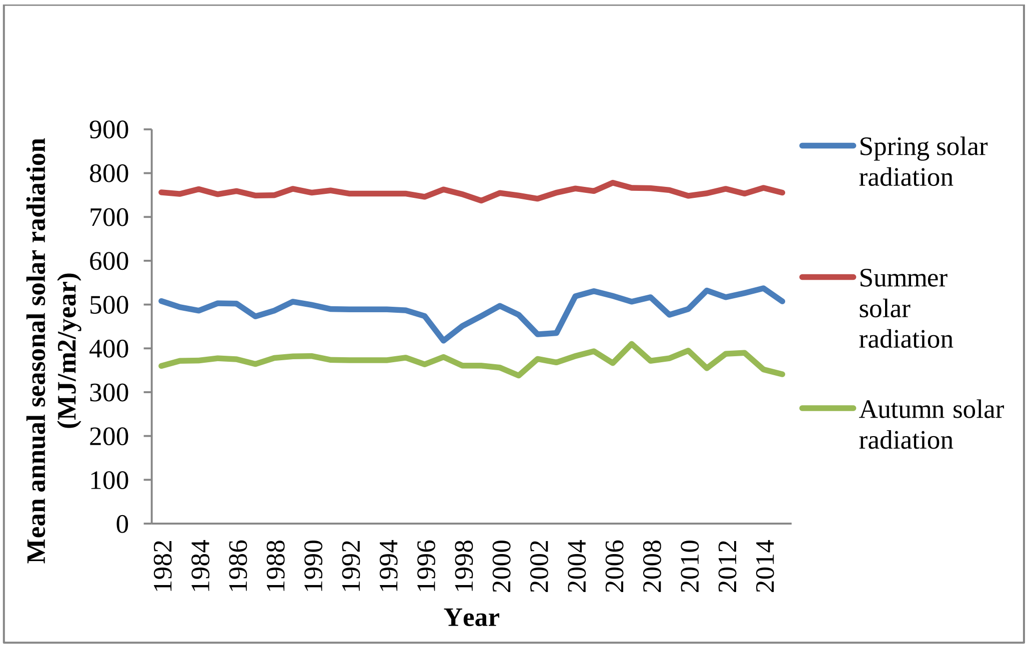

Figure 20 Temporal trend of mean annual seasonal solar radiation

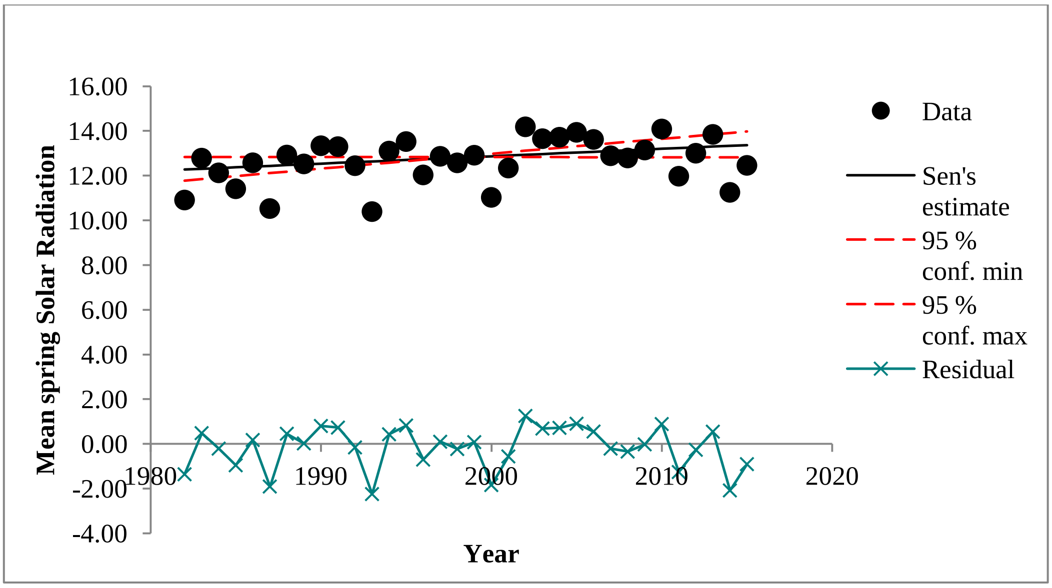

Figure 21 Chart demonstration in mean spring solar radiation by Mann-Kendall and Sen's slope estimator tests

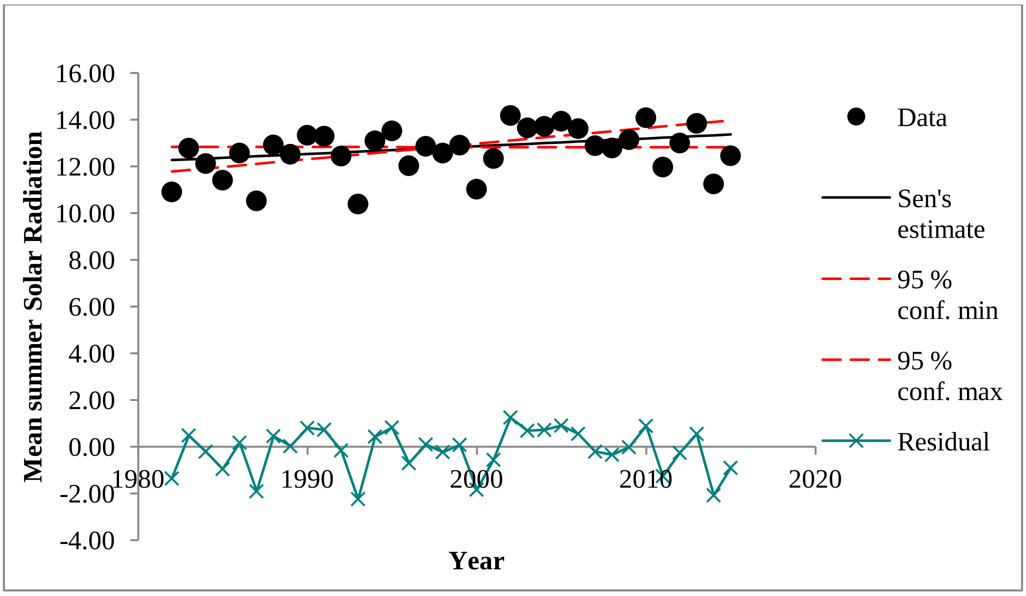

Figure 22 Chart demonstration in mean summer solar radiation by Mann-Kendall and Sen's slope estimator tests

Trends in mean annual seasonal solar radiation are indicating no significant trends over the study area in the period of 1982-2015. Z values in mean spring solar radiation (=1.53) (Figure 21), mean summer solar radiation (=1.11) (Figure 22), and in mean autumn solar radiation (=0.16) are showing insignificant increasing trends over the study period of 1982-2015.

Summarizing of monthly solar radiation, annual mean solar radiation, and mean annual seasonal solar radiation trends, it can be concluded that none of them showed significant increasing or decreasing trends from 1982 to 2015 in the study area.

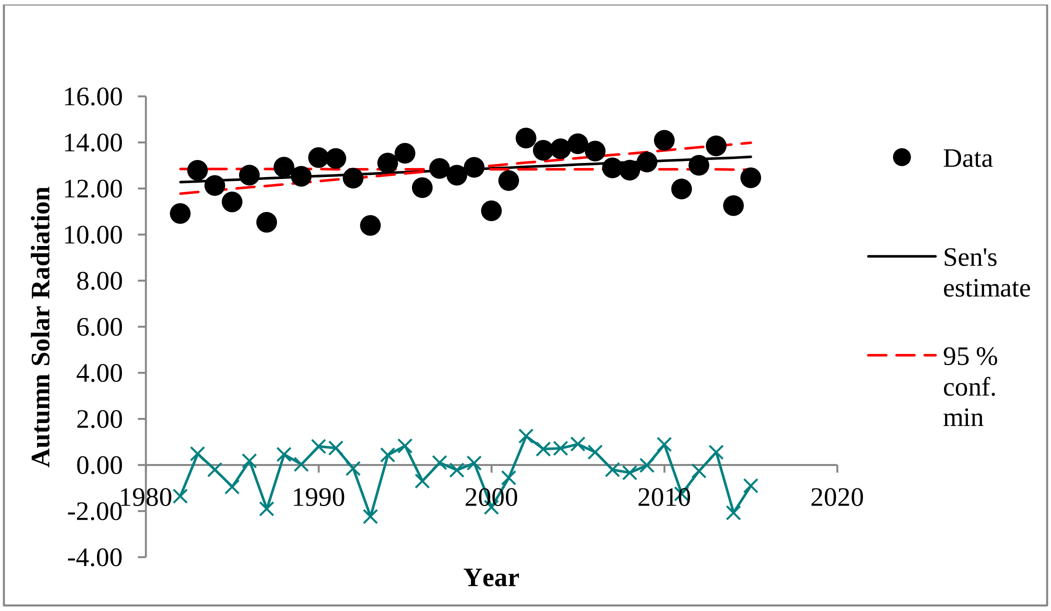

Figure 23 Chart demonstration in mean autumn solar radiation by Meann-Kendall and Sen's slope estimator tests

3.2.4 Trends in monthly mean temperature

The Mann-Kendall test shows strong significant increasing trend for monthly mean temperature over the entire country in the period of 1982-2015 (Table 7). Magnitude of the monthly mean temperature (Table 9) in valley regions (i.e., eastern part of the country) consisting of Andijon, Ferghana, and Namangan regions ranges from 0.385°C/10year to 0.45°C/10year with a mean of 0.42°C/10year, from 0.36°C/10year to 0.42°C/10year with a mean of 0.39°C/10year, and from 0.35°C/10year to 0.42 with a mean of 0.39°C/10year, respectively. Northern part of the country consists of Karakalpakstan Republic shows the significant increasing trend for monthly mean temperature that ranges from 0.36°C/10year to 0.5°C/10year with a mean of 0.43°C/10year. Magnitude of the trend in Bukhara and Khorezm regions (western part of the country) ranges from 0.3°C/10year to 0.4°C/10year with a mean of 0.35°C/10year, and from 0.34°C/10year to 0.41°C/10year with a mean of 0.37°C/10year, respectively. Trend magnitude in Navoi region which lies along the entire Kyzylkum desert ranges from 0.36°C/10year to 0.45°C/10year with a mean of 0.4°C/10year. Southern parts of the country including Kashkadarya and Surkhandarya regions show significant increasing trend which spans from 0.28°C/10year to 0.34°C/10year with a mean of 0.31°C/10year, and from 0.22°C/10year to 0.32°C/10year°C/10year with a mean of 0.28°C/10year, respectively. Jizzakh, Samarkand, and Sirdaryo regions show significant increasing trend ranges from 0.32°C/10year to 0.38°C/10year with a mean of 0.35°C/10year, from 0.31°C/10year to 0.37°C/10year with a mean of 0.34°C/10year, and from 0.36°C/10year to 0.38°C/10year with a mean of 0.37°C/10year, correspondingly. Tashkent City and Tashkent regions have also significant increasing trend which ranges from 0.36°C/10year to 0.37°C/10year with a mean of 0.36°C/10year, and from 0.35°C/10year to 0.39°C/10year with a mean of 0.37, respectively.

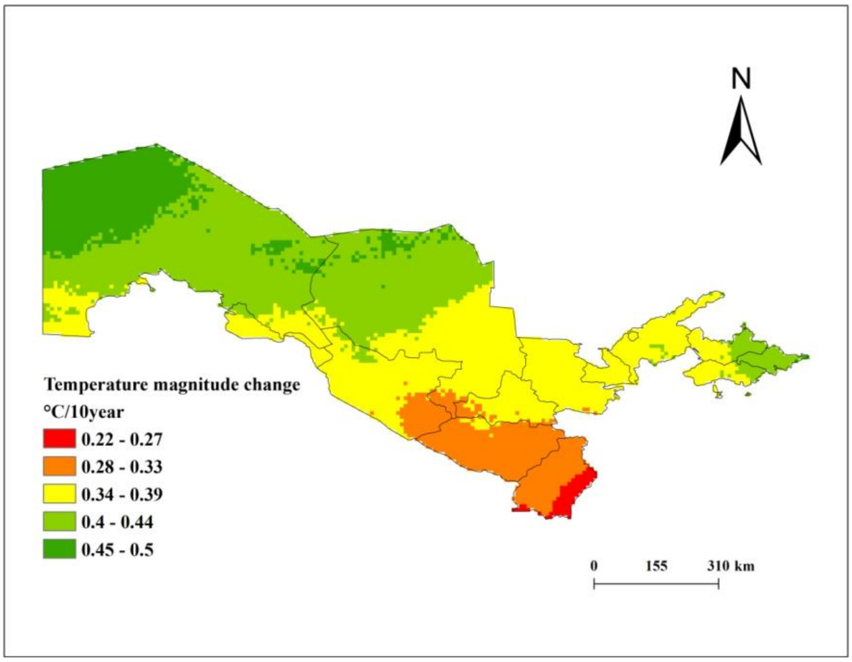

Figure 24 Geographic distribution of the magnitude of trend for monthly mean temperature in the period 1982-2015

Table 9 Distribution of the magnitude of trend for monthly mean temperature across regions in the period 1982-2015 (°C/10 year)

	Regions	Min	Max	Range	Mean
1	Andijon	0.385	0.45	0.07	0.42
2	Bukhara	0.3	0.4	0.1	0.35
3	Ferghana	0.36	0.42	0.05	0.39
4	Jizzakh	0.32	0.38	0.06	0.35
5	Karakalpakstan	0.36	0.5	0.14	0.43
6	Kashkadarya	0.28	0.34	0.06	0.31
7	Khorezm	0.34	0.41	0.07	0.37
8	Namangan	0.35	0.42	0.07	0.39
9	Navoi	0.36	0.45	0.15	0.4
10	Samarkand	0.31	0.37	0.06	0.34
11	Sirdaryo	0.36	0.38	0.02	0.37
12	Surkhandarya	0.22	0.32	0.1	0.28
13	Tashkent City	0.36	0.37	0.01	0.36
14	Tashkent	0.35	0.39	0.04	0.37

3.2.4.1 Trends in mean annual and mean annual seasonal temperature

Trends in mean annual temperature are showing gradual increasing trend (Figure 25) during the study period. Mean annual temperature means average of mean monthly temperature in each corresponding year while mean annual seasonal temperature means average of monthly mean temperature for each corresponding season of the relative year. Among seasonal mean temperature trends, as expected, mean spring temperature is the highest than mean summer and mean autumn temperature (Figure 26). Mean spring and autumn temperature fluctuated together from 1982-2000, and starting from 2000 mean spring temperature overcame mean autumn temperature while mean autumn temperature remained as before.

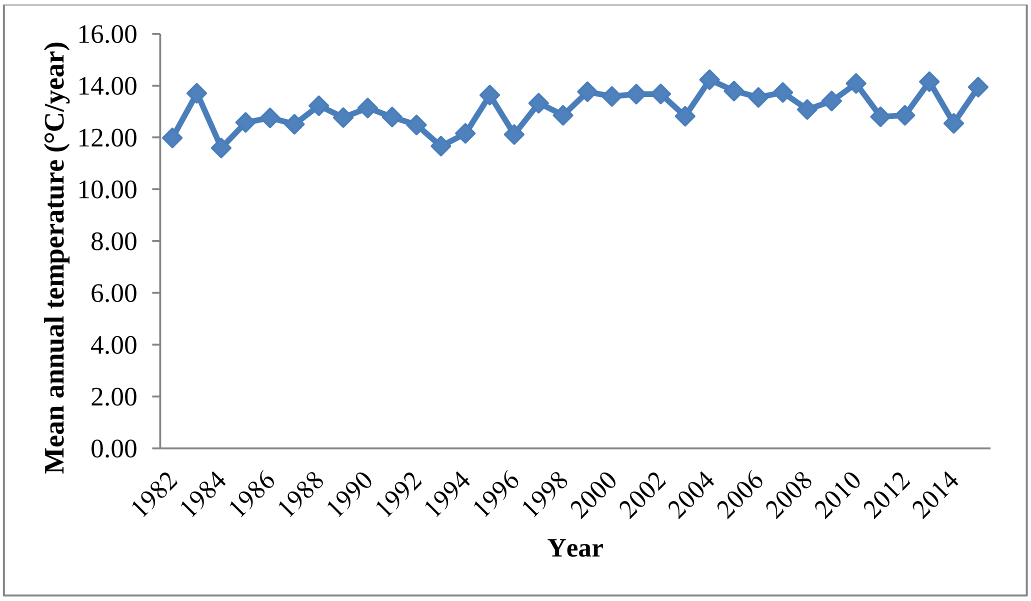

Figure 25 Temporal trend of mean annual temperature

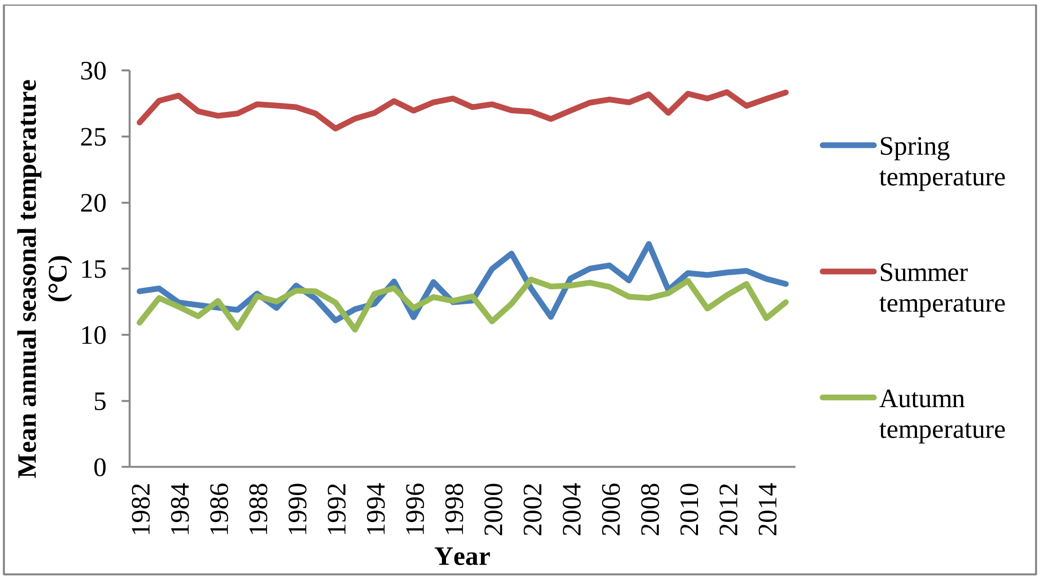

Figure 26 Temporal trend of mean annual seasonal temperature

Annual seasonal trends by Mann-Kendall test in mean monthly temperature are showing strong significant increasing trends over the study area during the stud period. Seasonal temperature means average of monthly mean temperature for the corresponding season of each year, i.e. spring temperature is average of mean March, April, May temperature for each year. Mann-Kendall test is showing strong significant (Z=3.26) increasing trend in mean spring temperature (Figure 27). Also, the test is showing strong significant (Z=2.88) increasing trend in mean summer temperature (Figure 28) too. However, Z value is equal to 1.93 and this significant rate can be referred as '+' significant increasing trend in mean autumn temperature. Comparing significant rates of mean the spring, summer, and autumn temperature, significant rate of mean spring temperature is higher than the mean summer and autumn temperature while mean autumn temperature has a slight significant increasing trend. It can be concluded that mean spring temperature has increased significantly during 1982-2015 in Uzbekistan than the mean summer and autumn temperature changing rates.

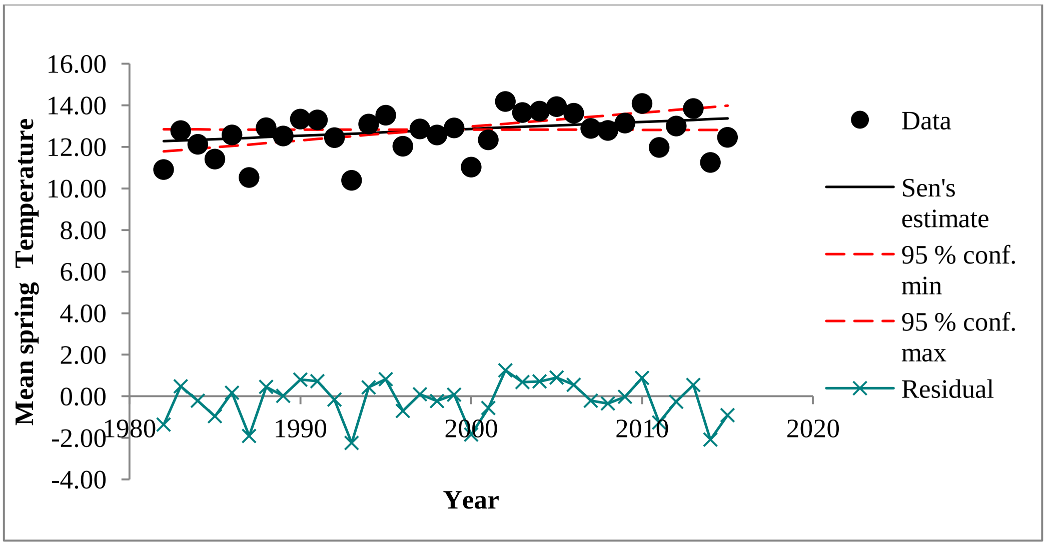

Figure 27 Chart demonstration in mean spring temperature by Mann-Kendall and Sen's slope estimator tests

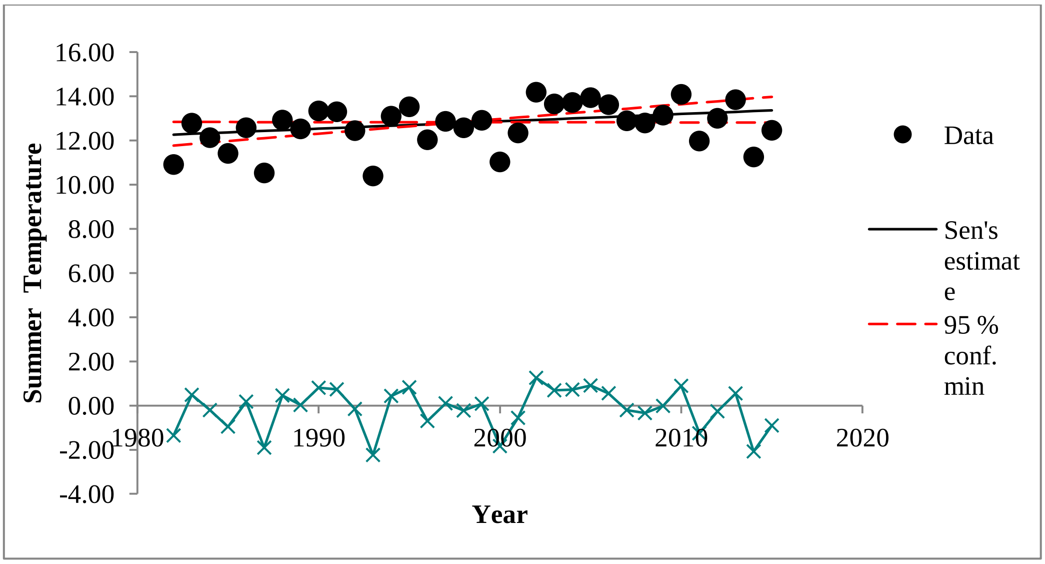

Figure 28 Chart demonstration in mean summer temperature by Mann-Kendall and Sen's slope estimator tests

Among climate variables only monthly mean temperature shows strong significant increasing trend over the entire country in the period of 1982-2015. Also all seasonal mean temperature rates have strong significant increasing trends. Mean spring temperature showed more stronger significant increasing trend than the mean summer and autumn temperature.

The Mann-Kendall test shows insignificant trend over the whole country for the monthly and mean annual solar radiation. This non-significant trend belongs to monthly and annual precipitation as well. Seasonal trends of these two climate variables are insignificant for the entire region too.

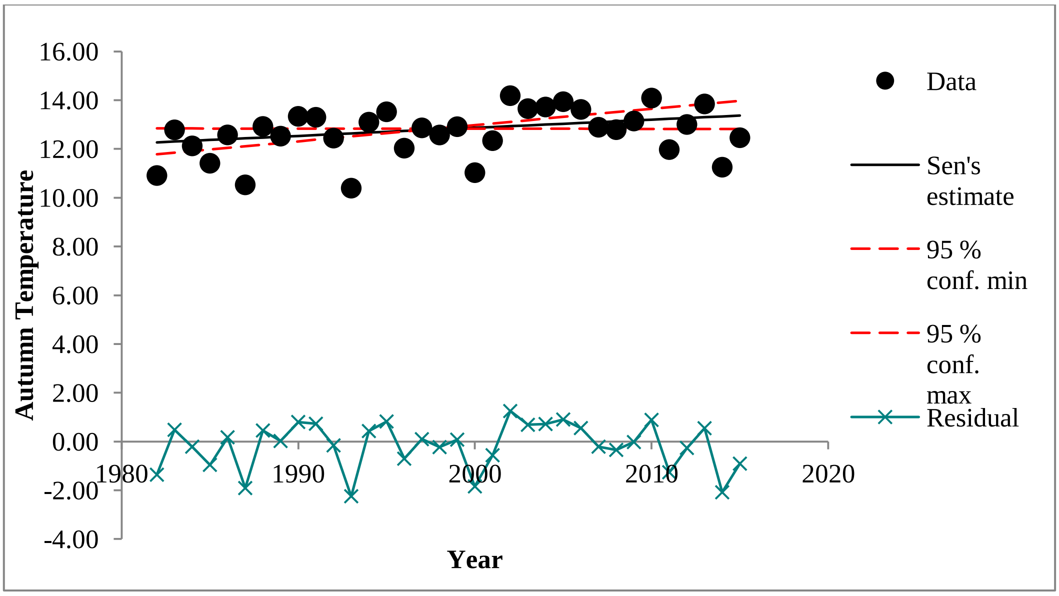

Figure 29 Chart demonstration in mean autumn temperature by Mann-Kendall and Sen's slope estimator tests

Further, trend results of precipitation by Mann-Kendall test shows that precipitation insignificantly increased either in the in the first period, and in the second period, indicating Z=0.57 and Z=0.25, respectively. Solar radiation trend results shows insignificant increasing and decreasing trend, in the first and second time periods constituting Z=0.57 and Z=-0.1 values, correspondingly. However, temperature's trend results indicating significant increasing trend (Z=2.98) in the first time period, but insignificant increasing trend (Z=0.19) during the second time period.

Splitting time series into two time periods for further trend results indicating significant increasing trend in temperature in the first time period among climate variables, and all of the climate variables' trends are insignificant in the second time period. Temperature showed significant increasing trend in the period of 1982-2015 and in the first period (1982-2009), but insignificant increasing trend in the second period (2010-2015). Other climate variables (precipitation and solar radiation) showed insignificant trend results for the all time periods, i.e. 1982-2015, 1982-2009, and 2010-2015.

CHAPTER IV Attribution of vegetation change

In the previous chapters trend analysis of NDVI, climate variables (precipitation, solar radiation, temperature) were checked via Mann-Kendall and Sen's slope estimator tests. In this current chapter attribution of vegetation change is described with the help of Pearson correlation analysis, single-factor and multiple-factor regression analyses.
Firstly, in order to show the dependent and independent variables correlation with each other, Pearson correlation test has been applied. In our case, monthly NDVI over the country is dependent variable, and climate variables (monthly mean temperature, monthly solar radiation and precipitation) over the country are independent variables. After that single-factor regression model builder has been applied to check how individual independent variables contribute to vegetation and equations for each independent factor's contribution have been given for each region. The last step of attribution of vegetation change detection is analyzed via multivariate regression model builder and show overall contribution of climate variables to vegetation change over the entire country in the period of 1982-2015.

4.1 Methods

4.1.1 Pearson correlation coefficient

Pearson correlation is used with two variables to check how these two variables are correlated with each other. *r* is the correlation coefficient that identifies the correlation level of two variables. *r* spans between -1 and 1. -1 indicates that there are strong negative relationship between two variables. This means that one variables increases in one unit whereas the other decreases in one unit. If correlation coefficient is equal to 1, then this means that there are strong positive relationship between two variables. This means that there is an increase for every unit increase in one variable while one unit increase in the other variable. If the correlation coefficient *r* equal to 0, then this means that there is no relationship between these two variables. Moreover, strength of association of correlation coefficient exists that consists of three levels. If *r* spans from 0.1 to 0.3 and from -0.1 to -0.3, then *r* is indicated as small strength of association. If r spans from 0.3 to 0.5 and from -0.3 to -0.5, then this association is indicated that there is medium level correlation between two variables. Finally, if r spans from 0.5 to1.0 and from -0.5 to -1.0, then this association is indicated that there is large association of correlation between two variables. Pearson correlation coefficient can be obtained by the following formula:

$$r_{xy} \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\,\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad \text{Equation 11}$$

where n is sample size, x_i and y_i are the individual of variables indexed with $i;$ $\bar{x}$ and $\bar{y}$are mean of variables which can be expressed as $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ and $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} x_i$.

The aforementioned formula is for correlation association of two variables that is applied to show how well these variables correlate with each other. This formula is applied to handle the issue by hand. However, there are bunch of computer-based software packages such as Excel, SPSS, R, MATLAB, etc. can calculate easily correlation coefficients. In this study, MATLAB, GIS and SPSS computer-based software packages have been applied to illustrate geographic distribution of correlation coefficient over the entire country, and to depict it as graphs.

4.1.2 Regression model building (one-factor regression and multiple-factor regression)

Having checked the relationship of each pair of two variables (NDVI vs. Precipitation, NDVI vs. Solar Radiation, and NDVI vs. Temperature) regression analysis, one-factor regression and multiple factor regression analyses were applied. One-factor regression gives relationship between dependent and independent variables with coefficient of determination and corresponding p value, also gives fitted equation, as well. One can know the contribution of the single variable on the dependent variable change via coefficient of determination denoted by R^2. R^2 is always positive and spans from 0 to 1. If R^2 is equal to 0, this means that independent variable or contributor does not influence dependent variable and vise versa. If R^2 is equal to 0.86, this means that 86% change in the dependent variable can be explained by change in the independent variable.

4.1.2.1 Single-factor regression

Linear regression shows a straight line that is so-called least squares regression line and this represents well observations in a bivariate dataset. Single-factor regression equation can be explained by the following Equation 12. Denote that Y is the dependent variable and X is independent variable.

$$\mathrm{Y}=B_0+B_1\mathrm{X} \qquad \text{Equation 12}$$

Here, B_0 is a constant, and B_1 is the coefficient of the regression. X is the value of the independent variable whilst Y is the dependent variable's value. For a random sample data regression equation is expressed as the following equation:

$$\hat{y} = b_0 + b_1 x \qquad \text{Equation 13}$$

where, b_0 is a constant, b_1 is the regression coefficient, x is the value of the independent variable, and $\hat{y}$ is the predicted value of the dependent variable.

One can use computer-based software packages to determine the constant and regression coefficients. It is more easier way to solve the equation. In the following equation, determining of a constant and regression coefficients are given and explained.

$$b_1 = \frac{\sum[(x_i - \bar{x})(y_i - \bar{y})]}{\sum[(x_i - \bar{x})^2} \qquad \text{Equation 14}$$

$$b_1 = r * (\frac{s_y}{s_x})$$

$$b_0 = \bar{y} - b_1 * \bar{x}$$

where, b_1 and b_0 are as described above; *r* is correlation coefficient between two variables; x_i is the *X* value of observation i, y_i is the *Y* value of observation i; $\bar{x}$ is the mean of X and $\bar{y}$ is the mean of Y; s_x is the standard deviation of *X* and s_y is the standard deviation of *Y*. Standard deviation formula is given in the following formula:

$$s_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \qquad \text{Equation 15}$$

where, x_i and $\bar{x}$ are as denoted in above interpretation.

Determination coefficient for single-factor linear regression is determined by the following formula:

$$R^2 = \{\frac{\frac{1}{N} * \sum[(x_i - \bar{x})(y_i - \bar{y})}{(\sigma_x * \sigma_y)}\}^2 \qquad \text{Equation 16}$$

Normally, one can use multifunctional software so that determine regression coefficients, constant (intercept), and *p* values with respect to significance level, i.e. 95% or 99%. In our case, analyses were done at the 95% significance level to reject or accept the null hypothesis H_0. The null hypothesis is that there is no relationship between climate variables and NDVI, and the alternative hypothesis is that there is a relationship between climate variables and NDVI, i.e. climate variables influenced NDVI in the period of 1982-2015 in Uzbekistan. Generally, single-factor regression equations can be expressed as in the following equations:

$$\Delta NDVI = a * Climate \begin{cases} Precipitation \\ Solar\ radiation + b \\ Temperature \end{cases} \qquad \text{Equation 17}$$

where, *a* is regression coefficient, *b* is constant or intercept. Regression coefficient interprets how and how much predictor and dependent variables are correlated with each other in the regression model. If regression coefficient is +3, this means there is a positive relationship between predictor and dependent variable. Furthermore, each one unit increase in the predictor variable causes three units increase in the dependent variable in this case and vice versa. If the regression coefficient is equal to -3, then this means that each unit increase in the predictor variable causes three units decrease in the dependent variable, and vice versa. Moreover, *p* value shows significant level of the regression model and its coefficients. If the *p* value is lower than the significance level (95%, i.e. 0.05 in our case), then this means that found regression coefficients are significant, otherwise, they are considered insignificant.

4.1.2.2 Multiple-factor regression

In multiple-factor regression one dependent variable and several independent variables exist (Equation 18). All of the independent variables participate in the multiple-factor regression model, while one factor is involved in and the others are constant in the sing-factor regression model. Multiple regression analysis can include many variables to be considered easily and simultaneously by a single model (Helsel, 1993).

$$\hat{y} = b_0 + b_1x_1 + b_2x_2 + \cdots + b_{k-1}x_{k-1} + b_kx_k + \varepsilon \qquad \text{Equation 18}$$

where, $\hat{y}$ is the predicted value of the independent variable, b_n is the regression coefficients, x_k is the value of the independent variable k, and ε is the intercept. To describe the multiple-factor regression equation matrices can be applied, i.e. Y, b, and X matrices as in the following.

$$Y=\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} \quad b=\begin{bmatrix} b_0 \\ b_1 \\ \vdots \\ b_k \end{bmatrix} \qquad X=\begin{bmatrix} 1\ X_{1,1}\ X_{1,2}\ \dots\ X_{1,k} \\ 1\ X_{2,1}\ X_{2,2}\ \dots\ X_{2,k} \\ \cdots \\ \cdots \\ 1\ X_{n,1}\ X_{n,2}\ \dots\ X_{n,k} \end{bmatrix} \qquad \text{Equation 19}$$

In the above regression matrices, dataset includes *n* records. Each record consists of scores of 1 dependent and k independent variables. Thus, there are k columns in the above X matrix. Y is an $n*1$ vector which includes predicted values of the dependent variable; b is a $k+1*1$ vector includes estimated regression coefficients. Matrix X consists of 1's plus k columns of each independent variable's values in the regression equation. Based on the aforementioned matrices regression equation can be expressed as in the following equation:

$$Y=X*b \qquad \text{Equation 20}$$

or the least squares normal equations are:

$$X'Y = X'Xb \text{ or } X'Xb = X'Y \qquad \text{Equation 21}$$

If the above equation is rearranged by mathematical rules, the following equation can be obtained:

$$\text{b}=(X'X)^{-1}X'Y \qquad \text{Equation 22}$$

Here, X' is the transpose of X matrix, and $(X'X)^{-1}$ is the inverse of $X'X$.

Generally, since all independent variables are involved in simultaneously in the multiple regression model, the equation can be expressed as in the following equation:

$$\Delta\text{NDVI}=\text{a*Precipitation+b*SolarRadiation+c*Temperature}+\varepsilon \qquad \text{Equation 23}$$

Here, a, b, c are regression coefficients, ε is intercept or constant, and Precipitation, SolarRadiation, Temperature are values of climate variables, respectively.

R^2 is the determination of coefficient of the multiple regression model that reflects the strength of the regression model fit. Determination of coefficient spans from 0 to1 meaning that 0 is no quality of the regression model fit, and 1 is very high quality of the regression model. Determination of coefficient can be found through several ways. Square of the correlation between two variables give determination of the coefficient. In multiple regression line regression model the determination of coefficient is equal to the ratio of the sum of squares of difference between fitted values and mean of dependent variable to the sum of squares of the difference between observed values and mean of the dependent variable, i.e.

ratio of explained sum of square (ESS) to total sum of square (TSS) in the following equation:

$$R^2 = \frac{\sum(\hat{y} - \bar{y})^2}{\sum(y_i - \bar{y})^2} \qquad \text{Equation 24}$$

Here, $\hat{y}$ is fitted values of the dependent variables in the multiple regression model, y_i is the observed values of the dependent variable, $\bar{y}$ is the mean of the dependent variable.

In order reject the null hypothesis p value should be lower than the significance level, i.e. $p<0.05$. In the research 95% confidence level was selected, so if the p value is lower than 0.05, then null hypothesis can be rejected and alternative hypothesis is accepted. Otherwise, the null hypothesis cannot be rejected.

Determining regression coefficients, intercept, determination of coefficient, and predicted values of the dependent variable in multiple regression model is more difficult than the single-factor regression model. Thus, computer-based software packages like, SPSS, Excel, MATLAB, etc. are very helpful in this case. All of these software calculate necessary values on behalf of human intervention based on input data. In the current research, GIS technology was applied to show geographical distribution of coefficient of determinant of the regression model. SPSS and MATLAB software were applied to determine all values.

4.1.3 Attribution of vegetation with climate

Attribution of vegetation change with climate variables is performed based on the multiple factor regression equation that developed for the second time period. Generally, mean NDVI over a period t, i.e. NDVI can be explained by human activities induced NDVI and climate influenced NDVI, $\overline{NDVI}_{hum,t}$ and $\overline{NDVI}_{clim,t}$, respectively.

$$\overline{NDVI}_t = \overline{NDVI}_{clim,t} + \overline{NDVI}_{hum,t} \qquad \text{Equation 25}$$

t_1 and t_2 are the first and second time periods, 1982-2009 and 2010-2015, respectively. NDVI over the first time period can be written as:

$$\overline{NDVI}_{t1} = \overline{NDVI}_{clim,t1} + \overline{NDVI}_{hum,t1} \qquad \text{Equation 26}$$

where, $\overline{NDVI}_{clim,t1}$ is mean NDVI estimated from climate, $\overline{NDVI}_{hum,t1}$ is human activities influenced mean NDVI which can be estimated as the residuals between the observed and fitted mean NDVI, i.e. $\overline{NDVI}_{t1}$ and $\overline{NDVI}_{clim,t1}$, correspondingly.

In order to calculate human activities induced NDVI, developed relationships between NDVI and climate over the first time period is applied to the second time period to calculate a time series of NDVI. So, human activities influenced NDVI over the second time period can be estimated as:

$$\overline{NDVI}_{hum,t2} = \overline{NDVI}_{obs,t2} - \overline{NDVI}_{cal,t2} \qquad \text{Equation 27}$$

where, $\overline{NDVI}_{obs,t2}$ is observed mean NDVI over the second time period, $\overline{NDVI}_{cal,t2}$ is the calculated mean NDVI over the second time period.

Total vegetation changes can be quantified over the second time period relative to the first time period can be calculated as:

$$\Delta\overline{NDVI}_{tot} = \overline{NDVI}_{t2} - NDVI_{t1} \quad \text{Equation 28}$$

Also, total vegetation change can be written as in the following equation:

$$\Delta\overline{NDVI}_{tot} = \Delta\overline{NDVI}_{clim} + \Delta\overline{NDVI}_{hum} \quad \text{Equation 29}$$

$\Delta\overline{NDVI}_{clim}$ and $\Delta\overline{NDVI}_{hum}$ can be calculated by the following equations:

$$\Delta\overline{NDVI}_{clim} = \overline{NDVI}_{clim,t2} - \overline{NDVI}_{clim,t1} \quad \text{Equation 30}$$

$$\Delta\overline{NDVI}_{hum} = \overline{NDVI}_{hum,t1} - \overline{NDVI}_{hum,t2} \quad \text{Equation 31}$$

4.2 Results and discussion

4.2.1 Pearson correlation

The correlation values between NDVI and climate variables and least squares regression line over the entire country are reflecting that monthly NDVI and monthly precipitation are negatively correlated (Figure 30). r=-0.34 indicates medium significant negative correlation between precipitation and NDVI in the period of 1982-2015. However, correlation between monthly NDVI and monthly solar radiation, monthly NDVI and mean monthly temperature is showing strong significant positive correlation, reflecting r=0.87 and 0.85, respectively. Confidence at the 95% confidence level between NDVI and temperature, NDVI and solar radiation, NDVI and precipitation spans from 0.828 to 0.875, from 0.851 to 0.888, and from -0.436 to -0.258, correspondingly (Table 10). Generally, Figure 30 shows the relationship between NDVI and climate variables as scatter plots. In these scatter plots, only relationship between NDVI and climate variables are plotted excluding relationship among climate variables. According to graphical illustration, dots indicating monthly data, relationship is quite variable in NDVI and precipitation, but relationship is the least squares regression line is accurate in NDVI vs. temperature and NDVI vs. solar radiation meaning that they have close relationship.

Correlation results between NDVI and climate variables and inter climate variables (Table 10). These results were obtained by processing monthly data in SPSS computer-based software. The results are showing strong positive significant correlation (r=0.963) between mean monthly temperature and solar radiation at the 99% significance level. However, correlation between mean monthly temperature and monthly precipitation is significant negative (r=-0.581) and there is a significant negative correlation between monthly solar radiation and monthly precipitation (r=-0.533). Confidence interval at the 95% confidence level between temperature and solar radiation spans from 0.828 to 0.875. Between temperature and precipitation, solar radiation and precipitation this confidence interval spans from -0.634 to -0.524, and from -0.592 to -0.47, respectively.

Correlation coefficients and their significance levels (*p* values) across regions are given as in table (Table 11) and as spatial distribution over the country (Figure 31). According to Pearson correlation results all regions except Karakalpakstan Republic and Navoi region have negative correlation between NDVI and precipitation (Table 11). Among them, only Andijan, Ferghana, Khorezm, Namangan, Sirdaryo and Tashkent city have significant correlation between NDVI and precipitation, but other regions' correlation coefficients are insignificant. But correlation between NDVI and temperature and NDVI and solar radiation are quite significant and predictable. Correlation between NDVI and temperature shows more strong positive relationship between them. Only Karakalpakstan Republic, Bukhara and Navoi regions' NDVI is insignificantly correlated to temperature. Other regions' correlations are significant. Andijan, Khorezm, Namangan regions and Tashkent city have very strong positive significant relationship between NDVI and temperature. Correlation between NDVI and solar radiation are almost the same relationship as NDVI and temperature. Bukhara region and Karakalpakstan Republic have insignificant positive relationship between NDVI and solar radiation. Only these two regions (Bukhara and Karakalpakstan) correlation between NDVI and all climate variables (precipitation, temperature, solar radiation) are insignificant.

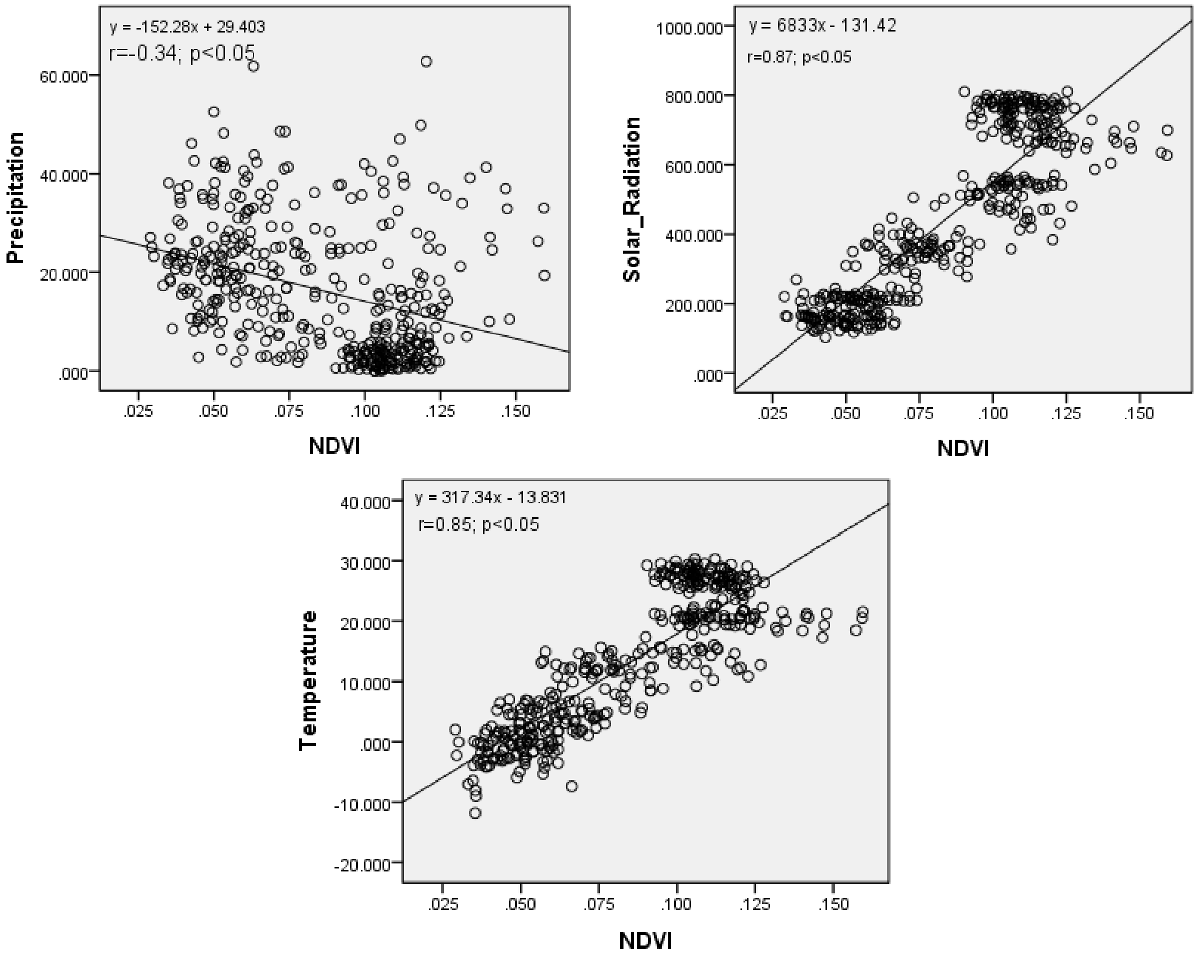

Figure 30 Comparing of monthly NDVI and monthly climate variables (or least squares regression line)

Table 10 Pearson correlation coefficients between NDVI and climate variables for the 1982-2015 time period. Variables are mean monthly scale in NDVI, temperature, solar radiation, and monthly scale in precipitation

		NDVI	Precipitation	Solar radiation	Temperature
NDVI	Pearson Correlation	1	$-.347^{**}$	$.870^{**}$	$.853^{**}$
	Sig. (2-tailed)		.000	.000	.000
	N	408	408	408	408
Precipitation	Pearson Correlation	$-.347^{**}$	1	$-.533^{**}$	$-.581^{**}$
	Sig. (2-tailed)	.000		.000	.000
	N	408	408	408	408
Solar radiation	Pearson Correlation	$.870^{**}$	$-.533^{**}$	1	$.963^{**}$
	Sig. (2-tailed)	.000	.000		.000
	N	408	408	408	408
Temperature	Pearson Correlation	$.853^{**}$	$-.581^{**}$	$.963^{**}$	1
	Sig. (2-tailed)	.000	.000	.000	
	N	408	408	408	408

**. Correlation is significant at the 0.01 level (2-tailed).

Table 11 Pearson correlation coefficient and significance values (95% confidence level) across regions

Rowid	**Regions**	**NDVI and Precipitation**		**NDVI and Temperature**		**NDVI and Solar Radiation**	
		r	**p**	**r**	**p**	**r**	**p**
1	Andijon	-0.44	0.00	0.86	0.00	0.83	0.00
2	Bukhara	-0.08	0.16	0.32	0.19	0.35	0.17
3	Ferghana	-0.42	0.00	0.85	0.00	0.82	0.00
4	Jizzakh	-0.03	0.14	0.49	0.01	0.55	0.02
5	Karakalpakstan	0.00	0.15	0.11	0.11	0.16	0.11
6	Kashkadarya	-0.11	0.07	0.50	0.04	0.54	0.02
7	Khorezm	-0.44	0.01	0.70	0.02	0.67	0.02
8	Namangan	-0.34	0.05	0.76	0.00	0.78	0.00
9	Navoi	0.02	0.17	0.36	0.08	0.43	0.03
10	Samarkand	-0.10	0.07	0.52	0.02	0.56	0.02
11	Sirdaryo	-0.60	0.00	0.89	0.00	0.86	0.00
12	Surkhandarya	-0.16	0.10	0.54	0.01	0.61	0.00
13	Tashkent City	-0.45	0.00	0.83	0.00	0.82	0.00
14	Tashkent	-0.22	0.12	0.59	0.04	0.67	0.02

Correlation results in monthly NDVI and climate variables (temperature is mean monthly, precipitation and solar radiation are in monthly scale) (Table 12) in the period of 1982-2009 show that NDVI is more positively correlated significantly to solar radiation than temperature reflecting r =0.87 and r=0.853, respectively. Correlation between NDVI and precipitation is significant negative, r=-0.316 at the 99% level. However, correlation relationship between NDVI and climate variables in the second time period (Table 13) is a little changed. Both correlations between NDVI versus solar radiation and NDVI versus temperature is positively increased simultaneously. NDVI versus solar radiation and NDVI versus temperature correlations are r=0.921 and r=0.904, respectively, i.e. monthly NDVI more closely positively correlated to solar radiation and temperature in the second time period (2010-2015). But correlation coefficient between NDVI and precipitation shows that NDVI versus precipitation negative correlation more strengthened in the second period (2010-2015) than the first period (1982-2009) from r=-0.316 to r=-0.493 (almost r=-0.5), i.e. NDVI closely negatively correlated with precipitation in the second period.

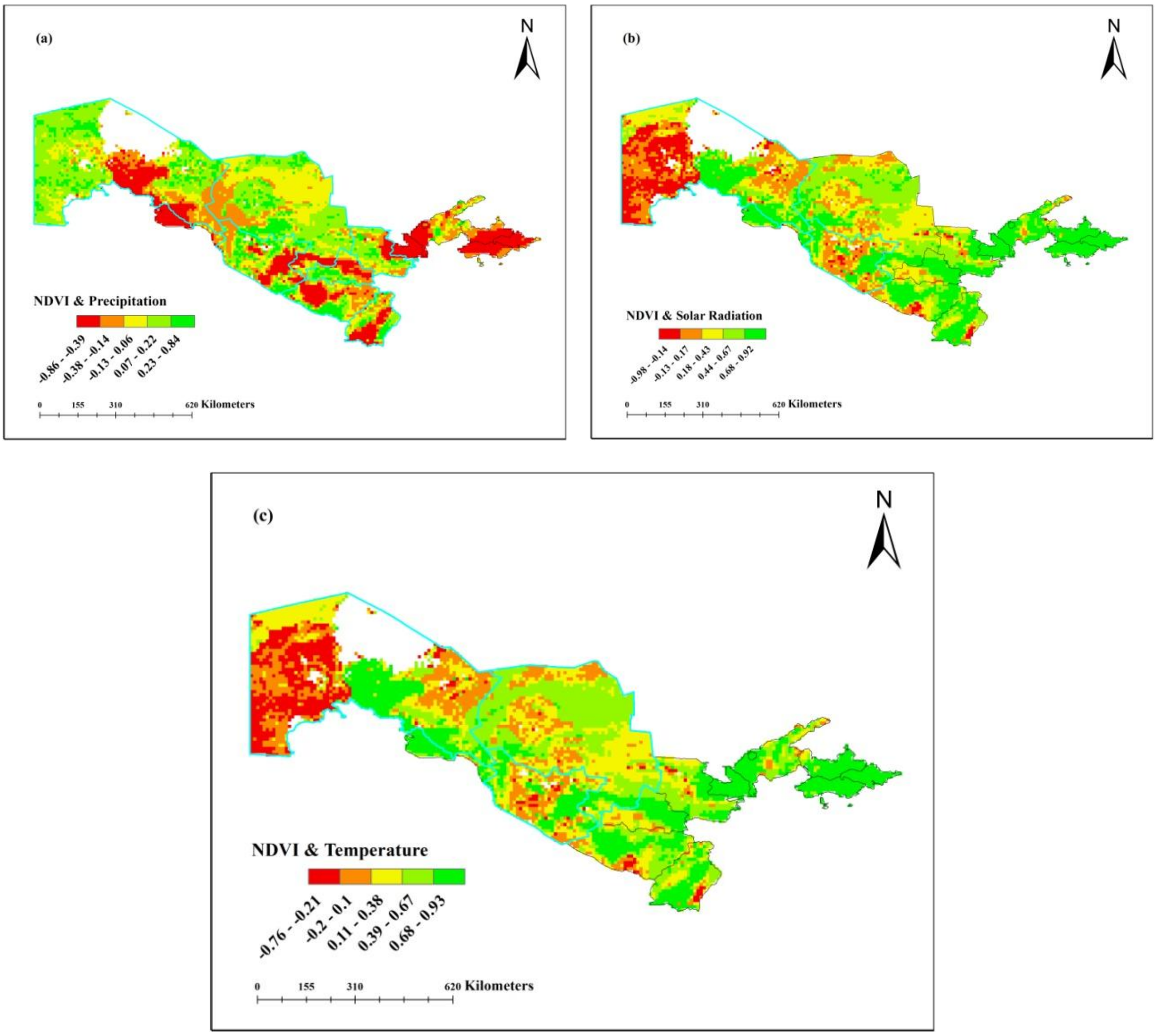

Figure 31 Spatial distribution of Pearson correlation coefficients between NDVI and precipitation (a), NDVI and solar radiation (b), NDVI and temperature (c) over the country in the period of 1982-2015. Regions with solid line indicates insignificant at the 95% level

Table 12 Pearson correlation coefficients between NDVI and climate variables for the 1982-2009 time period. Variables are mean monthly scale in NDVI, temperature, solar radiation, and monthly scale in precipitation

		NDVI	Precipitation	Solar radiation	Temperature
NDVI	Pearson Correlation	1	$-.316^{**}$	$.870^{**}$	$.853^{**}$
	Sig. (2-tailed)		.000	.000	.000

	N	336	336	336	336
Precipitation	Pearson Correlation	-.316**	1	-.520**	-.568**
	Sig. (2-tailed)	.000		.000	.000
	N	336	336	336	336
Solar radiation	Pearson Correlation	.870**	-.520**	1	.963**
	Sig. (2-tailed)	.000	.000		.000
	N	336	336	336	336
Temperature	Pearson Correlation	.853**	-.568**	.963**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	336	336	336	336

**. Correlation is significant at the 0.01 level (2-tailed).

Table 13 Pearson correlation coefficients between NDVI and climate variables for the 2010-2015 time period. Variables are mean monthly scale in NDVI, temperature, solar radiation, and monthly scale in precipitation

		NDVI	Precipitation	Solar radiation	Temperature
NDVI	Pearson Correlation	1	-.493**	.921**	.904**
	Sig. (2-tailed)		.000	.000	.000
	N	72	72	72	72
Precipitation	Pearson Correlation	-.493**	1	-.591**	-.635**
	Sig. (2-tailed)	.000		.000	.000
	N	72	72	72	72
Solar radiation	Pearson Correlation	.921**	-.591**	1	.963**
	Sig. (2-tailed)	.000	.000		.000
	N	72	72	72	72
Temperature	Pearson Correlation	.904**	-.635**	.963**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	72	72	72	72

**. Correlation is significant at the 0.01 level (2-tailed).

4.2.2 Regression analysis and attribution of vegetation

Single-factor regression results reflect the contribution of each climate variable in NDVI change while other climate variables remain constant. According to determination of coefficient and their significant values (Table 14), contribution of precipitation to NDVI is much lower than the solar radiation and temperature. The highest determination of coefficient in precipitation versus NDVI regression is equal to0.37 in Syrdarya region and this means that regression model NDVI versus precipitation is weak. Solar radiation's contribution is much visible in NDVI. High determination of coefficient values are in Andijan, Ferghana, and Sirdaryo regions, and all of them are significant. High values of determination of coefficient in DNVI versus temperature regression model are in Andijan, Ferghana, and Sirdarya regions again, reflecting 0.74, 0.73, and 0.8, respectively, i.e. 74%, 73%, and 80% of predictor's contribution can be explained by temperature in these regions. Bukhara, Navoi regions and Karakalpakstan Republic are reflecting insignificant determination of coefficients, indicating 0.23, 0.19, and 0.18, respectively. Sirdaryo region is reflecting the highest significant determination of coefficients either in NDVI versus solar radiation and NDVI versus temperature, i.e. 0.74 and 0.8, respectively.

Table 14 Determination of Coefficients of single-factor regression between monthly NDVI and climate variables across regions in the period of 1982-2015

Regions	**Precipitation**		**Solar radiation**		**Temperature**	
	R2	**P**	**R2**	**P**	**R2**	**P**
Andijon	0.21	0.00	0.69	0.000	0.74	0.00
Bukhoro	0.10	0.16	0.23	0.166	0.23	0.19
Ferghana	0.18	0.00	0.67	0.000	0.73	0.00
Jizzakh	0.07	0.14	0.36	0.025	0.31	0.01
Karakalpakstan	0.06	0.15	0.18	0.112	0.19	0.11
Kashkadarya	0.12	0.07	0.38	0.016	0.34	0.04
Khorezm	0.23	0.01	0.48	0.017	0.52	0.02
Namangan	0.15	0.05	0.62	0.001	0.62	0.00
Navoi	0.04	0.17	0.23	0.032	0.18	0.08
Samarkand	0.10	0.07	0.39	0.018	0.36	0.02
Sirdaryo	0.37	0.00	0.74	0.000	0.80	0.00
Surkhandarya	0.15	0.10	0.44	0.004	0.39	0.01
Tashkent City	0.21	0.00	0.67	0.000	0.69	0.00
Tashkent	0.12	0.12	0.50	0.018	0.42	0.04

Spatial distribution of determination of coefficient over the entire country is given in the Figure 32.

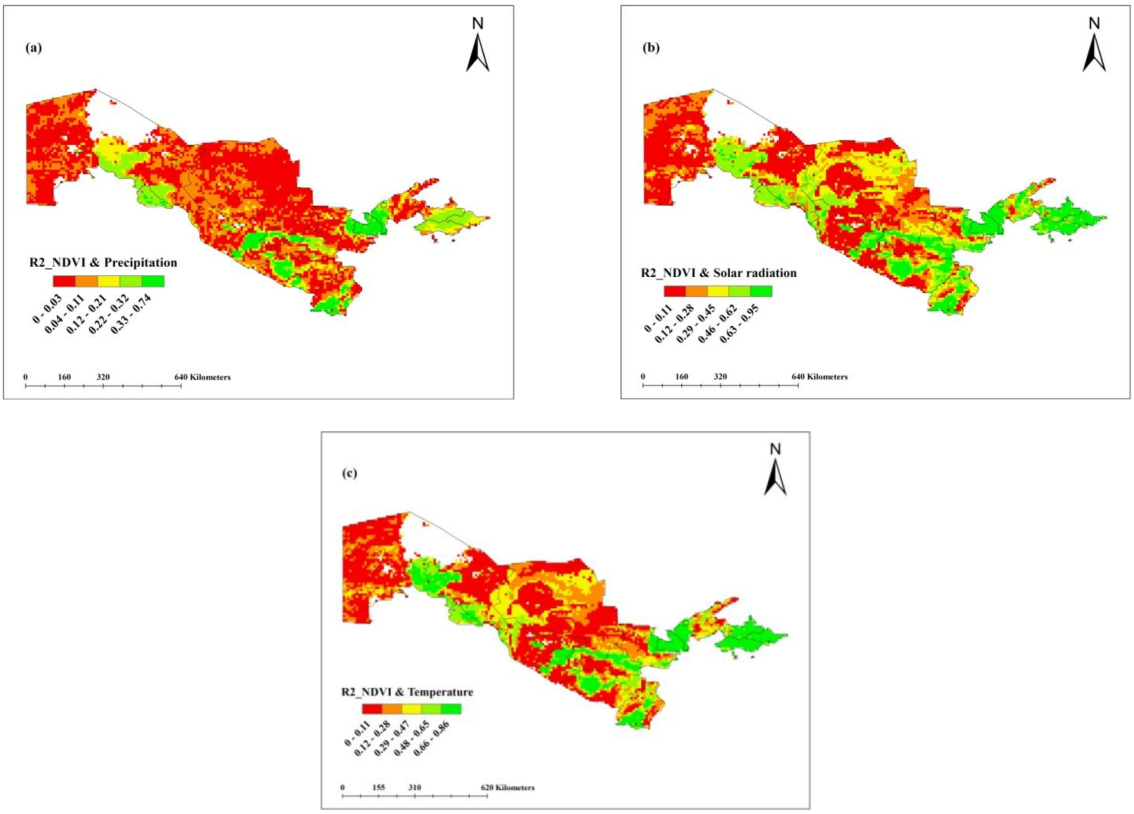

Figure 32 Spatial distribution of determination of coefficients of single-factor regression between monthly NDVI and climate variables across regions in the period of 1982-2015

Furthermore, equation of single-factor regression analyses results via SPSS software are given in Table 15 and Table 16 based on monthly precipitation, NDVI, solar radiation and mean temperature in the period of 1982-2015 over the entire country. Equations' fitness (Table 16) for the model is much lower for precipitation, and enough high for solar radiation and temperature representing significant values.

Table 15 Model summary of single-factor regression between NDVI and climate variables

Predictors	**NDVI**						
					ANOVA		
	Coefficient	**Constant**	**Significance**	**R2**	**Sum of Squares (regression)**	**Mean square**	**F**
Precipitation	-0.001	0.98	0.00	0.12	0.044	0.044	55.438
Solar radiation	0.00011	0.035	0.00	0.756	0.276	0.276	1260.68
Temperature	0.0023	0.055	0.00	0.727	0.265	0.265	1083.748

Table 4-16 Equations between climate and NDVI over 1982-2015

Climate variables	**Equation**	**Significance**	**R square**
Precipitation	NDVI=-0.001PRE+0.098	0.00	0.12
Solar radiation	NDVI=0.00011SR+0.035	0.00	0.75
Temperature	NDVI=0.0023TMP+0.055	0.00	0.72

Multiple regression model includes all climate variables simultaneously into one regression model so that identify overall contribution of the predictor variables. In the current multiple-factor regression model, determination of coefficient is showing that the highest significant R square value is in the Andijan region, i.e. $R^2 = 0.76$ (Table 17). Spatial distribution of determination of coefficient and F values from multiple-factor regression model are given in the Figure 33.

Table 17 Results of multiple regression for monthly NDVI and climate variables across regions in the period of 1982-2015

Regions	**Determination of coefficient**	**P value**
Andijon	0.76	0.000
Bukhoro	0.32	0.095
Ferghana	0.75	0.000
Jizzakh	0.52	0.004
Karakalpakstan	0.27	0.033
Kashkadarya	0.52	0.000
Khorezm	0.59	0.014
Namangan	0.69	0.000
Navoi	0.33	0.004
Samarkand	0.54	0.000
Sirdaryo	0.80	0.000
Surkhandarya	0.57	0.000
Tashkent City	0.72	0.000
Tashkent	0.59	0.015

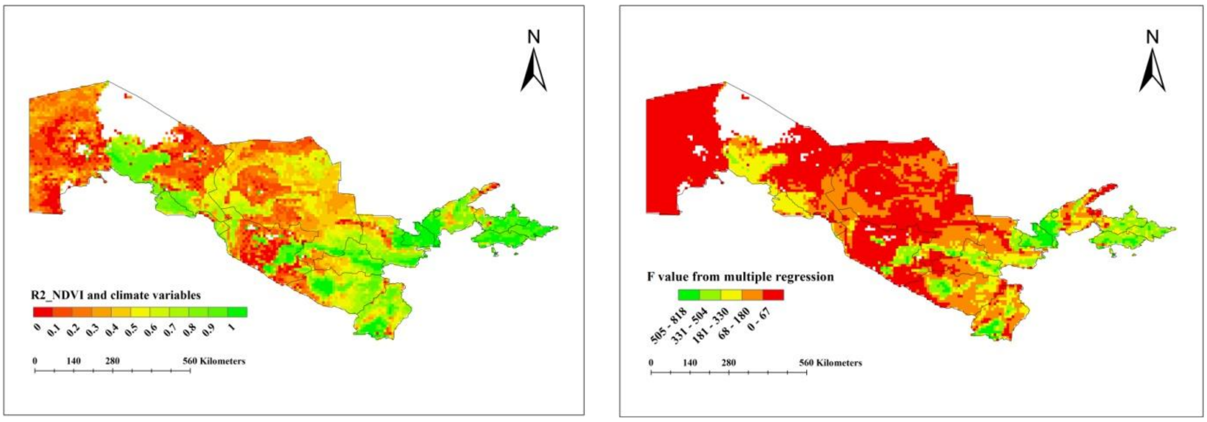

Figure 4-33 Spatial distribution of determination of coefficient and F value from multiple regression model

Table 18 Multiple factor regression model results over the first time period

	Significance	R^2	**Equation**
Constant	0.00		
Precipitation	0.00	0.794	NDVI=0.000509*PRE+0.000074*SR+0.001097*TMP
Solar radiation	0.00		
Temperature	0.00		

Table 19 Attribution of vegetation change with climate variables

NDVI changes			Contribution	
$\overline{NDVI}_{t1}$	$\overline{NDVI}_{t2}$	$\Delta\overline{NDVI}_{tot}$	$\Delta\overline{NDVI}_{clim}$, %	$\Delta\overline{NDVI}_{hum}$, %
0.08665	0.07627	-0.01038	90	10

Furthermore, equation between climate and NDVI is given in the period of 1982-2009 (Table 18). Determination of coefficient of the equation is high ($R^2 = 0.794$), implying that equation is reliable. Also all coefficient values and constant value are significant in the equation between climate and NDVI.

Attribution of vegetation with climate variables releases that human induced NDVI constituted 10%, and NDVI changes by climate variability is 90%, i.e. NDVI is not subject to human activities in the second period although the abrupt point change showed that there is significant abrupt change in 2010. Correlation coefficients of NDVI versus precipitation, NDVI versus solar radiation, and NDVI versus temperature are -0.316, 0.87, and 0.853 in 1982-2009, while they are -0.493, 0.921, and 0.904 in 2010-2015. The relationship of NDVI versus precipitation closely negatively correlated in the second time period, whereas correlations of NDVI versus solar radiation and NDVI versus temperature strengthened positively in the second time period meaning that climate variables are dominant factor in vegetation change.

DISCUSSION

Changes of vegetation and climate variables

Climate change is a central topic among scientific researchers in environmental sciences and vegetation change and global warming are parts of the process. There are uncertainties in vegetation change and its responses to climate variables. Especially this is ad hoc in arid regions including Uzbekistan. Uzbekistan is located at the centre of Central Asia and vulnerable to climate change. Detecting vegetation change and its attributions in time series over Uzbekistan will give broad feedback on vegetation and responses to climate change. Generally expressing overall vegetation is very low across the country and most areas are desert dominated areas (Xu et al., 2016). Our current research on vegetation change and its attributes with climate variables include 34 full years of NDVI and climate variables (precipitation, solar radiation, temperature). The results release that vegetation spans from north west part to eastern part of the country during the study time period. Western part of the country is vegetation sparse and eastern part of the country is vegetation abundant and monthly NDVI in this part reaches till 0.45. Abrupt change point in NDVI by Mann-Kendall test shows that there is a abrupt change in 2010. Mann-Kendall test releases that NDVI increased insignificantly over Uzbekistan in the period of 1982-2015. Moreover, NDVI increased insignificantly (Z=1.2) in the first period (1982-2009) and insignificantly (Z=-0.41) decreased during the second time period (2010-2015). This insignificant increase in the first time period matches with (Zhou et al., 2015) analyses and according to them NDVI insignificantly increased over the entire Central Asia before 1991. But the test is showing significant (Z=-2.08) decreasing trend in mean annual summer NDVI and in mean annual autumn NDVI (-2.96) over 1982-2015 for the country. The reason of upward trend of mean spring NDVI over mean summer NDVI after 2002 can be connected with significant decreasing trend in mean summer NDVI. Also, the test is showing strong significant (Z=-2.96) decreasing trend in mean annual autumn NDVI over 1982-2015 for the country.

Furthermore, monthly precipitation is quite variable in Uzbekistan in the period of 1982-2015 and the most precipitation density occurred in the south part of Uzbekistan. Precipitation increased insignificantly in both periods indicating (Z=0.57) and (Z=0.25), respectively. Moreover, annual seasonal precipitation trend results are more or less the same with monthly precipitation trend results in the period of 1982-2015. Mann-Kendall test is showing insignificant increasing trend in spring and autumn precipitation, indicating Z=0.77 and Z=0.68, respectively. However, summer precipitation is tending to insignificant decreasing trend (Z=-0.62).

Solar radiation is high in south part of the country as mean monthly temperature. According to trend results, solar radiation decreased insignificantly in both periods, indicating Z=-0.57 and Z=-0.17, respectively. Annual seasonal solar radiation trend results show insignificant increasing trends in spring, summer, and autumn solar radiation indicating values Z=1.53, Z=1.11 and Z=0.16, correspondingly.

However, temperature very significantly increased (Z=2.98) and insignificantly decreased (Z=0.19) in the second period. High temperature values occurred in the south part of the country during the study time period. Annual seasonal temperature trend results are showing strong significant increasing trend in all seasons including spring, summer, and autumn temperature indicating that Z=3.26, Z=2.88 and Z=1.93 (+), respectively. These increasing trend results are similar with (Zhou et al., 2015) that analyzed for the whole Central Asian countries including Uzbekistan.

Attribution of vegetation

Pearson correlation results release that NDVI is more positively correlated to solar radiation than temperature, however, generally interpreting NDVI versus climate variables is showing that NDVI is positively correlated to solar radiation and temperature (r=0.87 and r=0.853, respectively) and negatively correlated with precipitation (r=-0.347). Analyzing correlation analyses of NDVI versus climate variables into two time slaps release that NDVI is more correlated to climate variables in the second period than in the first period. Correlation coefficient of NDVI versus solar radiation and temperature are r=0.87 and r=0.853 in the first period, respectively. Correlation of NDVI versus precipitation is r=-0.16 in the first period. However, correlation of NDVI and climate variables strengthened in the second time period. Correlation of NDVI versus solar radiation and NDVI versus temperature are r=0.921 and r=0.904, correspondingly. Correlation of NDVI versus precipitation is r=-0.491, i.e. more negatively correlated with precipitation in the second time period. These results state that NDVI is more positively correlated to energy and more negatively correlated to water in the second time period than in the first one. Although NDVI and climate variables did not change significantly in the second time period (Z=-0.41 for NDVI, Z=0.25 for precipitation, Z=-0.17 for solar radiation, and Z=0.19 for temperature) correlation of NDVI versus climate variables increased in the second time period.

Determination of coefficient (**$\boldsymbol{R^2}$=0.8)** of multiple-factor regression analyses is enough high to conclude that NDVI is more vulnerable to climate than human activities. Moreover, according to contributions of human activities and climate change based on the developed of vegetation-climate equation, human activities' contribution constitute only 10% indicating that climate factor is the dominant in vegetation change over the entire country.

NDVI versus precipitation

As shown in the figures NDVI spans from western part of the country to astern part reaching up to 0.45 on valley regions. Eastern regions of Uzbekistan are NDVI abundant regions while western one are NDVI scarce ones. Also southern regions are rainfall abundant than eastern and western parts of the country. In these eastern parts, NDVI is more abundant whereas precipitation is more scarce. Middle regions are also abundant with NDVI than western regions and precipitation is a little sparse in these middle regions. Annual summer and autumn NDVI significantly decreased while summer precipitation insignificantly decrease and autumn precipitation insignificantly increased in the period of 1982-2015. *NDVI and precipitation insignificantly increased (significance level results of NDVI (Z=1.205) is higher than the precipitation's one (Z=0.57)) in the first period, and NDVI insignificantly decreased (Z=-0.413) while precipitation insignificantly increased (Z=0.258) in the second period where negative correlation strengthened in this period.* Negative relationship of NDVI and precipitation in both time periods is contradiction for most assumptions in dry land areas that precipitation is most dominant factor for vegetation greenness. In (Zhou et al., 2015) analyses, April and October were characterized as negative relationship with vegetation and precipitation in Central Asian countries. According to them, April and October are months with low temperature and this causes to form ice crystals in plant tissues leading to death of plant tissues.

NDVI versus solar radiation

Relationship of NDVI versus solar radiation is positive correlation in both periods. Solar radiation also did not change significantly in both periods. Solar radiation insignificantly decreased while NDVI insignificantly increased in the first period, and both variables insignificantly decreased in the second time period where their positive relationship strengthened in the second time period.

NDVI versus temperature

Temperature is the unique climate variable that very significantly increased in the time period of 1982-2015 and during the first time periods (1982-2009). NDVI also insignificantly increased while temperature very significantly increased in the first period. But temperature insignificantly increased in the second time period where NDVI insignificantly decreased in this time. Furthermore, their positive relationship strengthened in the second time period than the first one.

Quantitative analysis

As mentioned above, Uzbekistan is considered as arid zone and vegetation is sparse that other countries. Some countries have implemented their state projects to improve vegetation, and in these regions human activities are visible. For instance, China has implemented its Grain for Green Project (GGP) in Loess Plateau and as a result of human activities vegetation (contribution of human activities and climate is 55% and 45%, respectively) has significantly increased (Li et al., 2017) since 2000. However, Uzbekistan has not emerged any large-scale projects directed to increasing of vegetation . It is obvious from the results that western and north-west regions of the country are more vegetation scarce than eastern parts. Since there is not any promising projects implemented in the country we checked the abrupt point change in NDVI via Mann-Kendall test to split the time periods into two sub-periods. And trend analysis, correlation analysis, regression analysis have been applied to detect how the variables have changed in both periods and how they are correlated with one another. Developed equation and calculation methods released that, as expected, human activities induced NDVI in the second time period only 10%, however, NDVI did not change significantly both periods. Changing of NDVI over time is very variable and these changes depends on mostly climate. This 10% contribution of human activities mean two things:

1. NDVI insignificantly increased in the period of 1982-2015 and is quite variable, i.e. without significant steep slope. In some regions trees are massively planted in large cities and this contribution causes increase of NDVI.

2. However, in suburbs the condition differ from the urban cities. The most emphasized note here is that indigenous people in suburbs fell tree for heat energy uses during winter periods. This is subject to most rural areas of Uzbekistan.

Moreover, most arable land areas are irrigated lands and this require more water resources. Only 15-20% of consuming water resources form in Uzbekistan and other 80-85% of water resources form in neighbor eastern countries, i.e. Kyrgyz Republic and Tajikistan Republic.[14] One of the main reasons of scarcity of vegetation in western parts of the country is soil salinity level and ecological condition in these regions. Because, these regions are located around the desiccated Aral Sea, i.e. salt particles from the shrunk territory of the Aral Sea move to neighborhood regions via blowing wind and causes soil salinity level increase. As a result land degradation occurs in these regions and middle parts of the country. From the results it is certain that middle regions (Sirdaryo and Jizzakh regions) are vegetation abundant than western parts of the country. However, since the results were run in growing season the vegetation appears as more abundant. In reality, soil salinity level and land degradation are top problems in front of the local authorities. Land salinity has affected about 50-60% of irrigated lands in Uzbekistan (Bobojonov and Aw-Hassan, 2014; Zhou et al., 2015). Land degradation causes economic loss 0.85 USD billion annually (Aw-hassan et al., 2016). These two regions provide most cotton products in Uzbekistan and during the growing season vegetation is appeared as abundant because of massive cotton plants. However, having harvested the cotton products the vegetation turns to fall to the ground in all regions, thus summer and autumn NDVI significantly creased during 1982-2015.

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[14] MAWR - Ministry of Agriculture and Water Resources of Uzbekistan

CONCLUSION

Eastern part of the country is more vegetation abundant than western regions. Regions located in the middle part of the country are vegetation abundant, but this is temporary condition during the growing season in these regions because of massive planted cotton for state needs. NDVI is significantly strongly correlated to solar radiation and temperature and this positive correlation strengthened in the second time period than the first one. Negative correlation of NDVI versus precipitation also strengthened in the time period. Seasonal analysis of NDVI is revealing that summer and autumn vegetation significantly decreased during study time period. This require additional efforts from the government to remain the vegetation during the water scarce period, because this period is characterized with low precipitation (as showed the analyses) and significant temperature increasing. Since western regions have been referred to low-vegetation parts of the country, the government should take into account this so that improve vegetation growth by planting drought and salinity resistant plants. For this purpose, the government should give endowments to create new species which coincide with local site specific conditions. As the results revealed that human activities contributed much lower than climate action. Thus, large scale projects directed to improving vegetation condition should be implemented. Temperature significantly increased over the study time period and positively correlated with vegetation whereas relationship of vegetation versus precipitation is negative. Solar radiation did not change significantly over the study time period, but showed positive correlation with vegetation. Even, this positive relationship of vegetation versus temperature and vegetation versus solar radiation significantly increased during the second time period. However, negative relationship of vegetation and precipitation strengthened its negative correlation in the second time period. Vegetation did not change significantly during the whole study time period, but significantly decreased during summer and autumn periods. This can be related with temporary vegetation growth during the summer periods in Uzbekistan, in which this period is characterized with massive cotton production in Uzbekistan, especially in regions located in the middle of the country. From these results it can be concluded that vegetation was depended on energy than rainfall.

This research was conducted with the purpose of vegetation change and its attributes with climate variables. So far, the methods applied for trend analysis in this study have not been used by researches to detect trend analyses of vegetation and climate variables in Uzbekistan. Furthermore, attribution of vegetation with climate variables and trend analyses for each variable in time series over the country have not been studied. Several studies have been learnt for this purpose, but all of them are directed to the whole Central Asia regionally. Thus, in this context, this current research is considered the first study in term of trend analyses of vegetation and its attributes with climate variables in time series over the country. Moreover, for the future analyses, receiving water resources from eastern countries and volume of water resources for irrigation should be taken into consideration since most land are irrigated in Uzbekistan. Also eastern parts of the country which are vegetation abundant regions should be studied separately for trend analyses of vegetation and climate variables.

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