Climate change impact on extreme flood occurrence and flood-related damage to the Primorye Region agriculture

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Abstract. Research indicates that climate change aggravates extreme weather events resulting in flooding or soil waterlogging. Damaging abiotic stress imposed by flooding affects crop production negatively. Recently, floods, adversely affecting regional agriculture, occur in the Primorye region yearly. However, available statistics and research on flooding and its consequences for the region are fragmented and scarce. Based on meteorological data of temperature (1889 - 2019), along with annual (1911 - 2019), monthly, and daily (summer months 2015 - 2019) precipitation data in the Primorye region, this research aimed to grasp the exact situation in flooding events occurrence. The results demonstrated a significant increase in the mean annual temperature and extreme precipitation events. Further, the study discussed the deficiencies in the existing system of flood damage assessment and loss compensation. Deriving from the experience of the Federal Research Center of Agribiotechnology of the Far East named after A.K. Chaika (Ussuriisk), the study attempted to estimate the multifaceted negative economic and environmental impact of flooding events on crop production, including flooding influence on land fertility, the effect on pests and disease manifestation, impact on the crop seed quality. The results call for the further robust investigation of the structure (both tangible and intangible) and scale of flooding effects on regional agriculture and add-up to the knowledge base on the topic.

1. Introduction

Studies by Roshydromet, the Federal Service for Hydrometeorology and Environmental Monitoring, show that mean annual temperature over Russia has been increasing at an average rate of 0.43 °C per decade that excesses the global warming rate more than twofold since the mid-1970s. Warming is more evident in winter and spring and more intensive east of the Urals. Already observed and projected climate changes cause numerous (both negative and positive) consequences for agriculture, and in existing climate change scenarios for the 21st century, most of them will continue or even become more pronounced [1].

The higher average temperature in the cold season, changes in moistening in the country’s main agricultural regions, an increase in the solar energy available for crops, and longer duration of the
vegetation period over the last decades, favorably affected the total crop production in Russia and in the Far East. Supported by several years of records in gross crop harvest, in Russia, an opinion that climate warming is overall beneficial for the country is strong [2].

However, the favorable effect of climate conditions is projected to deteriorate by the end of the 21st century. Besides continued warming at a rate higher than the global mean, the frequency of extreme precipitation throughout the year increased significantly compared with the climatic norm across much of Russia and in the Far East region, increasing the risks of catastrophic floods [1]. Extreme flood is characterized by low frequency but large affecting area and enormous economic loss. In the future, the extremeness of precipitation in the region may even grow, leading to more frequent and higher rainfall and snow-related floods. Both flooding (when a plant or its part is submerged underwater) and soil waterlogging (when soil pores are saturated with water) are unfavorable as they undermine predictable high-quality crop yields and hinder sustainable agriculture development. The negative consequence of global warming, showing itself in northward and eastward distribution shifts of some pests and crop disease agents influence, is also predicted to grow [1].

Globally, an urgent need for effective measures to mitigate economic activities impacts on the Earth’s climate system and to cope with climate change is widely recognized. The development and practical implementation of these measures, which are often cost-intensive and even painful for national economies, should be based on objective scientific findings, rigorous and balanced information, and careful analysis of observations.

Flood damage is typically categorized as direct and indirect [3] and further categorized as tangible and intangible damage depending on whether it can be assessed in monetary values. Most of the environmental consequences cannot be evaluated in the monetary values, thus tend to be neglected by the statistics, and many of them tend to have prolonged impacts [4]. In the national "Program for agricultural development and regulation of agricultural, commodities and food markets", sub-program "Reimbursement of costs incurred by agricultural producers due to damage caused as a result of natural emergencies" remains one of the main state activities [5]. However, the existing system of direct-costs compensation of crop losses caused by natural disasters does not allow to fully estimate the structure (both tangible and intangible) and the scale of actual damage. While available official statistics reflect total sown area under a crop and gross harvest and yield of major crops, the systematic data on flood influence on land fertility, effect on pests and diseases manifestation, microbial activity in soil, impact on the crop yield quality is not reflected. Lack of precise damage evaluation makes it difficult to build comprehensive strategies to avoid losses in the future.

Damage evaluation becomes even more complicated if a flood-affected organization acts not only as a consumer-responsible agricultural producer but also as a scientific or breeding and seed-producing entity. In this case, intangible negative effects may include loss of long-term research observations, hindering new cultivars' development, or virus-free best quality seed production. Despite the state attention to the domestic seed supply problem during recent years, provision of domestic, quality seed material remains at a relatively low level in farms of all categories. Share of areas sown with elite seeds to Russia's total sown area was only 8.4 % in 2017 [5]. Flood damage to fields with the original, super-elite, and elite seeds may undermine quality crop production of agricultural enterprises of all types for future years.

Research on the flood issue in the Primorye region is not sufficient; available statistical data is fragmented. Therefore, the present study aimed to investigate regional climate data and grasp the actual situation in weather changes and related flood occurrence. Further, the study aims to correlate analyzed data on extreme precipitation and subsequent crop losses data. By doing so, the study aims to attract the scientific and practitioners' community's attention to the need for further robust investigation of the flooding effects on regional agriculture through an accurate assessment of both tangible and intangible, short-term and long-term flood damage.
2. Materials and methods

2.1. Data obtaining
Official data from the Federal State Statistics Service, information from the Russian Government and the Ministry of Agriculture of the Russian Federation including internal reports of the Primorye region Ministry of Agriculture, relevant literature review, and climate change assessment reports were scrutinized for this study. To illustrate trends not reflected in the available statistics, internal reports of the Federal Research Center of Agribiotechnology of the Far East named after A.K. Chaika (FRC of Agribiotechnology) were summarized.

A large cluster of daily weather data that amounted to more than 50 thousand values was received from the meteorological station Timiryazevskii and analyzed with the R Software 4.0.2. To create data visualizations, R package ‘ggplot2’ was used.

2.2. Location of the observed region
Primorye region is located in the South-East of the Russian Far East. The region borders China to the west and the Sea of Japan to the east. Meteorological station Timiryazevskii operates in the Timiryazevskii settlement of the Ussuriisk urban district since 1909. The station is located on an elevated flat area at an altitude of 34 m above sea level. By landscape it is a field station fully reflecting the climatic features of the western parts of the region. FRC of Agribiotechnology is located nearby (figure 1).

Figure 1. Location of the observed region and Timiryazevskii meteorological station.

3. Results and discussion

3.1. Evidence of climate change in the Primorye region
Since the very beginning of population resettlement from the European part of Russia to the Far East, the region's monsoon climate imposed additional tasks not only to grow the crop but also to preserve it during the harvesting period (August, September). The main feature of monsoon climate is an uneven distribution of precipitation during the year. With the release of tropical cyclones and typhoons in middle latitudes in the second stage of plant vegetation, 60-70% of the annual precipitation norm may fall here. Traditionally, in the Primorye region, cyclones and typhoons pick used to come more in late August-early September. Also, while 90% of all arable land in the Far East is concentrated in Primorye and Primorye, soils in the regions are subject to waterlogging [6], with the total area of exposed land is about 1 million km². Almost every year, there are dry periods, sharp shifts from excess moisture to its lack, when the upper layers of soil dry up in a very short period regularly occur [7].
Due to global climate change, unusually severe weather is occurring more frequently. Both temperature and precipitation are representative variables usually used to directly reflect and forecast the influences of climate change. Thus, the present study pays special attention to these variables. Changes in characteristics of monsoon and atmospheric processes over the Far-Eastern region manifested themselves in the long-term changes of the water temperature as well. The temperature in the surface waters of the Sea of Japan increases most significantly (1.72 °C/100 years), considerably exceeding the average 0.51 °C/100 years value for the global ocean. The temperature of surface waters in the Sea of Japan is expected to increase by another 1.9-3.1 °C by the end of the current century [1].

Available climatic data obtained from the meteorological station Timiryazevskii (figure 2) demonstrate that during the observed period mean annual temperature generally varies between about 2°C and 5°C. The warmest mean temperature was 5.7°C in 2019, and the lowest was 0.9°C in 1895 [8]. The observation of the Primorye region shows a significant increase by 2.3 °C in mean annual temperature from 1909 to 2019. These changes have beneficial effect on the growth of temperature-sensitive crops, and soybeans in particular, as the sum of positive temperatures increases. Thus, arable land is expanding in the region's colder areas increasing the volume of crop production. However, the temperature rise is critical and is expected to alter the frequency and intensity of extreme weather events. Notably, relatively small changes in mean values may lead to considerable changes in statistics of extremes, which is evident from the further analysis of monthly and daily precipitation.

![Figure 2. Mean annual temperature in the Primorye region from 1889 to 2019.](image)

Annual precipitation in Primorye did not significantly change from the year of observation 1911. Precipitation generally varies between 500 mm and 750 mm, with a minimum value of 382 mm in 1997 and a maximum of 994 mm in 1974. Especially wet years occurred in 1972, 1974, 2016, and 2018 with around 800 mm. Dry years occurred in 1970, 1977, 1987, and 1997 with less than 400 mm. However, from 2015 to 2019, a short-term fluctuation is observed, and annual precipitation was relatively high (about 700-800 mm) (figure 3) [8].

![Figure 3. Annual precipitation data for the Primorye region from 1911 to 2019.](image)
In recent years, meteorological station Timiryazevskii reports unusually high daily precipitation rates, exceeding average values up to ten times and sometimes exceeding monthly rates (figure 4). Monthly precipitation is also unevenly distributed, significantly affecting crop productivity. The following extreme events resulted in losses (discussed in detail in 3.2) at fields of FRC of Agribiotechnology. In the third decade of August 2015, the amount of precipitation in the Ussuriisk urban district was 160-177 mm (119-147% of the monthly norm); on August 7th, 2017, the daily rainfall amounted to 248.4 mm (169% of the monthly norm); in August 2018 number of days with rainfall was 23, the total amount of precipitation was 347.7 mm (259% of the monthly norm); in August 2019 precipitation was 226.5 mm (169% of the monthly norm) (figure 4). In June 2020, the amount of precipitation was 193.5 mm, 239% of the monthly average [8]. This amount of daily rainfall causes flooding and imposes water stress on crops.

![Figure 4. Daily precipitation in the Primorye region for summer months in 2015-2019.](image)

Uneven precipitation distribution coupled with unpredictable rainfall and related flooding demonstrates a tendency to regularity. To cope with the problem, it is necessary to develop response strategies at federal, regional, and organizational levels.

3.2. Issues in Assessing Flood Damage to Agriculture
Along with drought, salinity, and mineral deficiency, flooding (or waterlogging) has serious consequences, both economic and environmental, for the productivity of much arable land. Direct damage to agriculture is caused by direct physical contact of floodwaters, such as damage to buildings, stocks, and machinery; losses of crops and livestock; damage to soils. Indirect damage is caused not directly by a flood but mainly by disruption of physical and economic linkages, loss of production at flood-affected companies, and costs of traffic disruption and emergency services. Damage that can be easily specified in monetary values, such as damage to buildings, assets, and agricultural crops is tangible. A complete and reliable assessment of it requires detailed information obtained through a combination of continuous inventory of assets by professional valuation and insurance organizations.
and data of regular and detailed (large-scale) monitoring by remote sensing technology [3]. Intangible damage cannot be specified in monetary values, difficult to access, and therefore usually skipped from any official statistics. It includes casualties, health impacts, and damage to ecosystems (biodiversity loss, loss of soil nutrients or soil erosion etc.) [4].

In Russia as a whole and in the Far East region in particular, remote sensing application is still limited. The mechanism of agricultural insurance with state support has been significantly improved and from 2019, only agrarians, who have insured their risks, receive compensation for emergency losses. According to the Minister of Agriculture, a budget for agricultural insurance increased by 1.5 times, and insured farmland area increased by 39% from the 2018 year [2]. Even though, share of insurance against natural emergencies in damage compensation of both real estate and farmland remains low. In 2014 it was less than 3% against 55% in the most developed countries of the world [3]. In 2020 insured farmland increased to 6 million hectares, which is less than 5% of the total arable land. These factors impede precise analysis of flood-related agricultural losses.

Available information on the Primorye region flood losses is limited, fragmented and, in many cases, refers to separate dates and cover different types of activity, assets and thus lacks comparability if information from different sources [3]. For example, according to the national report [5], the damage to agricultural producers from the catastrophic floods of the 2013 year in the Far East amounted to about 10 billion rubles. Losses of agricultural crops on 627 thousand hectares (slightly less than 40% of the total area under crops in the federal district) were reported. However, experts opinion disagreed with the official estimations and insisted that direct damage, including the restoration of the soil fertility, amounted to 14 billion rubles at least [3]. In July - August 2019, the total damage to crop production caused by flood due to heavy rainfall in the Amur Region, Jewish Autonomous Region, Primorye Region, and Khabarovsk Krai, amounted to over 5 billion rubles; only in Primorye 14.5 thousand hectares of crops were damaged [2]. Even being incomplete and selective, estimates of natural emergencies damage are being reported every year. Available internal reports on flood-related crop losses assessment by the Primorye region Ministry of Agriculture demonstrate annual losses totaling to dozens of thousand hectares (figure 5) [2].

![Figure 5. Flood-related crop losses of main agricultural crops in the Primorye region for 2015-2019 reported by the Ministry of Agriculture of the Primorye region.](image)

3.3 *Flood-related issues at Primorye region through the prism of the FRC of Agribiotechnology of the Far East named after A.K. Chaika experience*

Cultivation of crops in challenging agroclimatic conditions of the Far East has made it vital to breed special crop varieties that not only meet consumers needs but are resistant to waterlogging, diseases, pests. In Primorye region, preservation and development of genetic collections as a basis for the creation of new domestic varieties; breeding of new varieties with expected economically valuable traits; development of a platform for marker-oriented and genomic selection; ecological and geographical
testing of varieties and hybrids; virus-free seed production of new promising varieties; monitoring and research of crop diseases and pests, development of diagnostic methods are the tasks of FRC of Agribiotechnology. Among tasks of the Center, there are production of original seeds of super-elite and elite class (most fully transmitting yield, disease-resistance, and other properties of the variety); improvement of adaptive, ecologically safe resource-saving technologies for high productive crops seed production; research and recommendations for the application of crop protection agrochemicals, fertilizers, and agricultural machinery. Given the FRC’s unique role and experience for the development of regional sustainable agriculture, the present study uses it as a prism to address the multifaceted impacts of flooding.

According to various estimates, in the Far Eastern flood of 2013, from one-third to half of the soybean was lost, and for potatoes, losses amounted to 80% [3]. Unsupplied to the market damaged crops should be replaced through the supply of products from other sources (including imports) and replacement costs should be included in the flood-related losses. However, there are goods and services that cannot be easily replaced. For instance, analysis of the internal reports of FRC of Agribiotechnology on flood-related crop losses (figure 6) demonstrates that in the period from 20 to 31 of August 2015, fields for potato breeding selection were lost on 1.2 from the total 1.5 hectares; original virus-free super-elite potato seeds were lost on 3 from the total 6.5 hectares; in August 2018, wheat was lost on 80 of the total 84 hectares in the organization. Direct crop production costs losses of these small-scale fields amounted to 1 million rubles. However, the long-lasting and not monetary impact of losses exceeding half of the total sown area was intangible and difficult to evaluate. In the situation when seed farms producing elite class seeds and other agrarians do not receive super-elite class seed material from the only breeding organization in the region for many crops, replacement costs should be measured not only as transportation from other regions (or even countries) but also as undermined supply of agro-climatically approved (or domestic) seeds for future years.

Flooding affects crop production in many ways. It can damage crops moving soil surface. Erosion washes the fertile topsoil away, increasing input costs, and reducing yields in future years. Soil deposition is another significant problem. More than a few centimeters of deposition, even of fertile silt, can smother even a well-developed existing crop. Sand and gravel can also be deposited on cropland by floodwaters, implying higher input costs and lower yields in future years.

Through runoff, leaching, and enhanced denitrification during anaerobic soil conditions, flooding promotes soil nitrogen losses. Denitrification is an anaerobic microbial process, so the same factors that determine oxygen depletion for crops (temperature, duration, and water movement) also determine the soil oxygen level; the less soil oxygen, the more soil nitrogen lost via denitrification [9]. Potentially, if the soil conditions become appropriate for machinery, nitrogen can be reapplied in the field. However, costs and workload increases make this practice hardly applicable to the conditions of Primorye.
Moreover, waterlogged crops can continue to suffer damage and yield losses after floodwaters withdraw. Soil and water conditions during flooding favor the development of plant pathogens. Flooding weakens plant defense, reduces the immunity of crops and increases susceptibility to viral and fungal pathogens, and causes various foliar diseases, root and stalk rots, to name a few [9].

In 2019 - 2020 an epidemic outbreak of phytofluorosis caused by waterlogging was observed in the Primorye region. A large amount of both air and soil moisture contributes to the spread of oomycetes from the genus Phytophthora [10]. With drops of rain or dew, spores penetrate the soil and infect the new potato's tubers. Prolonged warm and humid weather promotes rapid disease development. Losses of Solanaceae family yield can amount to 70%; in years favorable for pathogen development with humid, cool weather - up to 94%. The quantitative manifestation of partial resistance within the same potato variety depends on weather conditions and infectious load [11].

Some disease outbreaks can be controlled by fungicides application. However, this increases both production costs and environmental burden and violates the phytosanitary status of soils. Soil is considered a bank of a wide variety of microorganisms [12]. Microbiological activity is one of the most important factors determining the genesis and fertility of soils, the course of a wide range of processes in the soil, and soil regimes’ formation. Under its influence, the synthesis and destruction of organic matter of soils and plants, minerals, changes in the degree of oxidation and reduction, hydrophilicity and hydrophobicity of a number of compounds happen [13]. Soil microbiological activity is closely related to microbiological activity in other components of ecosystems.

Actinomycetes participate in the decomposition and synthesis of humus compounds in soil and in the accumulation of biologically active substances, forming the nitrogen balance of soils [12]. Our observations revealed the following contained amount of actinomycetes in the leaves, bark, plant litter, and in the soil of the surrounding fields of the FRC of Agribiotechnology (figure 7) [14]. The specificity of the actinomycetes complex was observed in these ecosystems of flooded soils. Representatives of Streptomyces, Micromonospora, Saccharopolyspora, Saccharamonospora, Actinomadura, Microbispora, Streptosporangium genera were detected in the soils.

All analyzed soil samples were infested with root rot pathogens to varying levels, and 58% of the surveyed areas of agroecosnes - with conidia of Bipolaris sorokiniana, pathogens of Fusarium and Phytophthora, including Phytophthora cactorum, above the threshold values. This was one of the main prerequisites for root epidemic outbreak in crops after waterlogging. It should be especially noted that not a single soil sample contained fungi of the Trichoderma species. Trichoderma spp. strains have been widely known to reduce the severity of plant diseases by inhibiting plant pathogens in the soil through their highly potent antagonistic and microparasitic activity, increasing plant growth potential, resistance to disease and tolerance to abiotic stress [13]. The absence of Trichoderma species demonstrated a low disease suppression ability of waterlogged soil in all samples.
Waterlogging negatively affects some crops, especially during the seed filling stage. Water stress affects crop production and yields decreasing by reducing the number of seeds per unit area. Even greater crop damage can be caused by weed growth, which imposes the necessity of additional weed control. Depending on the season, weed control measures may become less effective and only costly. New weed seeds can be brought in the fields by running water that increases control costs and reduces yields of future years [9].

Potential measures that can be used to mitigate soil waterlogging effects include the use of flood-tolerant varieties, adjusting agrotechnological practices, improving drainage, and practicing adaptive nutrient management strategies. However, these might be site- or crop-specific management practices, and they should be promptly validated for their cost-efficiency. One of the implications might be a strategic reassessment of fields for breeding and elite seed production purposes. Remote sensing and precise damage analysis might be applied to find the most appropriate new locations for such fields, with the minimum flooding risks potential. Application of agricultural machinery suitable for the regional specific conditions is another suggestion. Novel implements for sowing and cultivation that contribute to moisture distribution in the soil has been developed in the Primorye region [15].

4. Conclusions

Most of both negative and positive climate change consequences for agriculture are expected to continue or even become more pronounced. In this paper, a large cluster of weather data has been analyzed, showing extreme deviations from the norm in both temperature and rainfall in the Primorye region. The temperature rise by 2.3 °C from 1889 until nowadays has affected climate change in general. This study noted that precipitation had slightly changed for a hundred-year observation. However, since 2015, there has been a large increase in precipitation for several years in a row until 2019.

Observed weather events suggest that climate change’s favorable effects may deteriorate in the future; extremeness of precipitation in the region may grow, leading to more frequent and higher rainfall-related floods. Due to warming, some pests and crop disease distribution tend to shift to areas not affected before. The aggravated problem of field waterlogging in the region leads to reduced immunity of crops and increases viral and fungal pathogens’ susceptibility.

Data presented on the experience of the FRC of Agribiotechnology of the Far East named after A.K. Chaika is not a result of systematic long-term observation. Rather, through the single organization’s prism, our research attempts to highlight the importance of assessing all aspects of flood damage, including intangible.

Partially due to an abundance of farmland, Russia’s statistics have been reluctant to the precise structural analysis of both economic and environmental damage of floods. To cope with uneven precipitation distribution coupled with repetitive unpredictable rainfall and flooding extremes, it is necessary to develop response strategies at federal, regional, and organizational levels. Such strategies should reduce the damage from the negative impacts of climate change while effectively exploiting the benefits of positive impacts. The strategies should embrace a system of measures built on the robust scientific analysis results, and this research contributes to the formation of the so far insufficient scientific base.

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