Food and Agriculture Organization of the United Nations

AGRO-ECOLOGICAL ZONES

of Punjab – PAKISTAN

2019

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By:

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Foreword

Agriculture contributes approximately one-quarter of provincial gross domestic product (GDP) in the Punjab Province. The provincial share is two-third of the total national agricultural output, leading in major commodities meant for food security in the country. The sector employs roughly 13 million people or 45 percent of the Punjab labor force. However, the overall added value from agriculture in Punjab's economy is disproportionately low compared to other sectors of the economy.

The agricultural sector offers significant opportunities for rapid economic growth and potentially help millions to improve their livelihood. The production and productivity have remained nearly stagnant during last two decades. While the socio-economic needs of a rapidly growing population have put enormous pressure on the natural resources. Developing more efficient and sustainable agricultural systems to feed the future is a key challenge.

The main objective of launching agro-ecological zones (AEZ) in Punjab has been to formulate policies and strategies for sustainable and diversified use of natural resources and investments to harness production potential. The AEZs will enhance agricultural efficiency through better planning for climate smart agriculture. The government and associated stakeholders will be able to adapt to the unique zonal requirements and amend cropping systems according to water availability, soil and climatic conditions and market demands.

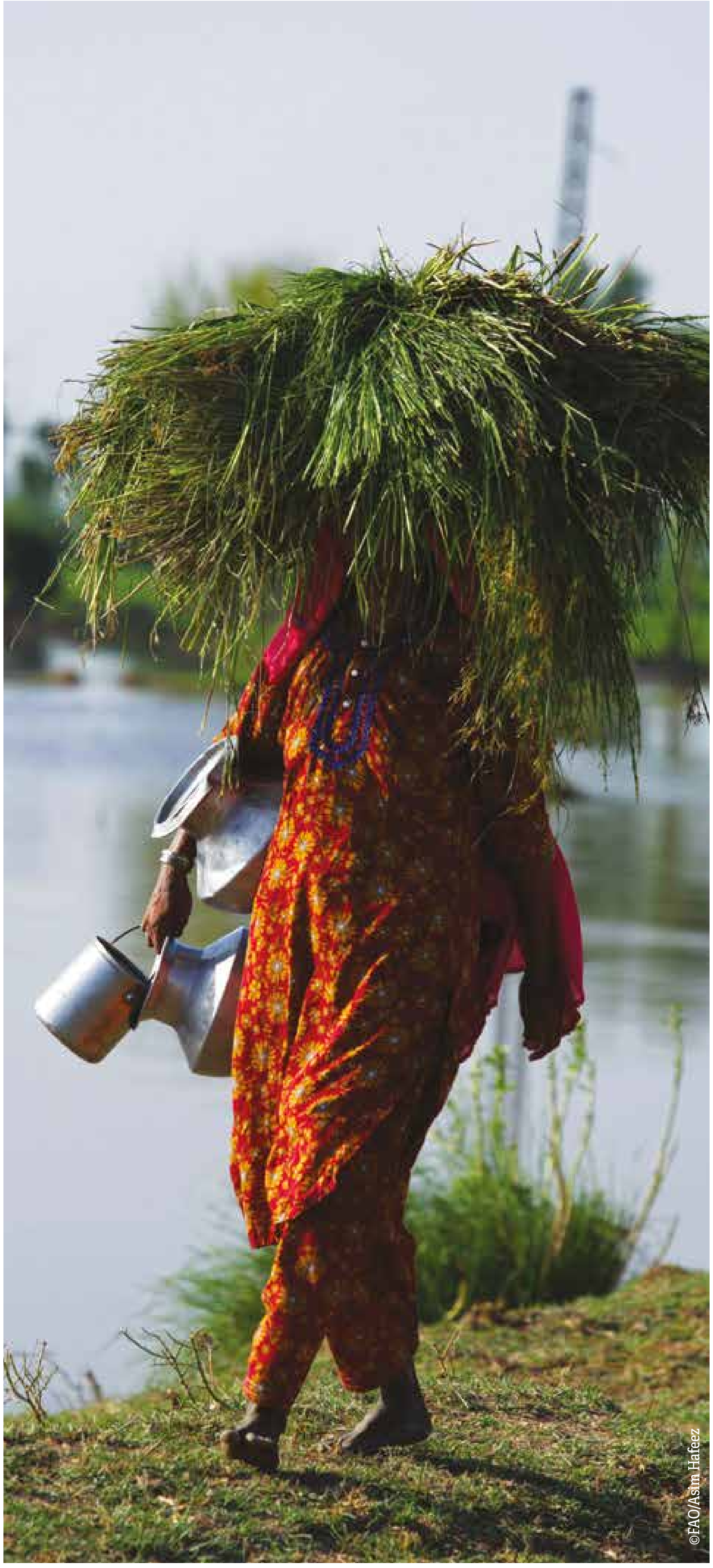
The data compiled in the AEZ report reveals an enormous potential for crop diversification and precision for enhanced crop productivity. That includes land characteristics, topography, land use, soil and water analyses, weather and climate, yield, and profitability which can lead to making recommendations towards "what" should be grown "where" and "when". Crop suitability maps have been developed for more than 50 commodities. This meticulous rehash of agro-ecological zones could make smallholders farming a profitable business and promote overall efficient agricultural enterprising.

The AEZ exercise presented in this document is an organic entity that can continue to evolve and become more precise with added data sets. Towards that end, we have already entered into a national program NCBC (National center for big data and cloud computing) as a precision agriculture and analytics lab (PAAL). Simultaneously, FAO has launched a range of site-specific studies to develop applications and products that could be easily adaptable by the smallholders and entrepreneurs for rural job creation. This piece of work shall also serve as a template to extend AEZ exercises to other parts of the country. With FAO being its underwriter, the global flavor has been added to an indigenous exercise. Together, I am confident that we have made a good case for reshaping the agricultural planning and investment in the country.

I close this foreword by recording my gratitude to the team AEZ and FAO for a job well done.

Iqrar Ahmad Khan

Chairman,
Agro-ecological zones Committee, Punjab



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Acknowledgements

The agro-ecological zoning (AEZ) of Punjab province is the result of a two-year-long effort by many institutions and teams of individuals with diverse disciplinary backgrounds. The initiative was taken up by the Office of the Secretary of Agriculture, Government of Punjab. The AEZ Formulation Committee was headed by Iqrar Ahmad Khan, SI, former vice-chancellor, University of Agriculture Faisalabad (UAF); with the vice-chancellors of Pir Mehr Ali Shah-Arid Agriculture University Rawalpindi (PMAS-AAUR) and Muhammad Nawaz Shareef University Agriculture Multan (MNS-UAM). Thanks also to: the director-general of the Pakistan Meteorological Department (PMD); the director-general of the Ayub Agricultural Research Institute (AARI), Faisalabad; the director-general of the Agriculture, Water Management, Punjab; the director-general of the Pest Warning and Quality Control, Punjab; the director-general of the Agriculture (Ext&AR) Punjab; and the chief executive of the Punjab Agricultural Research Board (PARB). Thanks also to: Ashfaq Ahmad, head of the Climate Change Research Group, UAF and Chair Climate Change, U.S. Pakistan Center for Advanced Studies in Agriculture and Food Security (USPCAS – AFS) UAF; Mobushir Riaz Khan (PMAS, UAAR); Abid Qayyum Solehri, chief of the Sustainable Development Policy Institution (SDPI), Islamabad; and representatives from the Pakistan Space and Upper Atmosphere Research Commission (SUPARCO) as well as from the Food and Agriculture Organization of the United Nations (FAO) as members of the committee.

Iqrar Ahmad Khan has led the technical team throughout the process and provided editorial comments on the final report and mapping products. Ashfaq Ahmad led the UAF-based team and has primarily contributed to finalizing crop norms, crop modeling, and suitability maps. These tasks were performed with the help of other team members, including Syed Aftab Wajid, Department of Agronomy (UAF); Muhammad Naveed Arshad and Muhammad Fahad, Agro-Climatology Lab (UAF). The task of agro-edaphic suitability and integration of climatic and edaphic evaluations was performed by a team led by Syed Hamid Hussain Shah, former Director Water Management, UAF, with Ishfaq Ahmad, Agro-Climatology Lab, UAF as a team member. The soil-related data and methodology were contributed by Zulfiqar Ahmad Dasti and Muhammad Anwar-ul-Haq, Institute of Soil and Environmental Sciences, while the water section and land cover data were compiled by Jehanzeb Masood Cheema, Chair, Precision Agriculture (CAS-AFS), and Muhammad Mohsin, UAF. The horticulture crop norms were compiled by Khurram Ziaf and Saeed Ahma, Institute of Horticultural Sciences, UAF.

Mobushir Riaz Khan and Muhammad Amin, Institute of Geo-Information & Earth Observation, PMAS AAUR, contributed to agro-climatic zoning maps and agro-ecological zone maps. Geospatial analysis of agro-climatic zone demarcation is based on the PhD dissertation of Muhammad Amin. Azeem Khan, Faculty of Agriculture, Engineering and Technology, UAF, contributed to the development of the methodological framework, data standards and inter-operability of geospatial data sets. The agro-economic zoning task was led by Muhammad Asif Kamran, chair Agriculture Policy CAS-AFS, UAF, and Senior Scientist, Nuclear Institute for Agriculture and Biology Faisalabad, with the support of Raza Ullah, Azhar Abbas and Amjed Iqbal, Institute of Agriculture and Resource Economics, UAF.

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Ece Aksoy, AEZ and GIS Specialist, Geospatial Unit, CBDS FAO; and Muhammad Qadeer ul Hussnain, FAO Pakistan, have supported the technical teams on FAO's Global agro-ecological zones (GAEZ v3.0) methodology and its country-level adaptation for Pakistan. They facilitated the technical teams in the review and standardization of AEZ methodology, refinement of input datasets, vetting of models, and standardization of mapping and reporting products, as per FAO standards. Furthermore, Muhammad Qadeer ul Hussnain deployed and managed the GeoNetwork-based geospatial data management platform for the handling of extensive data bi-products during the exercise. Final vetting, development of maps, and map templates have been done by Mehwish Ali, GIS Analyst, Information Management Unit, FAO Pakistan.

Lucia Moro, graphic designer, Geospatial Unit CBDS FAO, developed graphic layouts and infographics, selection of photos, and the publication process. Final editing and modification was completed by Amber Pervaiz, programme development specialist, consultant, FAO.

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Abbreviations and acronyms

AARI	Ayub Agricultural Research Institute
AESA	Agro-ecosystem analysis
AEZ	Agro-ecological zone
AFS	Agriculture and food security
AgMIP	Agricultural model inter-comparison and improvement project
AMIS	Agricultural marketing information services
ASTER	Advanced space borne thermal emission and reflection radiometer
CAS	Center for Advanced Studies
CBD	Convention on Biological Diversity
CRS	Crop reporting service
DEM	Digital elevation model
DG	Director-General
EBK	Empirical bayesian kriging
EC	Electrical conductivity
ET_o	Evapotranspiration
GAEZ	Global agro-ecological zones
GAUL	Global administrative unit layers
GCP	Ground control point
GDEM	Global digital elevation map
GDP	Gross domestic product
GIS	Geographic information system
GNP	Gross national product
GPS	Global positioning system
HEC	Higher Education Commission
IBIS	Indus basin irrigation system
IFS	Institute of Soil Fertility Research
IGEO	Institute of Geo-Information and Earth Observation
IPCC	Intergovernmental Panel on Climate Change
LCC	Lower chenab canal
NIAB	Nuclear Institute for Agriculture and Biology
NR	Net revenue
PARB	Punjab Agriculture Research Board
PARC	Pakistan Agricultural Research Council
pH	Potential hydrogen
PIDA	Punjab Irrigation & Drainage Authority
PMAS-UAAR	Pir Mehr Ali Shah Arid Agriculture University Rawalpindi
PMD	Pakistan Metrological Department
RS	Remote sensing
RSC	Residual sodium carbonate
SAR	Sodium adsorption ratio
SDG	Sustainable Development Goal
SDPI	Sustainable Development Policy Institute
SRTM	Shuttle radar topographic mission
SUPARCO	Space and Upper Atmosphere Research Commission
TC	Total cost
TFC	Total fixed cost
TMI	Thorn-thwaite moisture index
TR	Total revenue
TVC	Total variable cost
UAAR	University of Arid Agriculture Rawalpindi
UAF	University of Agriculture Faisalabad
UN	United Nations
UNCITRAL	United Nations Commission on International Trade Law
USP-CAS-AFS	U.S.-Pakistan Center for Advanced Studies in Agriculture and Food Security

Message from FAO Representative in Pakistan

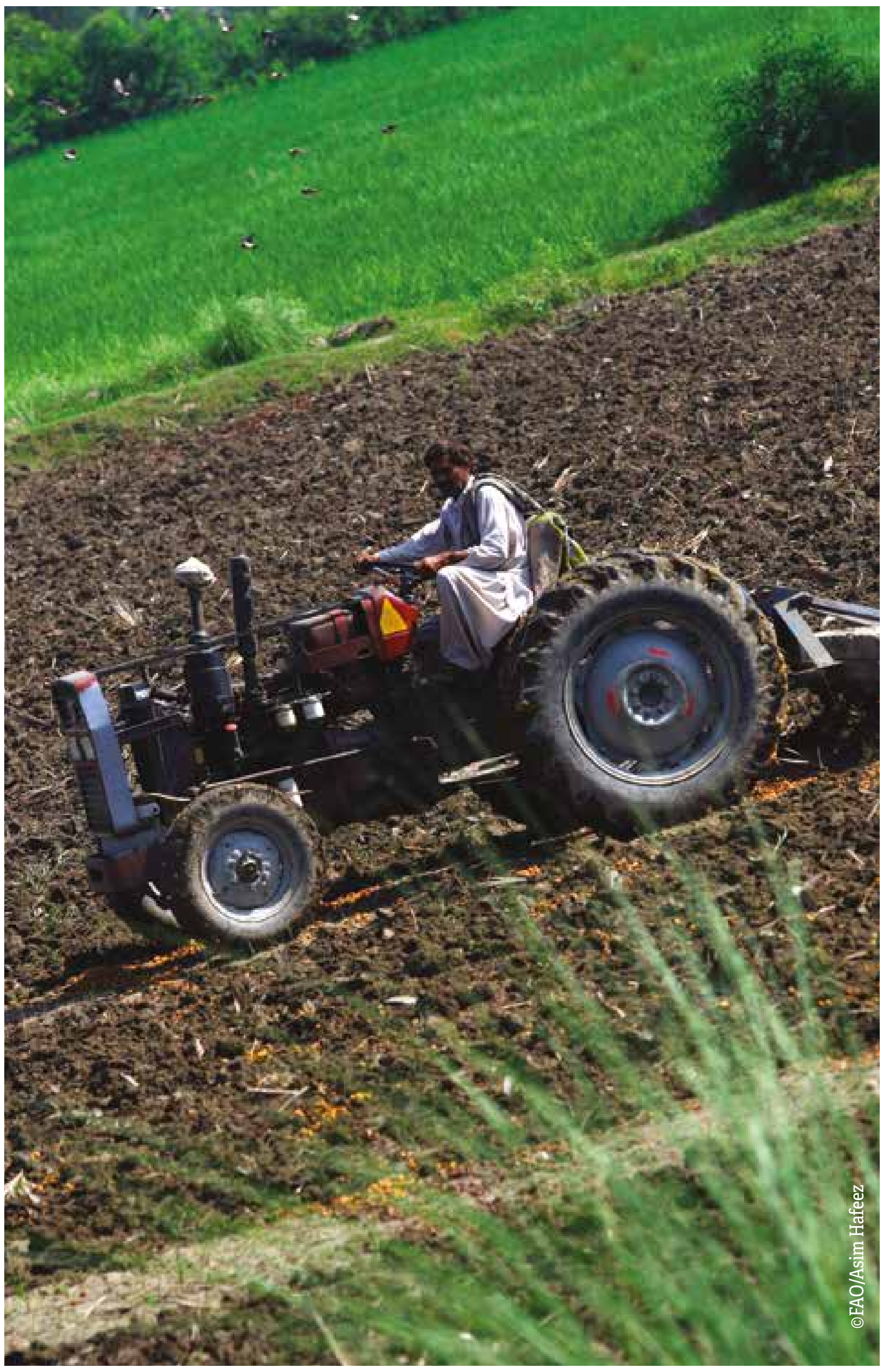
The agro-ecological zonings of Punjab province (AEZs) is a cornerstone in the efforts towards the transformation of Punjab's agricultural and food systems. It is the result of two years of collective work by institutions and teams with high levels of technical expertise. AEZs will allow the identification of the most suitable cropping systems through critical analysis and assessment of agro-climatic and edaphic variables, as well as the available resources for crop production, and the development of agriculture integrated production planning. It will further aim to assist agriculturalists in improving the yield of major crops, by correctly identifying the production potential of the agricultural systems which is driven by climate, soil characteristics, and landform conditions. This will, in the end, enhance agricultural efficiency and economic development, coupled with sustainability.

AEZs will provide policy makers and planning officials at all levels with the information necessary to help them develop relevant policies and strategies for sustainable use of natural resources. At the same time it will promote agriculture sector, building the framework for the development of agro-based industrial sectors, minimizing the yield gap of various crops grown in Punjab and helping contribute to identify opportunities for agricultural diversification. The result will contribute to improving food security and nutrition in rural Punjab.

The Food and Agricultural Organization of the United Nations (FAO) stands ready to continue assisting the agricultural sector of Pakistan to add to the contribution from agriculture to the national economy and livelihoods of rural communities. The AEZ is meant to serve as a living document for the policymakers, agriculturalist and educational institutions of Pakistan and will be updated periodically. The Higher Education Commission of Pakistan (HEC) will provide a constant flow of fresh data and tools through its dedicated lab on "Precision agriculture and analytics" to generate analysis that will ensure the current report is a living document.

I hope this AEZ report will help to put sustainable agricultural practices and food security in Punjab at the forefront of efforts to achieve Sustainable Development Goal 2 (SDG2) The goal aims to end hunger, achieve food security, and improve nutrition while promoting sustainable agriculture. This can be achieved by ensuring sustainable food systems and by implementing resilient agricultural practices that increase sustainable productivity as well as production, generate decent work employment opportunities and incomes, and contribute to improved nutrition and livelihoods in rural and peri-urban areas. The AEZ report is one important step towards a climate smart, revived and vibrant agriculture sector in Pakistan.

Ms. Minà DOWLATCHAHI
FAO Representative in Pakistan



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Executive summary

Agriculture, the largest sector of Pakistan's economy, provides employment to 42.3 percent of the country's labor force and contributes 23.3 percent to gross domestic product (GDP). However, that contribution has been decreasing continuously over the last two decades and sustainable enhancement of agricultural productivity has become the most important recent challenge. The rapidly growing population puts enormous pressure on natural resources; therefore, developing more efficient and sustainable agricultural systems to feed future generations is urgent.

For the last two decades, there has been no improvement in the yield of major crops: this may be due to factors including climate variability, cultivation of crops in areas that are not suitable for those crops (e.g. planting rice in an area more suitable for cotton), declining water availability, gradual changes in soil nutrient status and a lack of true-to-type cultivars. Moreover, agriculture has been dominated by five crops: wheat, rice, sugarcane, maize, and cotton. The narrow choice of crops is due mainly to a lack of understanding about the scope for more crops and a misallocation of resources. As well, the country has been unable to take advantage of the diversity of climate and land geographies, and consequently, it has become a net importer of otherwise locally cultivable crops such as fruits, vegetables, pulses and oilseeds, among others. This also means the country spends enormous amounts of foreign exchange to import edible oil, pulses, and seeds of many agricultural crops. There is a need to diversify and add more crops to existing cropping systems to achieve sustainability and diversification. The disadvantages and limitations associated with the expansion of cropland make it critically important to know where and how to increase crop yield on existing cropland area. An assessment of the physical and biological potential of natural resources that leads to the delineation of agro-ecological zones (AEZ) specific to crops presents a useful preliminary evaluation of this potential and ensures that representation is maintained at an appropriate biogeographic scale for regional sustainable development planning.

Agro-ecological zoning refers to the division of an area of land into land resource mapping units, each having a unique combination of landform, soil and climatic characteristics, and/or land cover with a specific range of potentials and constraints for agricultural land use. The establishment of agro-ecological zones is urgently needed to enhance agricultural efficiency and sustainable development planning because the successful adoption of cropping systems and crops in a specified region heavily depends on critical analysis and assessment of agro-climatic norms and available resources for crop production.

In 1980, the Pakistan Agricultural Research Council (PARC), performed an AEZ exercise, in which Pakistan was divided into ten distinct zones based on physiography, climate, land use, and water availability. They further divided Punjab into four broad categories with 11 subzones. The information obtained through this process has been beneficial and has since been used. However, considering rapid changes in land and water resources of the country, and climate change over the past two decades we need adaptation strategies to sustain, as well as enhance, our agricultural productivity and sustainably to ensure national food security. Climate is a prime factor that exerts a major influence on vegetation, soil health, and water resources. Changing climate is likely to cause a surge in the vulnerability of agricultural systems due to increases in temperature, changes in rainfall patterns, and more frequent extreme weather events worldwide. Plans at present foresee work on dynamic AEZs, or at least redefining AEZs (e.g. best-fit cropping systems), according to resource availability, climatic conditions, and economic benefits.

For this purpose, a team of scientists and researchers from the University of Agriculture Faisalabad and University of Arid Agriculture Rawalpindi, in collaboration with FAO and the Government of Punjab Agriculture Department, worked to delineate AEZs of Punjab, based on the most up-to-date information on natural resources, climate and agricultural markets. Unlike previous AEZ exercises carried out in 1980, when only regional climate data were used to delineate AEZ for conventional crops, the current methodology took advantage of big data and analytics and brought into the equation the following high resolution datasets to delineate new AEZs at 100 m scale, keeping in view the small landholdings of the country:

- the precipitation and potential evapotranspiration derived soil moisture index and agro-climatic zones;
- the quantity and quality of total available water (including surface water and groundwater);
- the soil characteristics, including texture, organic matter, and chemical properties;
- land-use characteristics and topography;
- crop norms for more than 60 existing and future crops in Punjab; and
- economic suitability zones for the produce.

The new AEZs revealed an enormous potential for crop diversification as well as sustainably enhanced crop productivity. That meticulous assessment of agro-ecological zones will help to make smallholder farming a profitable business and enhance agriculture efficiency overall because successful adoption of cropping systems and crops in a specified region heavily depends on critical analysis and assessment of agro-climatic norms and available resources for crop production.

Policymakers can use the updated AEZs and associated information on land characteristics such as soil quality, topography, weather, agricultural land use, yield, and profitability to formulate optimal policies for sustainable agricultural production. Land characteristics can be further evaluated for their production potential, which leads to final recommendations regarding what should be grown, where and how it should be grown.

Climate is a prime factor
that exerts a major influence
on vegetation, soil health
and water resources.

Climate change is causing
an increase in the vulnerability
of agricultural systems
due to increases in temperature,
changes in rainfall patterns,
and more frequent
extreme weather events
around the world.

Introduction

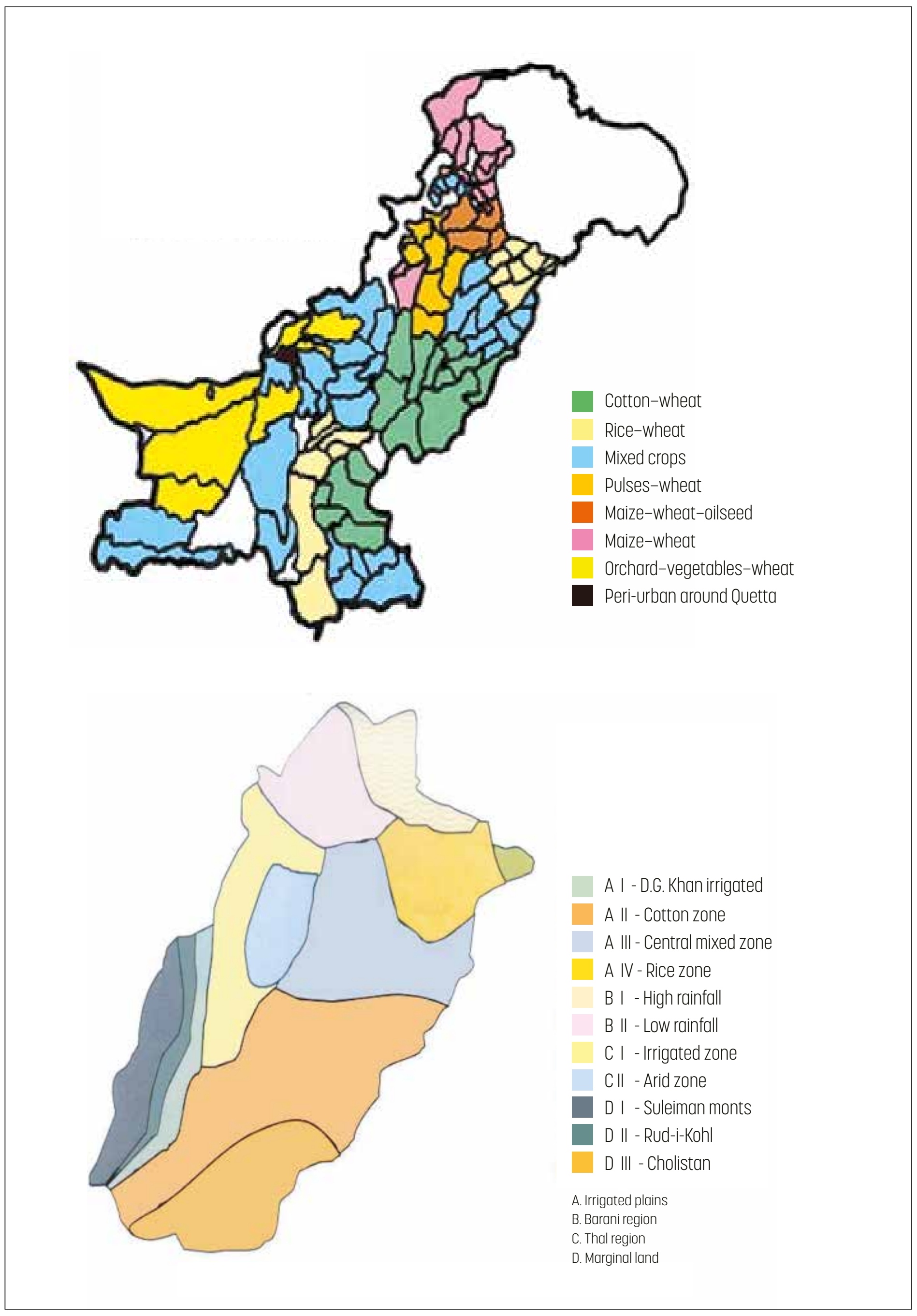
Agro-ecological zones in Punjab: description of previous efforts and why this work is essential

Agriculture is the largest sector of Pakistan's economy, contributing 23.3 percent to the total gross domestic product (GDP). It accounts for 42.3 percent of the total employed labor force in the country. However, the contribution of agriculture to the overall national economy has been decreasing (from 27.3 percent in 1985 to 19.8 percent to date) as compared with other sectors. There has been no significant improvement in the yield from major crops and yield stagnation has become a major challenge. There could be several reasons for this yield stagnation: climate variability, cultivation of certain crops in unsuitable areas for those crops (planting rice in areas better suited to cotton), progressively declining water availability, gradual changes in soil nutrient status, and lack of true-to-type seeds, to name a few.

Climate is a prime factor that exerts a major influence on vegetation, soil health, and water resources. A changing climate is likely to elevate the vulnerability of agricultural systems (Rosenzweig *et al*., 2014) by increased temperatures, changes in rainfall patterns, and more frequent extreme weather events worldwide (IPCC, 2014). There has been an explicit change in the weather patterns in Pakistan (Ahmad *et al*., 2015). These changes have been amplified over the last decades by rising emissions of greenhouse gasses. Mean temperature has been increasing by 0.2 °C to 0.6 °C per decade (AgMIP, 2016) and night temperatures have increased by more than day temperatures. Climate change and variability have impacted crop production and could also be the reason for the shift in cropping systems in some regions of Punjab province. Projected changes are expected to have a negative impact on the yield of crops (Ahmad *et al*., 2015). The increase in night temperature is more detrimental to agricultural crops. For sustainable agricultural production, current spatial and temporal changes in rainfall and temperature need to be considered (Ghazala *et al*., 2009).

Along with changes in rainfall and temperature, climate change also affects water resources, soil organic matter, and nutrient status. Reduction in canal water availability for successful crop production is a crucial factor. Soil conditions and fertility are not supporting the current agricultural system. Soil degradation could be one of the most important factors in stagnant crop yields.

Economic conditions, marketing infrastructure and resource availability in a region play a crucial role in the adoption of agricultural crops and cropping systems. Pakistan spends a large amount of foreign exchange on importing edible oil, pulses, and seeds of many agricultural crops. Based on the availability of suitable resources, there is a need to add these crops to our cropping systems.



Source maps: PARC, 1980

The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. *Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Figure 1. *Existing agro-ecological zones of Pakistan and Punjab*

The purpose of establishing agro-ecological zones (AEZ) in Punjab is to devise policies and strategies for sustainable and diversified use of natural resources to improve production potentials in agriculture. To sustain agricultural productivity, we also need adaptations to the changing climate, which could be a threat to our national food security. There is a need to plan cropping systems for different areas according to water availability, soil and climatic conditions. In order to plan the cropping systems Pakistan Agricultural Research Council (PARC) in 1980 divided Pakistan into ten distinct zones based on physiography, climate, land use and water availability (Figure 1). They further divided Punjab into four broad categories with eleven sub-zones.

As discussed above, there has been an explicit change in factors defining AEZs compared with those of 1980. Climate change, water availability/quality, economic and marketing infrastructure, import and export scenarios of agriculture commodities require a redefining of AEZs.

Agro-ecological zoning refers to the division of an area of land into land resource mapping units, each having a unique combination of landform, soil and climatic characteristics, and the land cover having a specific range of potentials and constraints for agricultural land use (FAO, 1996). The establishment of AEZs shall enhance agriculture efficiency through sustainable development planning. Successful adoption of cropping systems in a specified region heavily depends on critical analysis and assessment of agro-climatic norms and available resources for crop production.

Establishment of AEZ requires climate, soil, water allocation and crop yield data of previous years for future planning. Each AEZ should have a similar combination of constraints and potentials for land use, and guidance towards the optimum agriculture production. On a regional scale, AEZs are influenced by latitude, elevation, and temperature, as well as seasonality, rainfall amounts and distribution during the growing season. The AEZs being established will include biophysical attributes of the land such as elevation, climate, land use, land cover, vegetation, soil conditions, fertility, crop area, the yield of crops, a cost–benefit ratio, water allowances and water availability to cluster land-use types into more homogeneous areas.

The University of Agriculture Faisalabad (UAF) defined and analyzed AEZ requirements on a finer scale, through the use of more input parameters, new geospatial technologies, and methods to enhance the efficiency of land and water resource management.

Study area

Policymakers need updated information on land characteristics such as soil quality, topography, weather and agricultural land use to plan for sustainable agricultural production. Land characteristics can be evaluated for their production potential in order to make final recommendations regarding what should be grown where, and how it should be grown.

The Food and Agriculture Organization of the United Nations (FAO) defined AEZs as regions with the same agricultural capacity characterized according to homogeneous climatic and edaphic conditions (Rosenzweig *et al.*, 2014). Due to the importance and global attention towards AEZ, a guidebook was published for AEZ as an aid for countries in enhancing land and water resource assessments (FAO, 1996). AEZ methodology mainly comprised the steps showed in Figure 2.

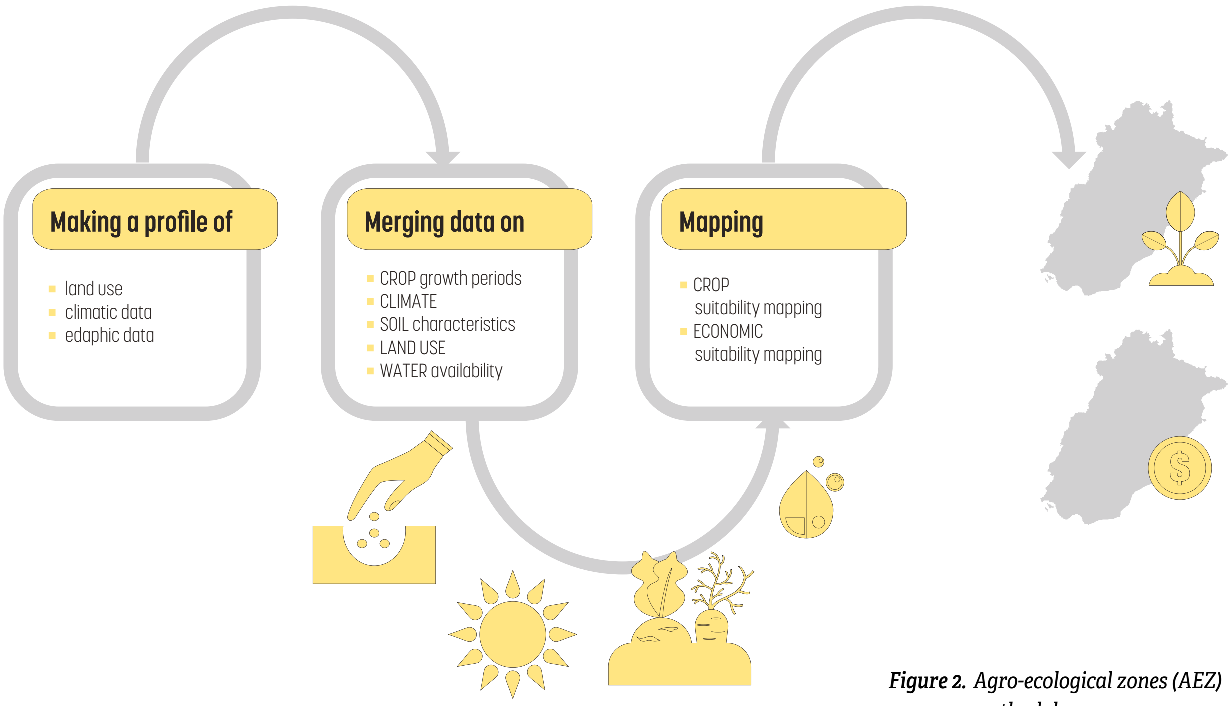


Figure 2. *Agro-ecological zones (AEZ) methodology*

In the literature, many approaches have been published for the delineation of AEZs, so the outputs of the process of AEZ delineation vary in number. Due to its flexibility in data manipulation and management, its ability to process multi-dimensional operations and fast improvements in technology, the focus has been given to Geographic Information System (GIS) as an effective tool in managing and analyzing information for AEZ delineation (Guyer *et al.*, 2007). The success of zoning a particular region lies in the adoption of available new research tools, particularly the vital inputs from space technologies such as remote sensing (RS) and GIS (Rondeaux, Steven, & Baret, 1996). Remote sensing technology has been of great use to planners in efficient use of natural resources at national, state and district levels. Agro-climatic zoning for Indian Punjab in the past involved the manual integration of agro-climatic and other natural resource data (Mavi, 1984). GIS/RS have introduced a new era for resource assessments and monitoring in terms of information quality (Van Ittersum & Rabbinge, 1997).

A significant amount of data can be lost in this method due to inconsistencies in geographical location. Now, because climatic and edaphic data have geographic references, the use of GIS technology improves the result of AEZ mapping by producing more accurate results as it preserves pieces of information that could be lost using previous methods.

Need for Agro-ecological zoning work: Emerging population growth and recent socio -economic situations add to mounting pressure on natural resources. The production potential of agriculture systems is driven by climate, soil characteristics, and landform conditions, and by use and management applied to the land. Sustainable management of soil and water resources requires sound policies and planning, based on knowledge of these resources and the demand for which the resources are put to use.

Answers to the following types of questions provide the basis for policy formulation and land-use planning:

- How is land with different potentials and constraints distributed within the country and in component provinces or districts?
- What uses can be recommended for different types of land in different locations?
- How do potential yields vary among locations, years and seasons?
- What is the balance between population demand and land availability in specified areas, and how does this respond to improvements in inputs or management?

Taken within the context of the objectives of government and those of land users, this information supports the development of land-use policies and enabling strategies in such specific areas as:

- provision of appropriate, area-specific, extension information and advice;
- establishment of agricultural inputs, or of relief programs;
- setting agricultural research priorities, and establishing networks for agro -technology transfer;
- formulation of legislation or guidelines to regulate and minimize environmental damage, and the establishment of environmental monitoring;
- identification of particular development programs or projects.

The purpose of zoning, as carried out for rural land-use planning, is to classify areas with similar sets of potentials and constraints for development. Specific programs can then be formulated to provide the most effective support for each zone. Each zone has a similar combination of constraints and potentials for land use and serves as a focus for the targeting of recommendations designed to improve the existing land-use situation, either through increasing production or by limiting land degradation.

When combined with an inventory of land use, expressed as land utilization types and their specific ecological requirements, zoning can also be used as the basis of a methodology for land resource appraisal.

AEZ can be regarded as a set of core applications, leading to an assessment of land suitability and potential productivity, and a further set of advanced or peripheral applications, which can be built on the inventories and results of the core AEZ studies. Outputs of core applications include maps showing AEZs and land suitability, plus quantitative estimates on potential crop areas, yields, and production. Such information provides the basis for advanced applications such as land degradation assessment, livestock productivity modeling, population support capacity assessment and land-use optimization modeling.

In the present study, Agro-ecological zones were delineated using the FAO approach, based on climatic and soil characteristics, crop norms, and economic variables. For this purpose, agro-eco-climatic zones were first identified, based on climatic data by computing the ETo and moisture index. Second, soil mapping units were constructed using soil types and soil basic physiochemical characteristics like pH, EC, nutrient and organic matter status. For this purpose, 0.282 million sampling points were used to prepare soil maps. Third, both the agro-climatic maps and soil maps were overlaid and AEZs were delineated into homogeneous climatic and edaphic sets. Fourth, the delineated AEZs were evaluated, based on crop requirements (crop norms) and crop suitability maps of 59 crops. Last, crop yield data and the cost of production of available crops were used for the economic assessment of the AEZs.

LOCATION

Punjab is the most populous province of Pakistan. It is located at 31.17˚ N and 72.70˚ E with an area of about 205 344 sq km. Punjab occupies about 26 percent of the land area of Pakistan. It is bordered by Sindh, Balochistan and Khyber Pakhtunkhwa, as well as the regions of Islamabad Capital Territory and the Azad Kashmir. It also shares borders with the Indian states of Punjab, Rajasthan, and Jammu and Kashmir. The land of Punjab is made up of soils deposited by the Indus River and its tributaries during the Quaternary Era. The Indus River is the longest river of Pakistan and therefore, also of Punjab. Most of the agriculture area in Pakistan depends upon the upper Indus Plain. It is also called the "Grain Basket of the Sub-Continent". Its contribution to the country's economy is reflected in its high share of total gross domestic product (GDP).

CLIMATE

Punjab lies in arid to semi-arid region of Pakistan with observed temperature ranges from -2 ˚C to 45 ˚C but can reach 50 ˚C (122 ˚F) in summer and -7 ˚C in winter. Maximum average annual temperature varies between 28˚C and 32 ˚C and the minimum annual average temperature varies between 15 ˚C and 19 ˚C. There is a trend towards increasing temperatures owing to global warming, which is estimated to be more than 0.5 ˚C. The last 50 years exhibited an increase in rainfall trend with a total change of 228 mm. Climatically, Punjab has three major seasons:

- hot (April to June) when the temperature rises to about 45 ˚C;
- rainy season (monsoon rainfall) July up to September, Average annual rainfall ranges between 1 140 to 1 270 mm (sub-mountain region)and 508 to 630 mm on the plains;
- cool/foggy/mild weather from October to March. Temperatures drop to as low as -0 ˚C.

Humidity varies from 53 percent to 62 percent, fluctuating with the climate variables. Sunshine hours depend upon the length of days; for example May, June, and July have long days with more sunshine hours as compared to December and January.

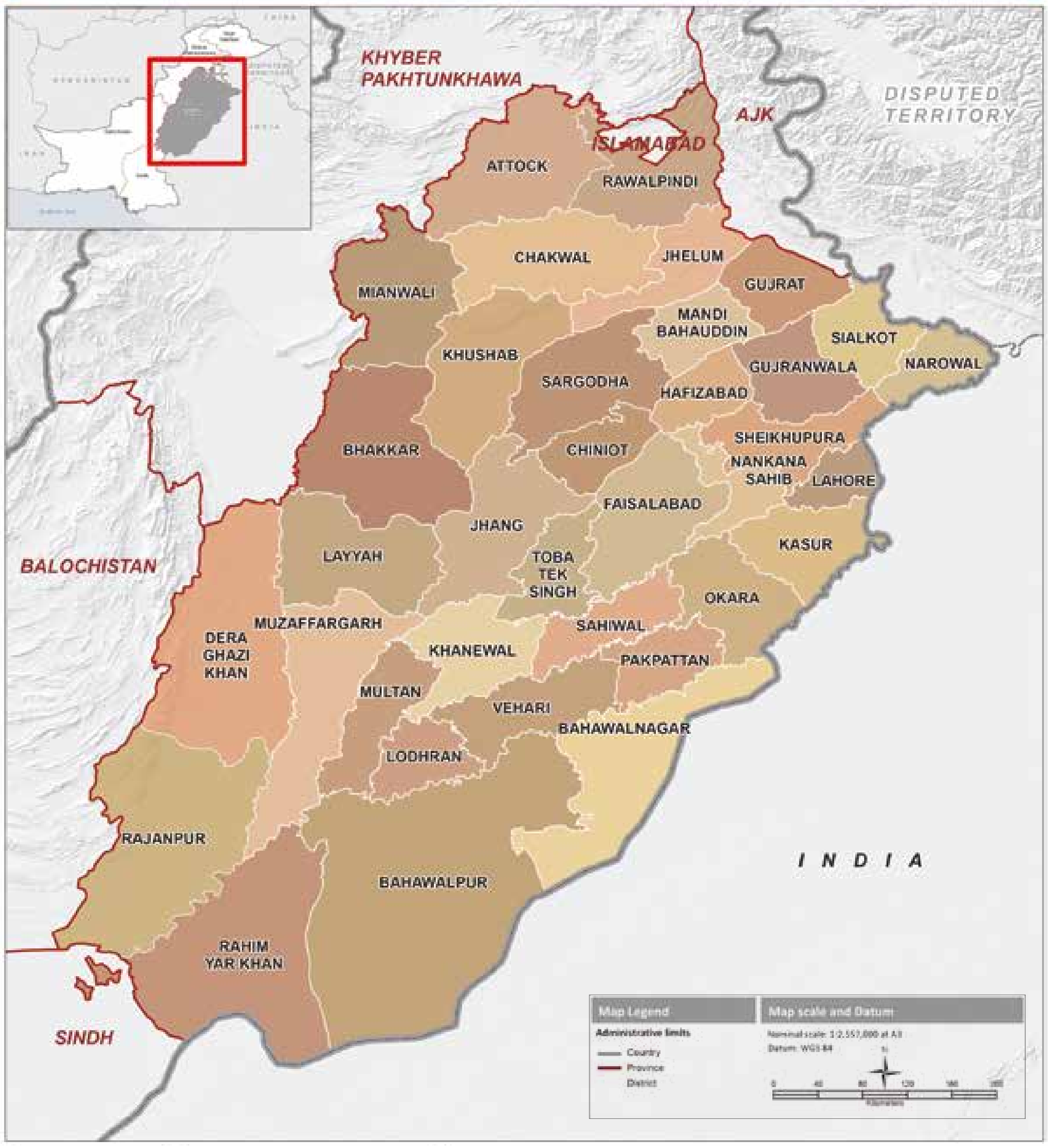
OBJECTIVES OF THE STUDY

The objectives of this study are to:

- identify different agro-ecological zones in Punjab based on agro-climatic and edaphic variables;
- identify the suitability of crops in AEZs for sustainability;
- assess agro-economic performance in delineated AEZ.

The delineated agro-ecological zones will be useful for:

- promoting the agriculture sector (soil-water productivity);
- providing a framework for the development of agro-based industrial sectors (as per zonal needs);
- minimizing the yield gap of various crops being grown in Punjab;
- maintaining food security.



Map created by: IM Unit, FAO Pakistan.
Data sources: FAO, Government of Punjab, GAUL

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Figure 3. Location map of Punjab Province

1 The agro-ecological zones methodology

Methodological framework for agro-ecological zones formation in Punjab

The agro-ecological study comprises four steps A, B, C and D as shown in Figure 4. The main application of AEZ, leading to an assessment of land suitability and productive potential under specified uses, comprises three groups of compound activities:

- mapping of agro-ecological zones based on inventories of land resources and climatic conditions;
- assessment of land utilization types and their ecological requirements;
- use of land suitability classifications and current soil characteristics for the development of AEZs.

Figure 4 explains the relationship between these activities and their component procedures. The final and intermediate methodology can then be applied in a sequence of more advanced applications which are determined according to the objectives of the study as described on page 3. The present chapter describes how to apply the procedures for the AEZ application, leading to an assessment of land suitability and potential productivity with particular reference to crop-based production systems according to agro-climatic conditions.

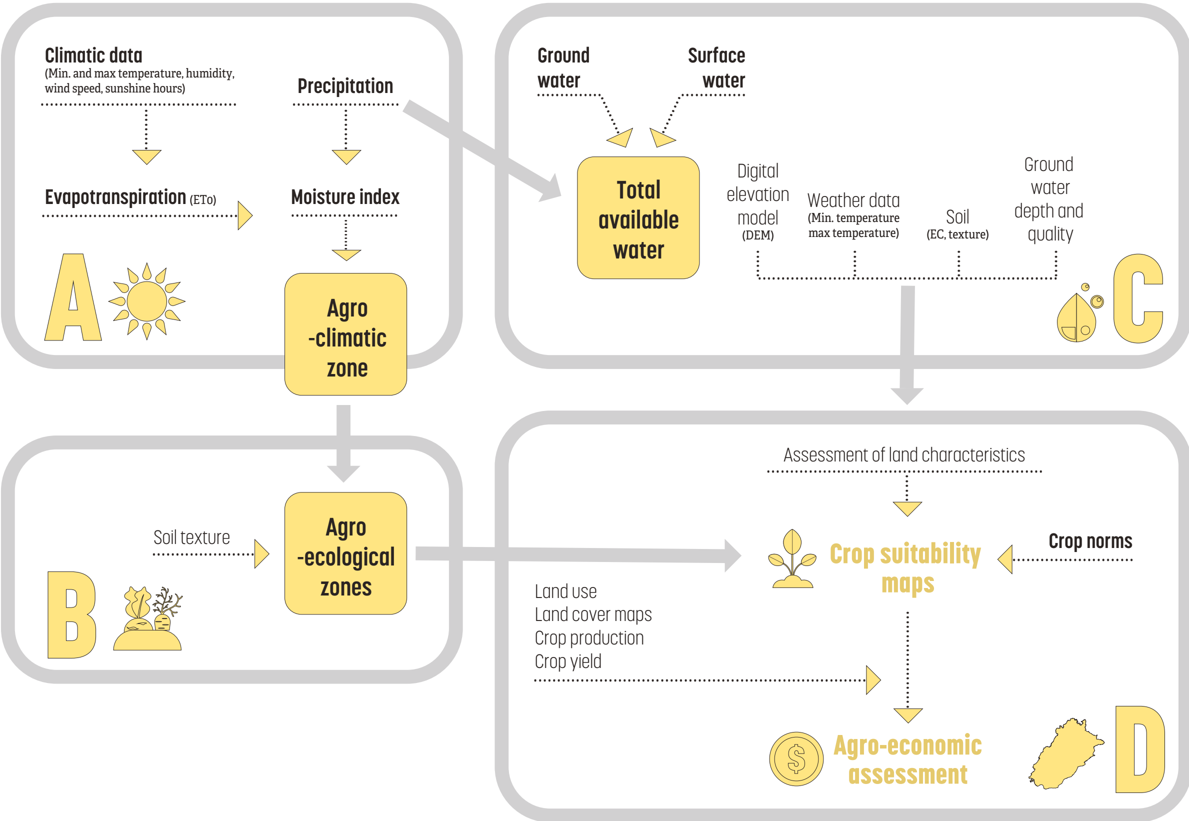


Figure 4. Methodology flow chart

Step 1 - Preparation of agro-climate zones
For delineation of agro-climatic zones; first, evapotranspiration (ET_0) was calculated by using data inventory of maximum temperature, minimum temperature, wind speed, sunshine hours and humidity. A moisture index was then calculated by resultant ET_0 with rainfall, as listed in Figure 4 section A.

Step 2 - Delineation of agro-ecological zones
Redefining AEZs was based on the moisture index calculated by using ET_0 and rainfall with an overlay of analysis of soil texture. The data were acquired from concerned departments, such as climate data from Pakistan Meteorological Department (PMD); soil data from the Institute of Soil Fertility, Department of Agriculture, Punjab were not based on the same grid size. To resolve this problem, all the data has been converted into the same grid size of 100 m. The same grid size means that at each point we can have information on climate and soil. Therefore, the AEZ model has been developed based on the data availability of all input parameters at each grid. The procedure for developing a high-resolution database for each input parameter having a grid size of 100 m × 100 m is explained in detail in the Geostatistical section.

Step 3 - Assessment of land characteristics
To assess land characteristics, we used different data layers, such as groundwater depth, surface water availability, maximum temperature, minimum temperature, soil properties and digital elevation model as illustrated in Figure 4, section C.

Step 4 - Land suitability and potential
Assessment of land suitability was carried out through a combination of matching constraints with crop requirements, and by modeling of potential biomass production and yield under constraint-free conditions as shown in Figure 4 section D. This activity is normally carried out in two main stages; first, the agro-climatic suitability is assessed, and second, the suitability classes are adjusted according to edaphic or soil constraints. In agro-climatic suitability, attributes of temperature regimes to crop requirements for photosynthesis and phenology, as reflected by the crop groups, were used to determine which crops qualifies for further consideration in the evaluation.

A range of land uses and land covers should be selected to reflect current land use and/or land use under a projected improved situation. All subsequent assessments of land suitability and potential productivity carried out as part of the AEZ study will refer to these specific land use types as practiced in defined AEZs.

The agricultural exploitation of the climatic potential of crops depends on the soil properties, and on how the soil is managed. In many places, the impact on soil is caused by changing climate action and, as a result, the interaction between climate and soil in most instances has a mutual effect on enhancing crop productivity. The close interrelation of climate (zonal), soil and plants help in assessments of land suitability. This compound activity is comprised of the following variables:

- define thermal zones;
- compile climatic resource inventory;
- compile soil and landform resource inventory;
- compile present land use and land cover inventory.

Integrate the above to make a land resources inventory based on AEZs.

2 Description of agro-ecological zones input datasets

2.1 Topography

The Advanced spaceborne thermal emission and reflection radiometer (ASTER) instrument on board the National Aeronautics and Space Administration (NASA)'s Terra spacecraft has an along-track stereoscopic capability using a near-infrared spectral band to acquire the stereo data. ASTER has two telescopes, one for nadir-viewing and another for backward-viewing, with a base-to-height ratio of 0.6. The spatial resolution is 15 m in the horizontal plane. Parameters such as the line-of-sight vectors and the pointing axis were adjusted during the initial operation period to generate Level-1 data products with a high-quality stereo system performance. The evaluation of the digital elevation model (DEM) data was carried out by both Japanese and U.S. science teams separately, using different DEM generation software and reference databases. The vertical accuracy of the DEM data generated from the Level-1A data is 20 m with 95 percent confidence without ground control point (GCP) correction for individual scenes. Geolocation accuracy that is important for the DEM datasets is better than 50 m. This appears to be limited by the spacecraft position accuracy. In addition, a slight increase in accuracy is observed by using GCPs to generate stereo data.

2.2 Soil data

The soil is a key element of agriculture, without which we could not grow plants. Each type of soil is not suitable for each crop due to the effect of different crop growth factors. Soil conditions and characteristics are one of the key factors that directly drive crop growth potential and thus, a soil data set is key information when developing agro-ecological zones. Important soil characteristics like soil electrical conductivity (EC), soil pH, and soil texture were added in the current exercise of developing AEZ of Punjab, Pakistan. The point data for these soil characteristics were obtained from the Institute of Soil Fertility Research (IFS), Department of Agriculture Research, Punjab, Lahore; the information from more than 0.283 million locations or sampling points were provided by IFS. These soil data were collected after point-to-point sample collection through core method and laboratory analysis established in each district of the province. The procedures and methodology followed for laboratory analysis of soil samples are given below:

SOIL SAMPLING PROCEDURE

Soil samples were collected following stratified, random as well as free soil survey design throughout the province. The samples were collected manually through soil augers from a depth of 30 cm and compost samples were sent to laboratories established in each district to conduct analysis for basic soil characteristics.

SOIL MOISTURE PERCENTAGE

Soil saturated paste was put in an oven at 105 ˚C and dried until a constant dry weight was achieved. Saturation moisture percent was determined by the following equation:

$$\text{Soil moisture \%age} = \frac{\text{Loss in weight on oven drying (g)}}{\text{Oven-dried soil weight (g)}} \times 100$$

SOIL pH

A soil sample of convenient size was taken in a bottle and the required amount of distilled water was added to prepare a 1:5 suspension. After agitating the suspension in a mechanical shaker for 15 minutes, the contents were allowed to stand for at least an hour, agitated again for 5 minutes, and filtered. For soil pH determination, a soil suspension with ratio 1:5 was prepared using distilled water and shaking intermittently for an hour. The pH reading was recorded by digital pH meter (WTW pH 315i) after calibrating with a series of standard buffer solutions of pH 4.00, 7.00 and 9.00.

Sr. No.	Dataset	Source
1	Topography	30m ASTER-GDEM
2	Soil data (soil, texture, EC, pH)	Government of Punjab, Pakistan
3	Climatic data (maximum temperature, minimum temperature, wind speed, humidity, sunshine hours)	Pakistan Meteorological Department
4	Rainfall	Pakistan Meteorological Department
5	Land cover and land use	FAO
6	Groundwater quality data (EC, SAR, RSE)	PIDA, Government of Punjab
7	Groundwater depth	PIDA, Government of Punjab
8	Surface water	PIDA, Government of Punjab
9	Admin boundaries	UAAR-IGEO Repository
10	Crop production and yield data	Crop Reporting Survey, Government of Punjab

Table 1. Agro-ecological zones input dataset

SOIL EC

Electrical conductivity (EC) is commonly used for indicating the total concentration of the ionized constituents of solutions. It is closely related to the sum of the cations (or anions) as determined chemically and usually correlates closely with the total dissolved solids. Soil EC is one of the major criteria for the assessment of soil salinity and sodicity problem in the soil as it gives the direct estimate of total soluble salts in the soil solution. Soil EC was determined from the suspension as prepared for pH measurement; the electrode of EC meter (WTW Cond 315i) was dipped in the suspension and EC of the suspension was recorded in dSm-1.

SOIL TEXTURE

The hydrometer method (Bouyoucos, 1962) was used for particle size analysis. To make the dispersion solution, 10 g of sodium hexametaphosphate [(NaPO3)6] and 2.5 g of sodium carbonate [Na2CO3] were dissolved in 250 ml of distilled H_2O. Then, a 40 g air-dried soil sample was put into a 600 ml beaker and a 60 ml dispersion solution was mixed into it. After that, the mixture was covered and left for 24 hours. On the following day, the mixture was put into the soil-stirring cup and stirred at high speed. After stirring, this material was transferred into a 1 liter calibrated cylinder and the total volume was filled up to the position of the mark by adding de-ionized water.

2.3 Climate data

Climate plays a significant role in crop production, crop growth duration, crop water requirements, and irrigation scheduling. The agricultural land area is determined by climate and water availability (Kahlown & Ashraf, 2005). Potential evapotranspiration (ET_o) is a representation of the environmental demand for evapotranspiration and represents the evapotranspiration rate of a short green crop (grass). It is a reflection of the energy available to evaporate water, and of the wind available to transport the water vapor from the ground to the lower atmosphere. Evapotranspiration is a major constituent of the hydro cycle. Thus, it is a transfer of water to the atmosphere by evaporation from the soil and transpiration from plants. Evapotranspiration varies for different vegetation types under various climatic conditions. The average annual rainfall in Pakistan is very low (250 mm). Most of the crops in Punjab require irrigations at different stages of growth. Due to increases in temperature, the evapotranspiration rate becomes higher and water is transformed into vapor.

There are four methods generally used to determine potential crop evapotranspiration (ET_0). These are: (i) Blaney-Criddle, (ii) radiation, (iii) Penman, and (iv) pan evaporation methods. In the present study, a modified-Penman method is used as it offers the best results with minimum errors (Ahmad, 1985). For areas such as Punjab, where measured data on temperature, humidity, wind speed, and sunshine duration or radiation are available, an adaptation of the Penman method provides the most reasonable results. The original Penman equation predicts evaporation losses from an open water surface (E_0). Experimentally determined crop coefficients are used to determine ET of crops. The Food and Agriculture Organization of the United Nations (recently recommended the Penman-Monteith method as the standard method. Climatic data used for the Penman-Monteith method is: minimum air temperature, maximum air temperature, relative humidity, sunshine duration, and wind speed. The formula for this method is as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where:

ET_o = reference evapotranspiration (mm/day)
Rn = net radiation at the crop surface (MJ/m²/day)
G = soil heat flux density (MJ/m²/day)
T = mean daily air temperature at 2 m height (°C)
u2 = wind speed at 2 m height (m/s)
es = saturation vapour pressure (kPa)
ea = actual vapour pressure (kPa)
es - ea = saturation vapour pressure deficit (kPa)
Δ = slope vapour pressure curve (kPa/°C), and
γ = psychrometric constant (kPa/°C).

The analysis of the performance of various algorithms revealed the need for formulating a standard method for the computation of the reference crop evapotranspiration. For this reason, the FAO Penman-Monteith method (Kaleemullah *et al.*, 2001) has been recommended as a standard. The ET_0 of Punjab was calculated using the UAAR Spatial ET_0 Calculator which uses the Penman-Monteith methods for calculating reference crop evapotranspiration (Allen *et al.*, 1998).

2.4 Data requirements for evapotraspiration calculation

The following data of the different weather stations of Punjab were collected from 19 meteorological stations installed in Punjab by Pakistan Meteorological Department (on a daily basis) and were used as input for the calculation of ET_0.

- maximum/minimum temperature;
- relative humidity;
- wind speed; and
- sunshine hours.

The rainfall data were also collected for the same period to determine moisture regime for delineation of agro-climatic zones.

2.5 Land cover and land use

Land cover refers to the surface cover on the ground, whether vegetation, urban infrastructure, water, bare soil or other. Identifying, delineating and mapping land cover is important for global monitoring studies, resource management, and planning activities. Identification of land cover establishes the baseline from which monitoring activities (change detection) can be performed, and provides the ground cover information for baseline thematic maps. Land use refers to the purpose the land serves; for example, recreation, wildlife habitat, or agriculture. Land use applications involve both baseline mapping and subsequent monitoring, since timely information is required to know what type of use currently applies to a particular quantity of land; and to identify land use changes from year to year. Land cover and land use data prepared on the spatial resolution of 10 m for 2000–2014 were obtained from the FAO database.

2.6 Surface water availability

The Indus Basin Irrigation System (IBIS) is a supply-based irrigation system with prior water rights allocated according to landholding. The irrigation water allocation to the farmers is managed through a 'Warabandi' (turn) system that delivers water to crops without consideration for crop stage and its water requirement. It is a rotational method for equitable distribution of the available water in an irrigation system by turns that are fixed according to a predetermined schedule specifying year, day, time and duration of supply to each irrigator in proportion to the size of farmers' landholding in the outlet command. IBIS, the largest contagious irrigation system in the world, has the delivery efficiency of only 36 percent (Hussain *et al.*, 2011). Apart from the constraint from the supply-based nature of the system, the hydrological variability in the systems due to precipitation patterns is not addressed through storage, leaving the IBIS with a limited storage capacity of flow for only 28 days. The Water apportionment accord of 1991 controls inter-provincial water distribution and the variability of water allowance across canal systems which influences the cropping pattern. Due to regular high seepage from the upstream of the canal system, regular recharge provides the way for farmers growing rice. Table 2 shows the water allowance and gross command area of different canals in Punjab.

Canal name	Water allowance (cusec/1000 acres)	Gross command area (mha)
Thal Canal	2.23	1.090
Upper Jhelum Canal	2.86	0.269
Lower Jhelum Canal	3.04	0.706
Marala Ravi Canal	12.30	0.066
Upper Chenab Canal	7.27	0.434
LCC (Jhang Branch +Gugera)	3.17	1.530
Raya Branch (BRBD Internal)	7.01	0.179
Central Bari Doab Canal	9.01	0.315
Lower Bari Doab Canal	4.25	0.762
Rangpur Canal	6.91	0.158
Upper Dipalpur Canal	4.95	0.172
Lower Dipalpur Canal	6.52	0.248
Muzaffargarth Canal	8.14	0.323
Sidhnai Canal	5.26	0.347
Pakpattan Canal	5.88	0.455
Fordwah	6.41	0.215
Dera Ghazi Khan Canal	8.61	0.44
Mailsi Canal	5.68	0.435
Sidiquia Canal	4.26	0.466
Bahawal Canal	6.85	0.325
Abbasia Canal	6.90	0.065
Panjnad Canal	6.09	0.598

Table 2. Water allowance of different canals

2.7 Groundwater irrigation

Since the 1970s, the use of groundwater has increased in the agriculture sector, with the number of tube wells grown to more than 1.0 million. Groundwater not only supplies additional water to fulfill irrigation deficits but also provides flexibility to match crop water requirements. Extensive groundwater use by the private sector (with six percent annual growth) can cause saline water to contaminate freshwater aquifers by the excessive lowering of water tables in fresh groundwater areas. The continued abstraction of groundwater has resulted in over-pumping and consequent depletion of water tables in many areas. Recently, this problem has become more serious due to the continued and extended drought faced by the country. The more noticeable areas affected by these problems are Lahore, some parts of Balochistan, and some densely populated urban areas of Sindh and Punjab. It is reported that in 26 canal commands, the water table is getting lower with various degrees of depletion. Those canal command areas are most affected where water allowances are lower and crops are heavily dependent on tube-well irrigation.

The groundwater of acceptable quality has the potential to provide the flexibility of water supply in canal commanded areas and to extend irrigation to rain-fed areas. There is a potential for further utilization of lower quality groundwater supported by careful management strategies if conjunctive surface and groundwater use can be implemented properly there. Consequently, the existing policy issues now relate to the development of legal frameworks for groundwater exploitation that should be environmentally sustainable and viable on a long-term basis.

2.8 Methodology to map surface and groundwater resources in Punjab

The hierarchy of the surface water supply system includes the main canal, branch canals, major and minor distributaries, watercourses and farmer field channels. The major canals take off from the river and there is no direct watercourse for irrigation: watercourse outlets are from the distributaries and minors. Minors are mostly designed in the areas where the length of the watercourse is going to increase more than three km. The command area of the watercourse is in the range of 400 acres to 500 acres. The discharge of each watercourse was converted into the depth of the water availability. Water distribution at the watercourse level was considered equal. The simple model of discharge over the area was considered for the estimation of the depth of water. This high-resolution data was then further interpolated using the ordinary kriging in the ArcGIS based on the system design and the rigid supply from the water distribution system to the fields. The rigid supply-based water distribution made it easier to apply the simple, ordinary kriging to interpolate the watercourse command-based point data into the spatial information for the whole of Punjab.

Spatially, the distribution of groundwater irrigation in the Punjab data was estimated by applying the water balance approach in the unsaturated form media. Thus, total water availability was estimated by examining all the resources at the high spatial scale in the ArcGIS.

2.9 Geostatistical analysis

In this study, a 100 m spatial resolution grid was used for the empirical Bayesian kriging interpolation technique exploring the correlation of various climatic variables. For an accuracy assessment of interpolation, 90 percent of data were used during the interpolation process, then the remaining 10 percent data were used for regression analysis for validation of interpolated results. During the interpolation of different variables topography (digital elevation model) was also used for more analytical results.

Empirical bayesian kriging (EBK) is a geostatistical interpolation method that automates the most difficult aspects of building a valid regression kriging model. Other kriging methods in geostatistical analysis require a manual adjustment to parameters to receive accurate results, but EBK automatically calculates these parameters through a process of subsetting and simulations.

Empirical bayesian kriging also differs from other kriging methods by accounting for the error introduced by estimating the underlying semivariogram. Other kriging methods calculate the semivariogram from known data locations and use this single semivariogram to make predictions at unknown locations; this process implicitly assumes that the estimated semivariogram is the true semivariogram for the interpolation region. By not taking the uncertainty of semivariogram estimation into account, other kriging methods underestimate the standard errors of prediction.

Empirical bayesian kriging is offered in the geostatistical wizard and as a geoprocessing tool. The semivariogram may be mathematically described as the mean square variability between two neighboring points of distance as shown in the following equation:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i + h) - z(x_i)]^2$$

where γ (h) is the semivariogram expressed as a function of the magnitude of the lag distance or separation vector h between two points, N (h) is the number of observation pairs separated by distance h and z (xi) is the random variable at location xi. The experimental semivariogram, γ (h) is fitted to a theoretical model such as spherical, exponential, linear, or gaussian to determine three parameters, such as the nugget (c0), the sill (c) and the range (A0). These models were defined by Isaaks and Srivastava (1989). The improved interpolated maps were further considered in GIS for the extraction of point data at the resolution of 0.005°.

CLIMATIC VARIABLES

Climatic maps were prepared by using 90 percent of data during empirical bayesian kriging in ArcGIS 10.3.1 software with 100 m resolution. During the interpolation of one parameter the remaining variable was used for their reverse impact.

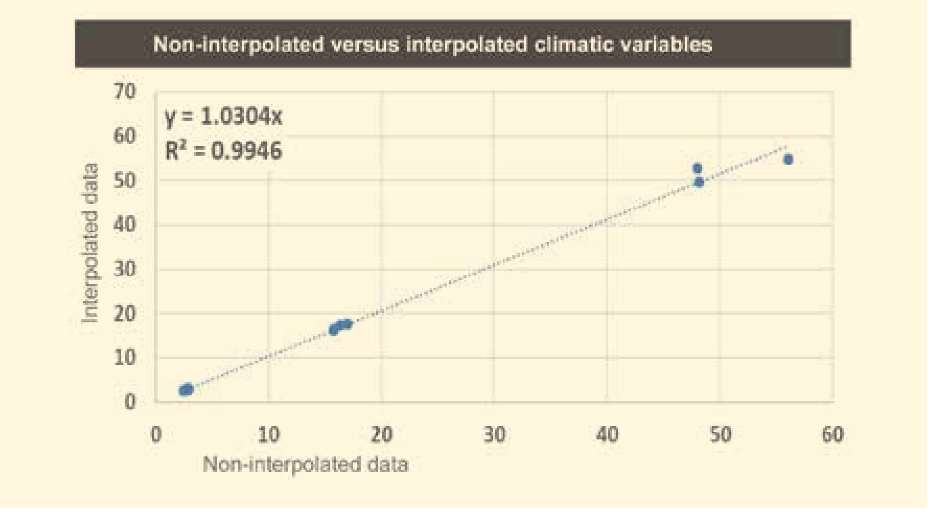
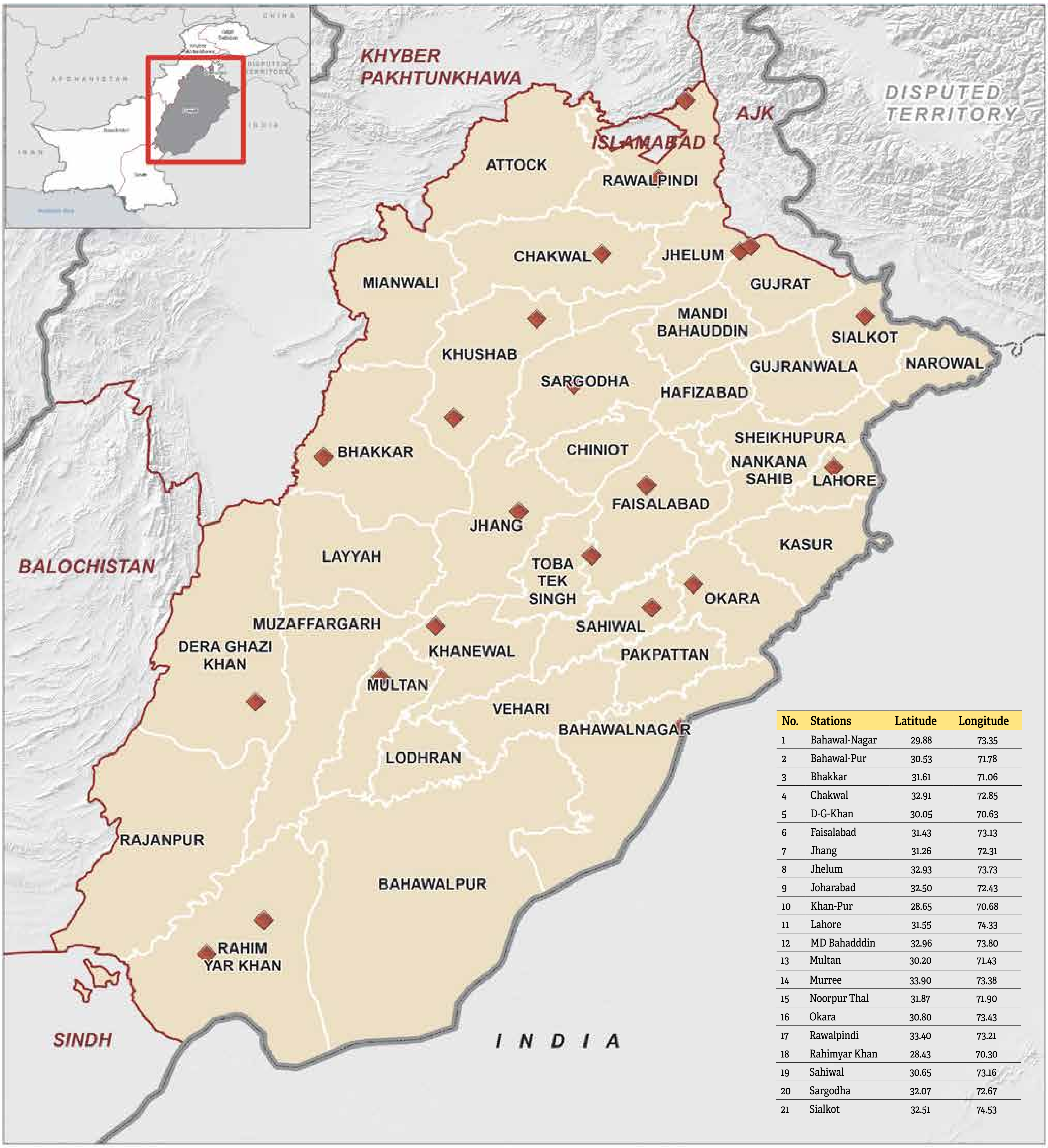


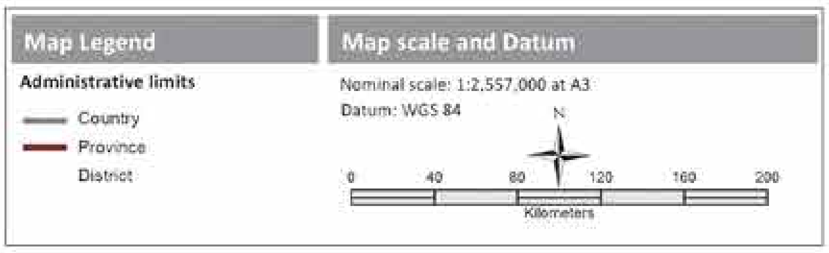
Figure 5. Validation of interpolation for climatic data

For validation of the interpolation method, about 10 percent of data were not used during the interpolation process; interpolated results were then interpolated on that particular location where we withdrew 10 percent data. Regression analysis was then interpolated and non-interpolated with R^2 of 0.9946.



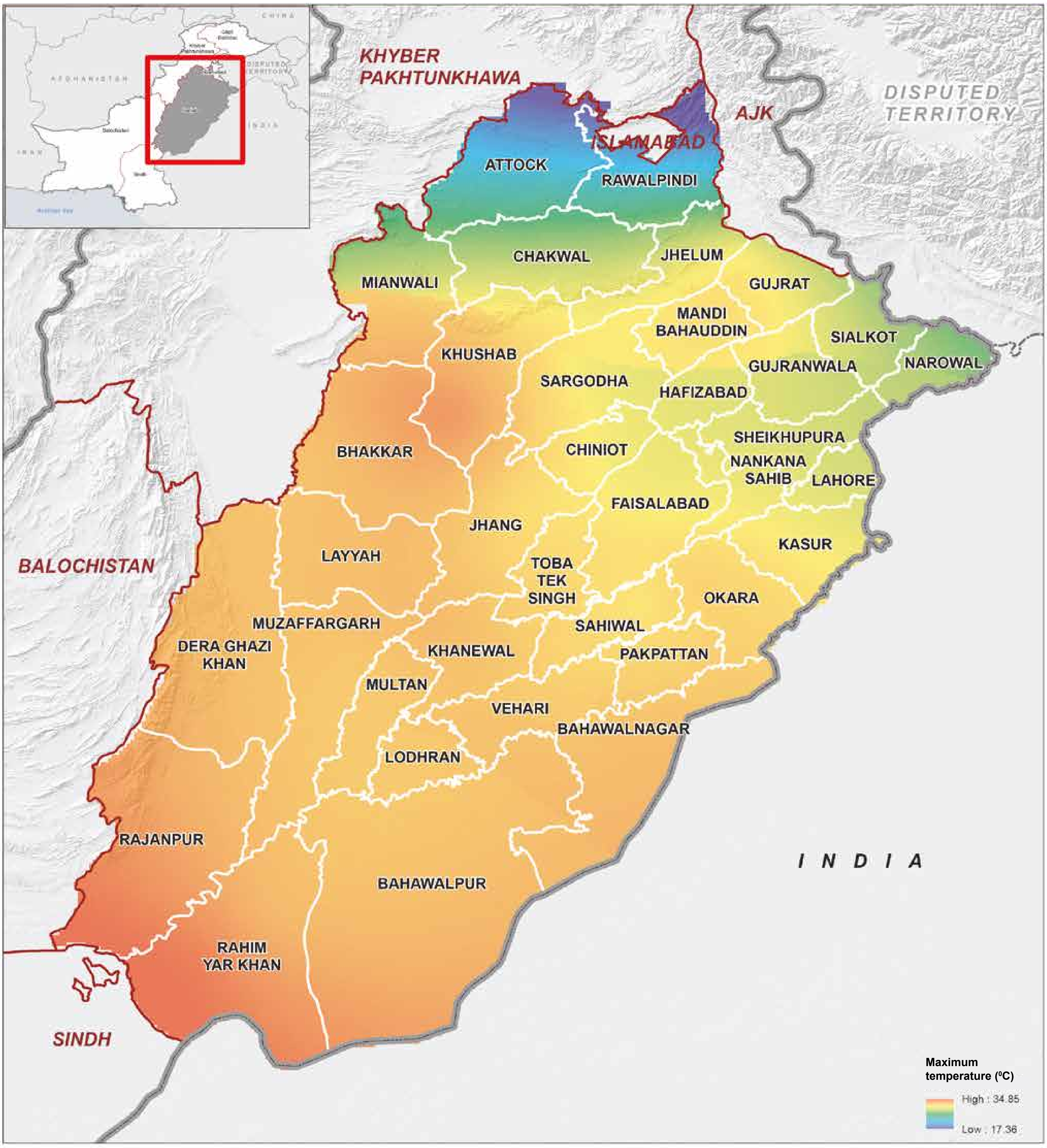
No.	Stations	Latitude	Longitude
1	Bahawal-Nagar	29.88	73.35
2	Bahawal-Pur	30.53	71.78
3	Bhakkar	31.61	71.06
4	Chakwal	32.91	72.85
5	D-G-Khan	30.05	70.63
6	Faisalabad	31.43	73.13
7	Jhang	31.26	72.31
8	Jhelum	32.93	73.73
9	Joharabad	32.50	72.43
10	Khan-Pur	28.65	70.68
11	Lahore	31.55	74.33
12	MD Bahadddin	32.96	73.80
13	Multan	30.20	71.43
14	Murree	33.90	73.38
15	Noorpur Thal	31.87	71.90
16	Okara	30.80	73.43
17	Rawalpindi	33.40	73.21
18	Rahimyar Khan	28.43	70.30
19	Sahiwal	30.65	73.16
20	Sargodha	32.07	72.67
21	Sialkot	32.51	74.53

Map created by: IM Unit, FAO Pakistan. Data sources: FAO, Government of Punjab, GAUL. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
*Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.



Location of weather stations in Punjab

Spatial distribution of weather station data points used in this study. A total of 19 weather stations were used for collection of weather data (minimum temperature, maximum temperature, wind speed, sunshine hour, humidity and rainfall). The table on the bottom left corner reports spatial and tabular information of each.



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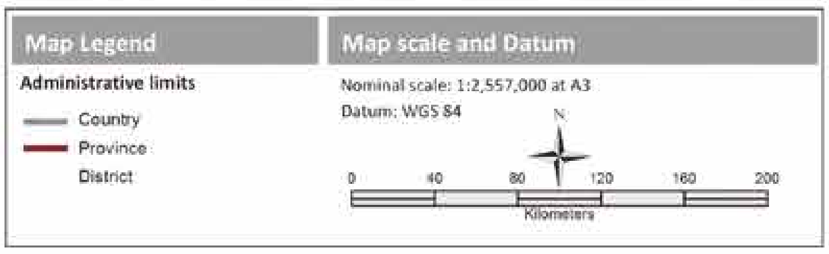
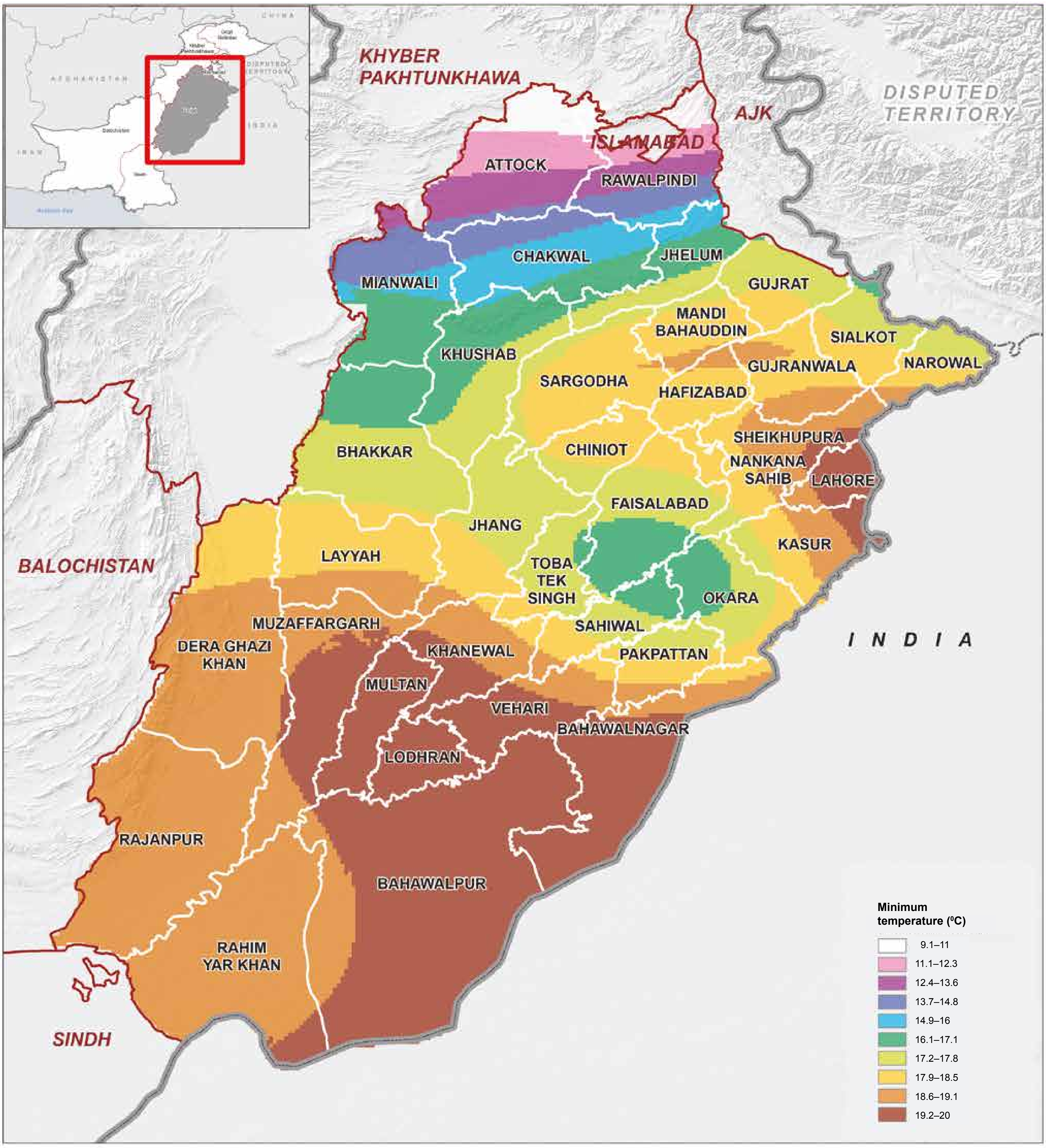


Maximum annual temperature in Punjab

Average maximum–maximum temperature observed in Rahim Yar Khan (32.9 °C), Rajanpur (33.5 °C), Bhakkhar (33.4 °C), Faisalabad (29.5 °C), Chakwal (27.8 °C), DG Khan (31.3 °C), Murree (17.6 °C), Rawalpindi (20.4 °C), Narowal (26.5 °C) and Gujrat (29.8 °C).



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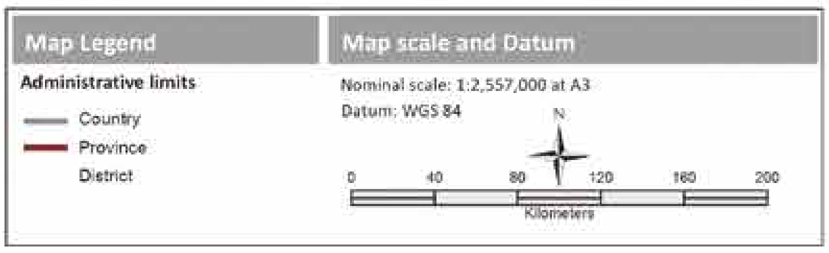
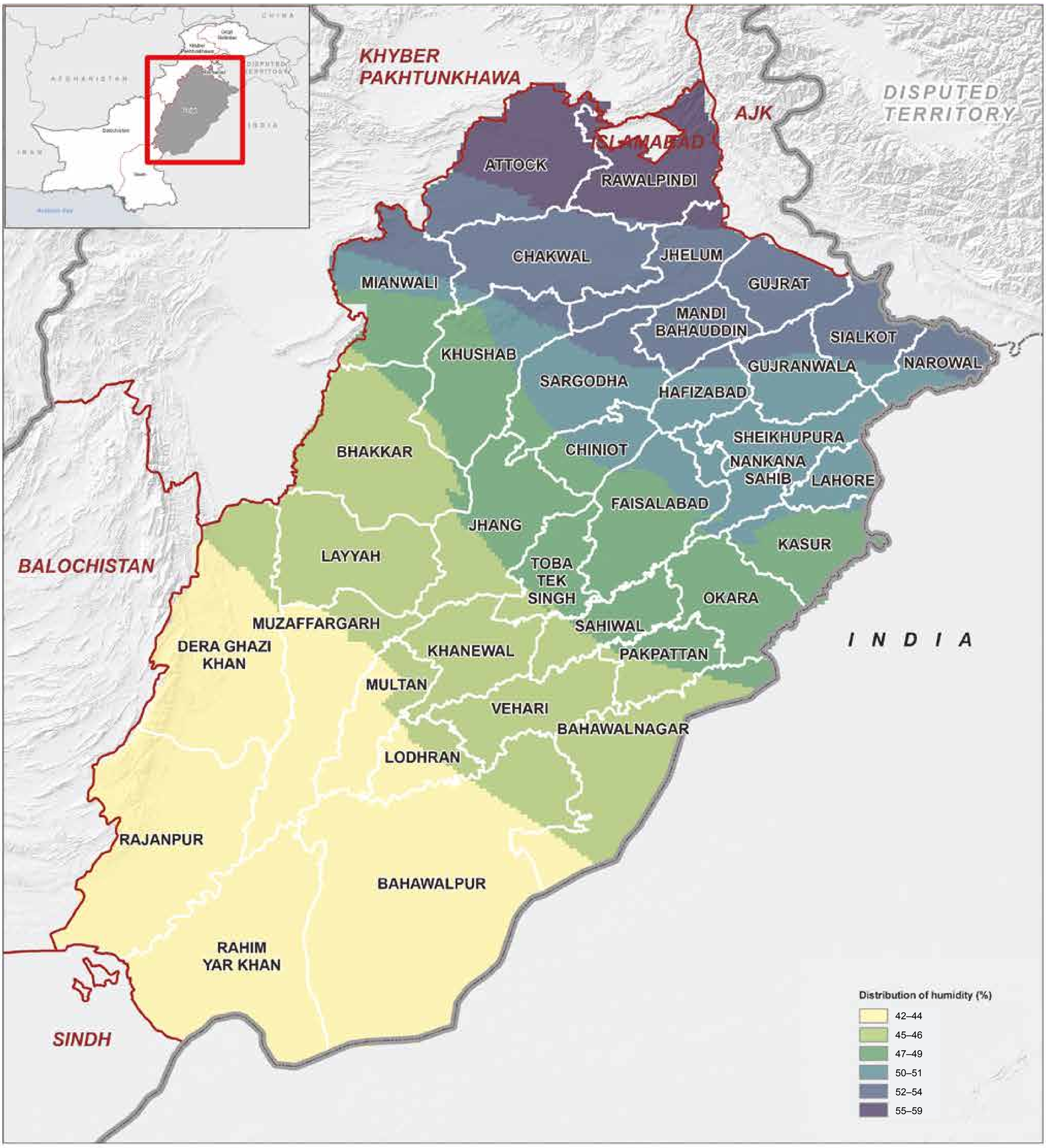


Minimum annual temperature in Punjab

The variation of the minimum temperature is significant with the variation observed in Murree (12.4 °C), Rawalpindi (13.5 °C), Gujrat (16.8 °C), Narowal (17.8 °C). The minimum–maximum temperature was observed in Bahawalpur (18.8 °C), Lahore (19.8 °C), D.G Khan (19.2 °C).



Map created by: IM Unit, FAO Pakistan. Data sources: FAO, Government of Punjab, GAUL. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
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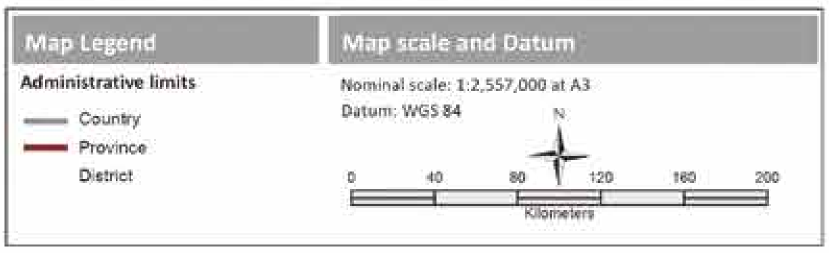
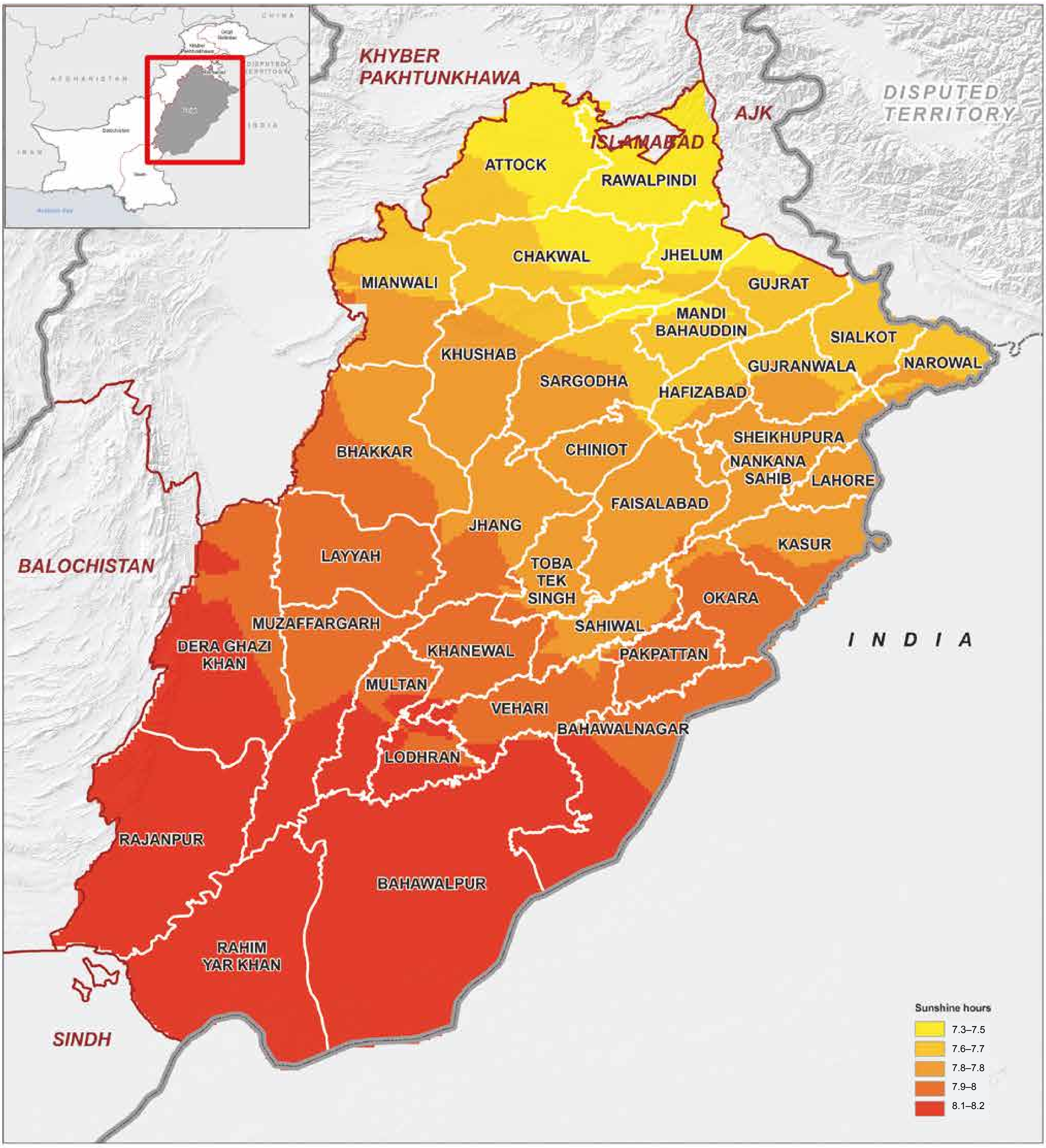


Humidity in Punjab

During the study, maximum humidity was observed in the upper side of Punjab (Murree, Rawalpindi, and Attock) and minimum humidity was observed in the area of Punjab where temperatures were high.



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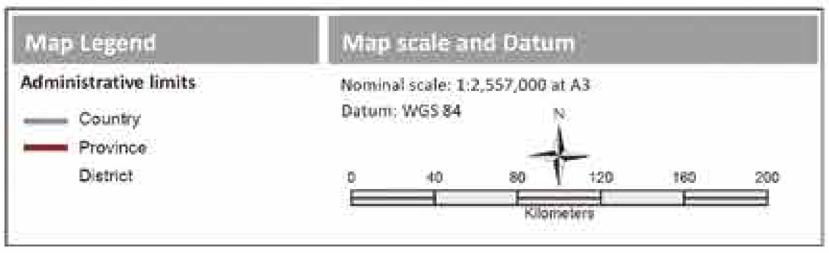
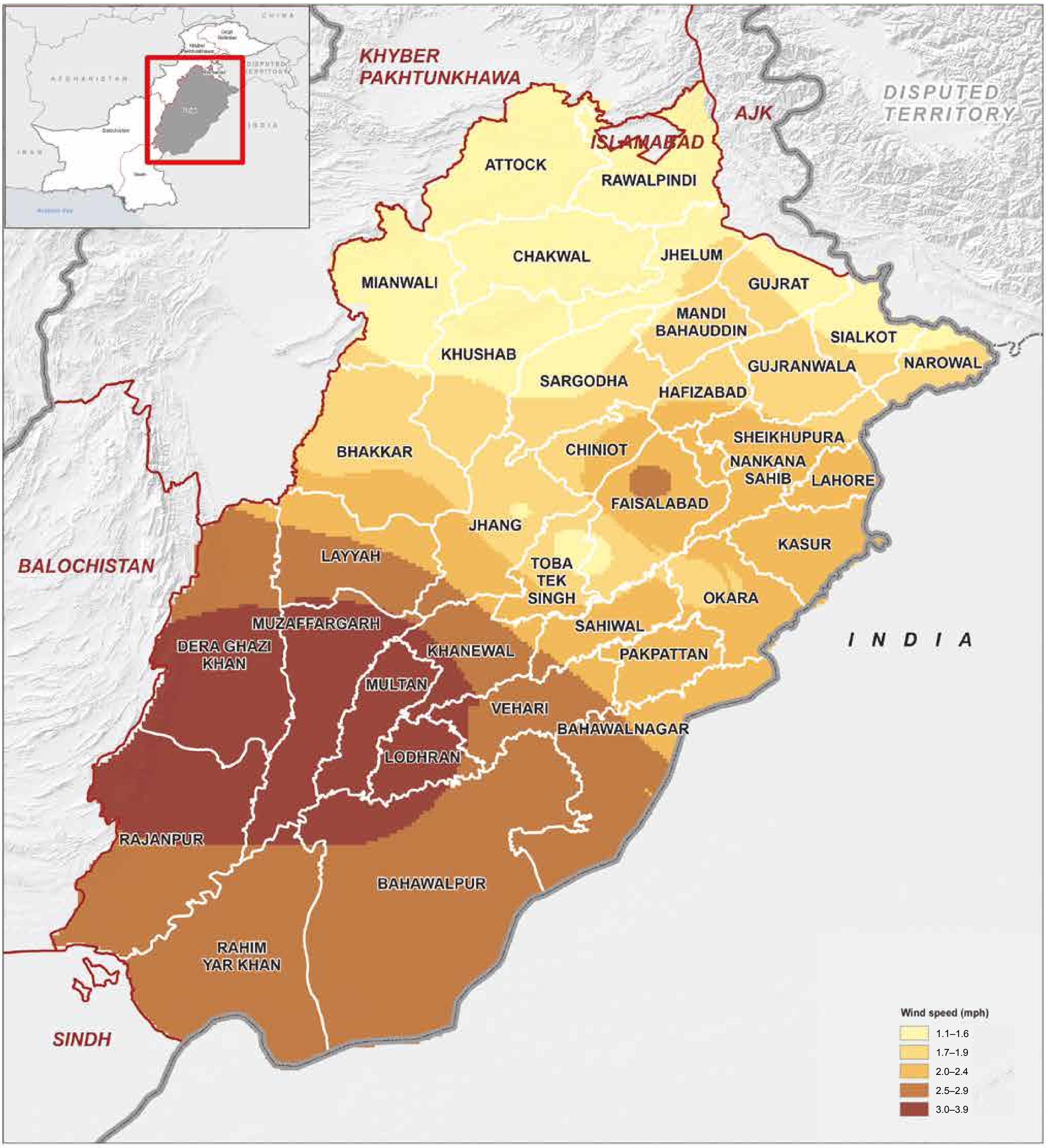


Sunshine hours in Punjab

Sunshine hours averaged a maximum 8.18 in district Rajanpur and the minimum sunshine hours were in Rawalpindi district at 7.2.



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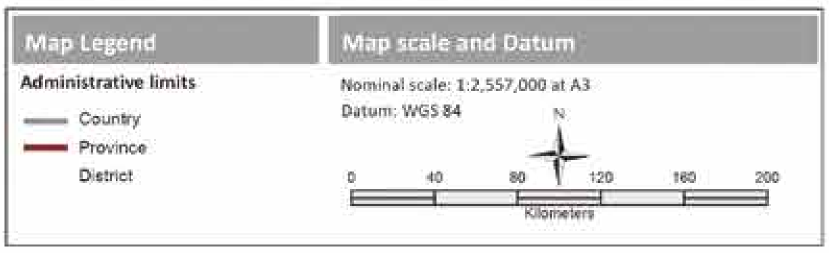
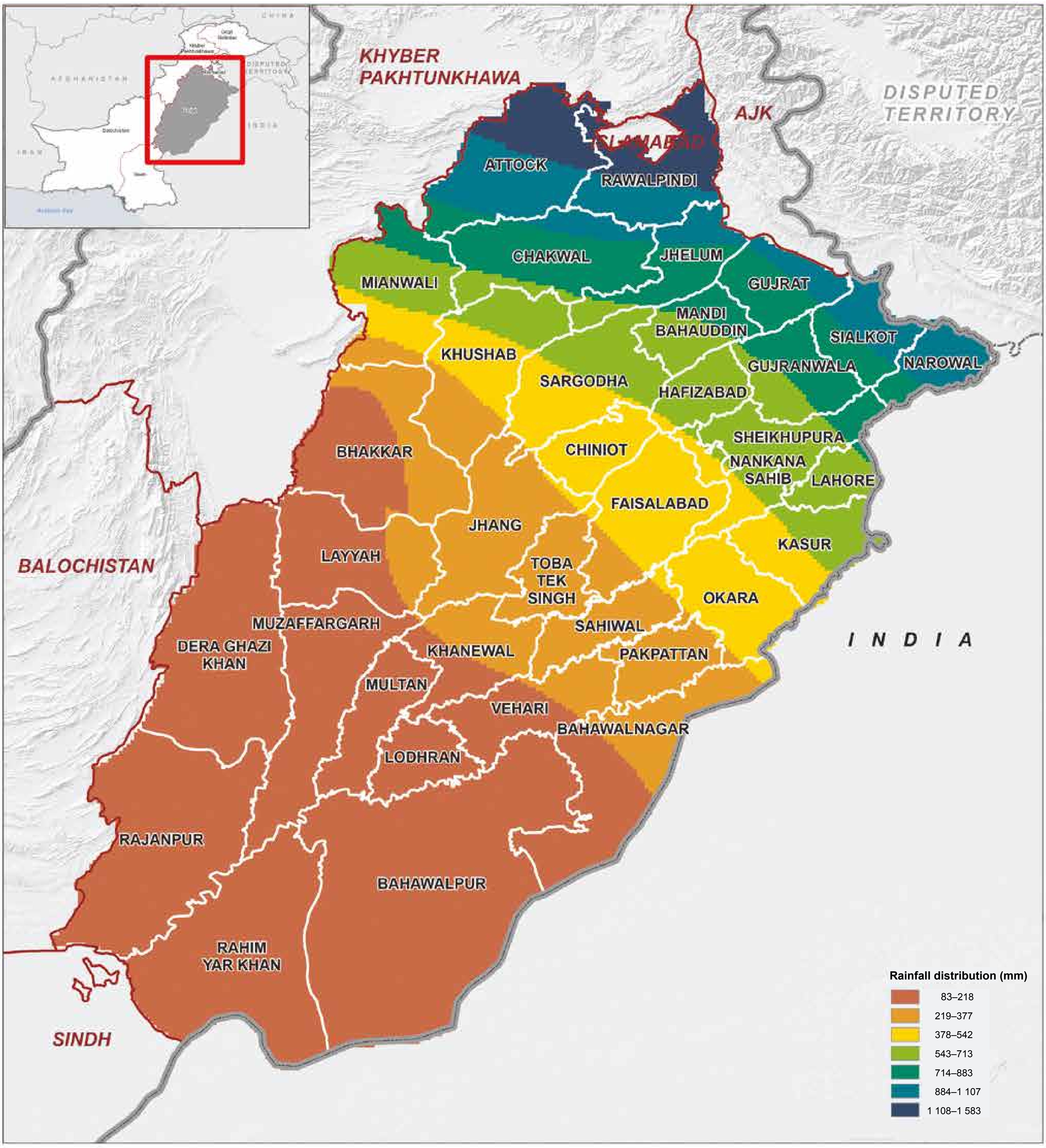


Wind speed in Punjab

The maximum wind speed was observed in Muzaffargarh (3.9 5 mph) and the minimum wind speed was observed in Murree (1.08 mph).



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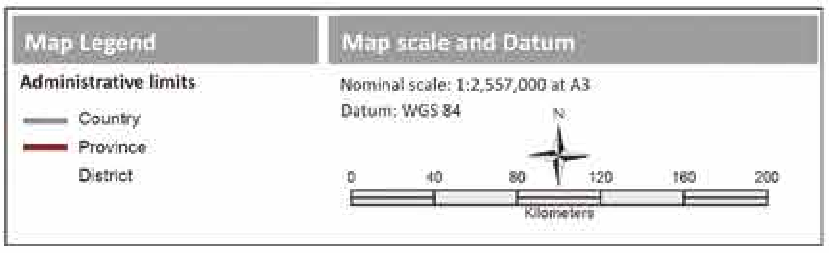
Rainfall distribution in Punjab

Rainfall variability of Punjab was observed in a gradually increasing trend from south to north, about 1 000 mm to 1 500 mm rainfall was mapped in the upper four districts (Rawalpindi, Attock, Jhelum, and Chakwal) of Punjab. The lower or southern part of Punjab has received a very low amount of rainfall due to aridity, about 300 mm to 180 mm rainfall mapped in Rajanpur and DG Khan districts.



2.10 Soil data

The government of Punjab conducted a GPS based survey of all of Punjab for collection of soil parameters (EC, pH, P, K N, and texture). About 0.283 million points were collected from across Punjab. After a survey of soil data, a soil density rate per unit area was calculated as shown in the Density map on the right.

For cross-validation of the interpolation method, about 10 percent of data were not used during the interpolation process; then, interpolated results were extracted from the location where we withdrew the 10 percent data. We then drew regression analyses that were interpolated and non-interpolated. The map below shows that about R^2 is 0.8755, its mean interpolation results of soil data were observed with 87 percent accuracy.

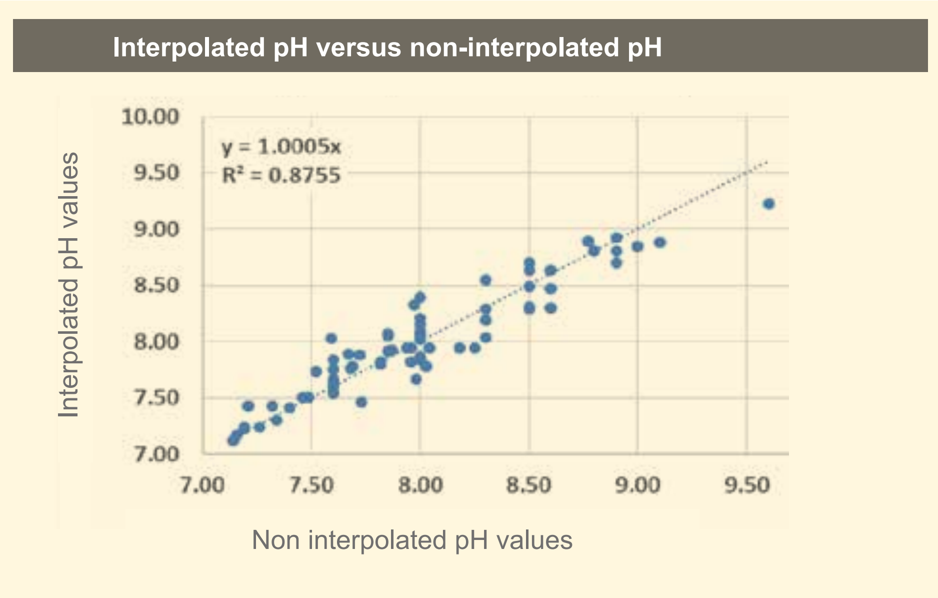
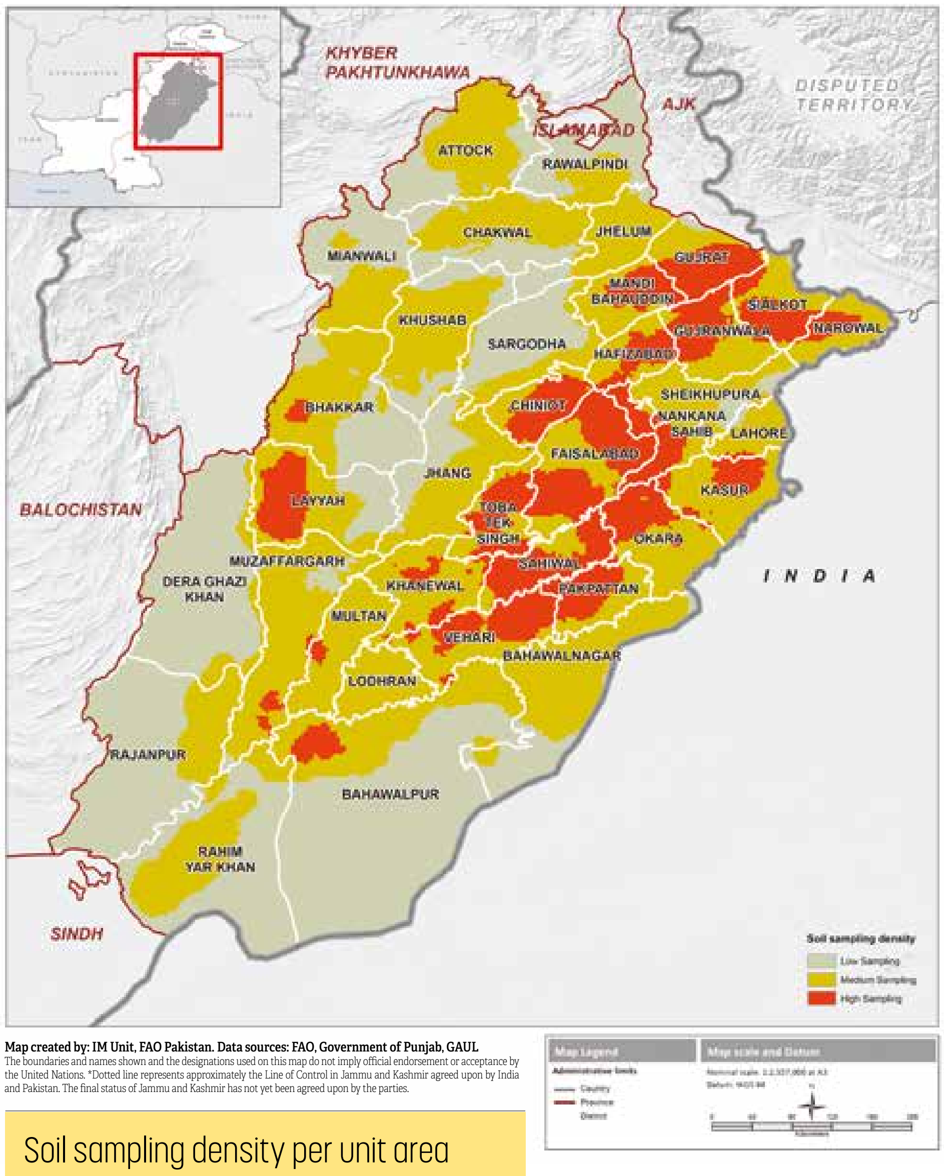
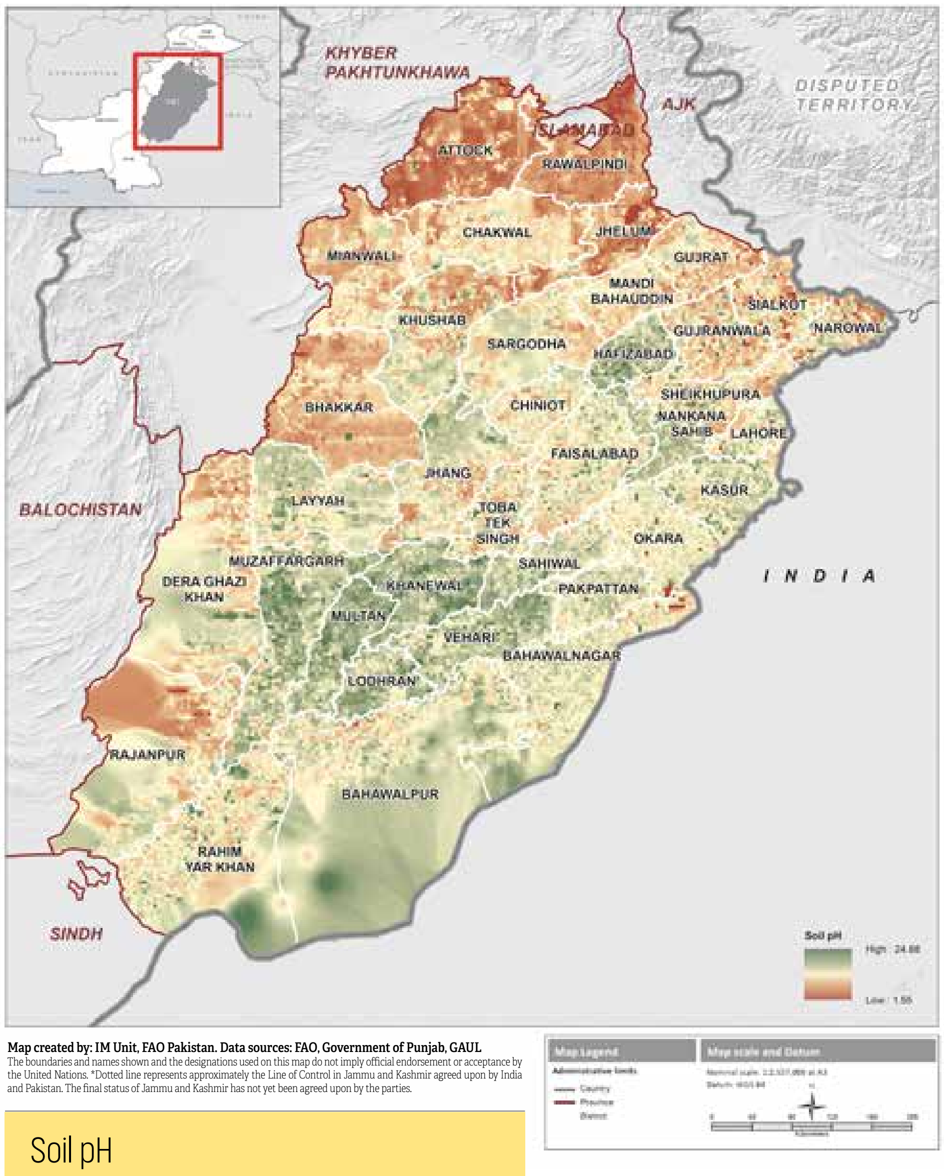


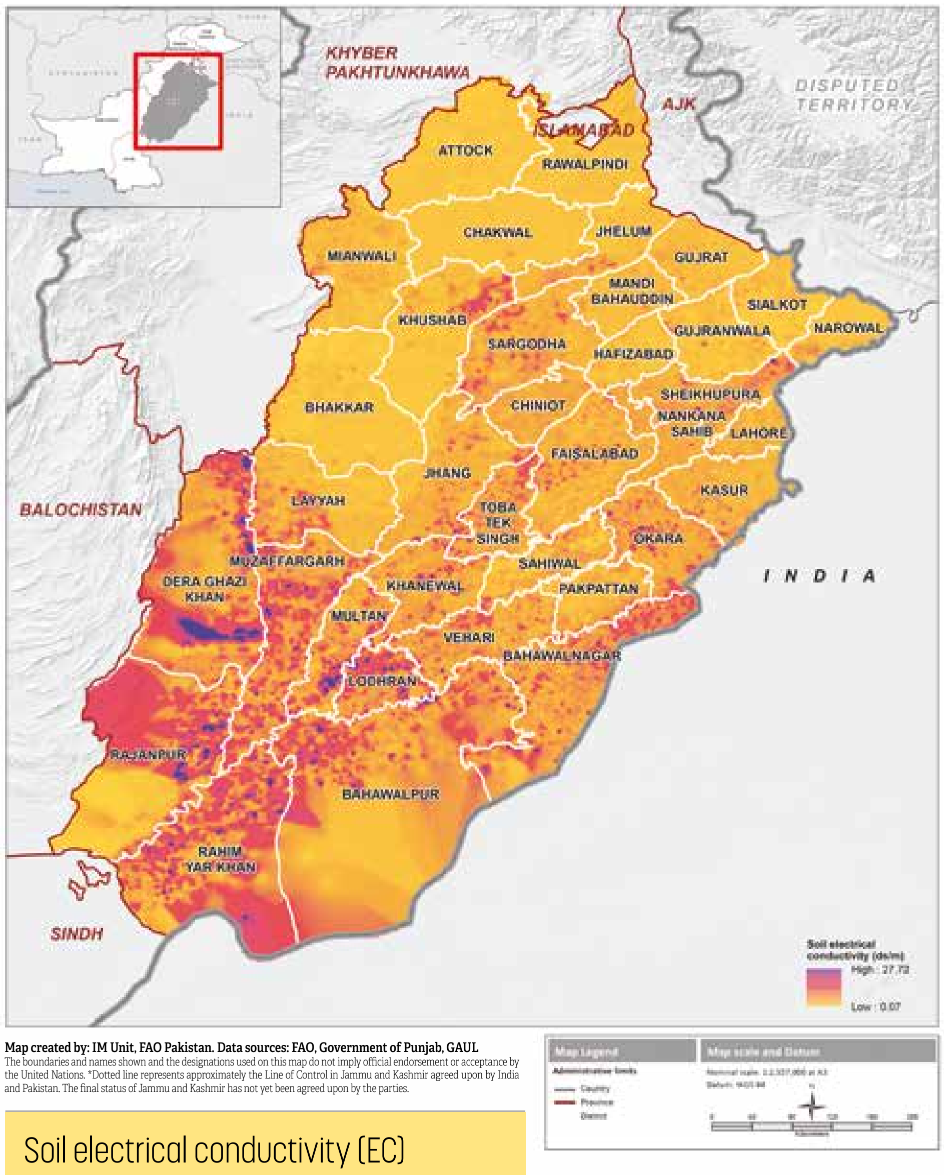
Figure 6. Validation of soil pH



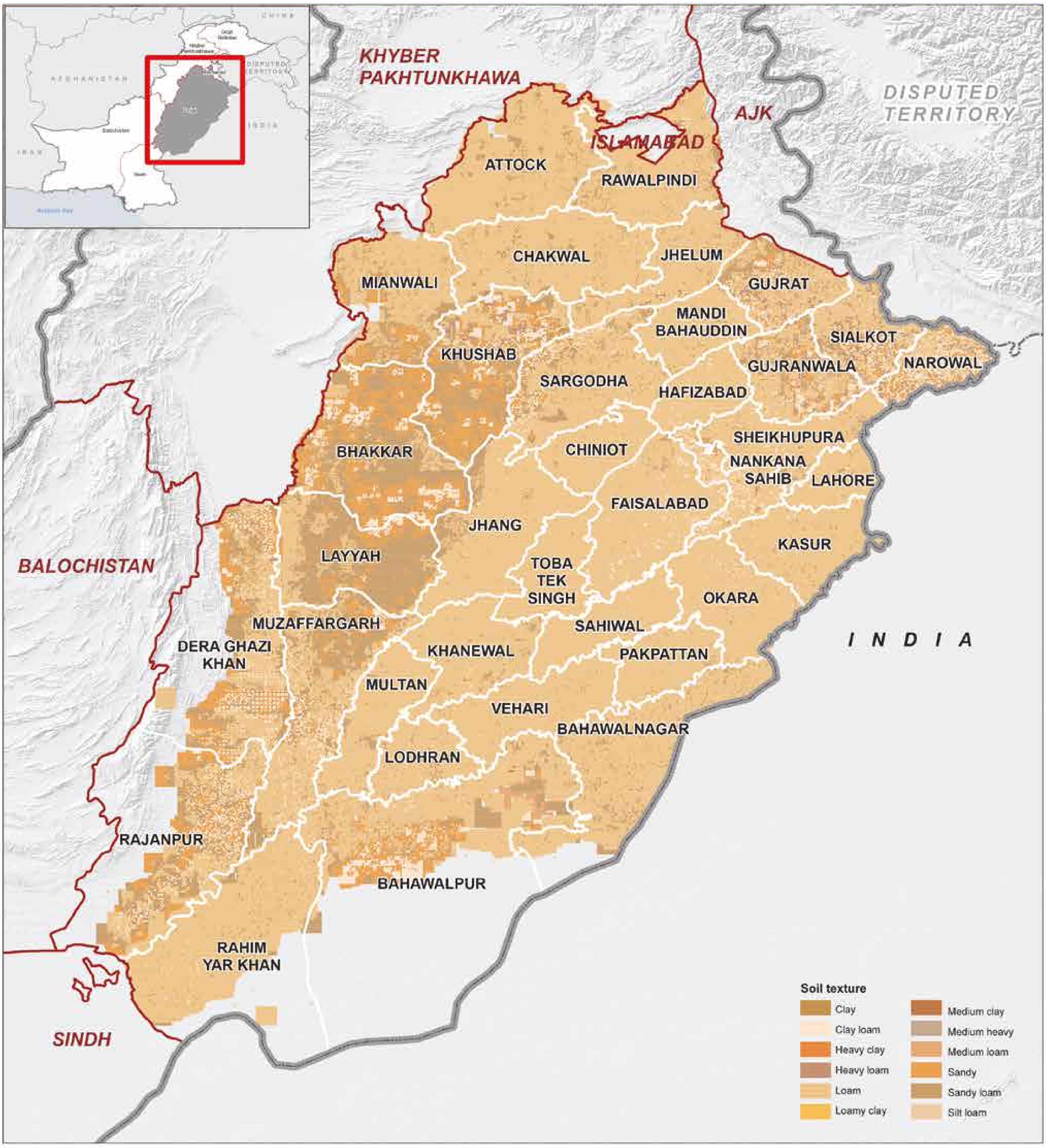
Soil sampling density per unit area



Soil pH



Soil electrical conductivity (EC)



Map created by: IM Unit, FAO Pakistan. Data sources: FAO, Government of Punjab, GAUL. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
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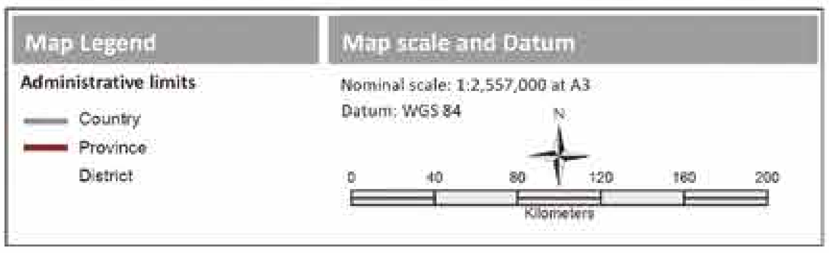


Soil texture

Texture is a most important parameter of soil. There are two different soil textures reflected in the map above i.e. sandy and loam, which are the dominant soil types across Punjab.

2.11 Water data

SURFACE WATER

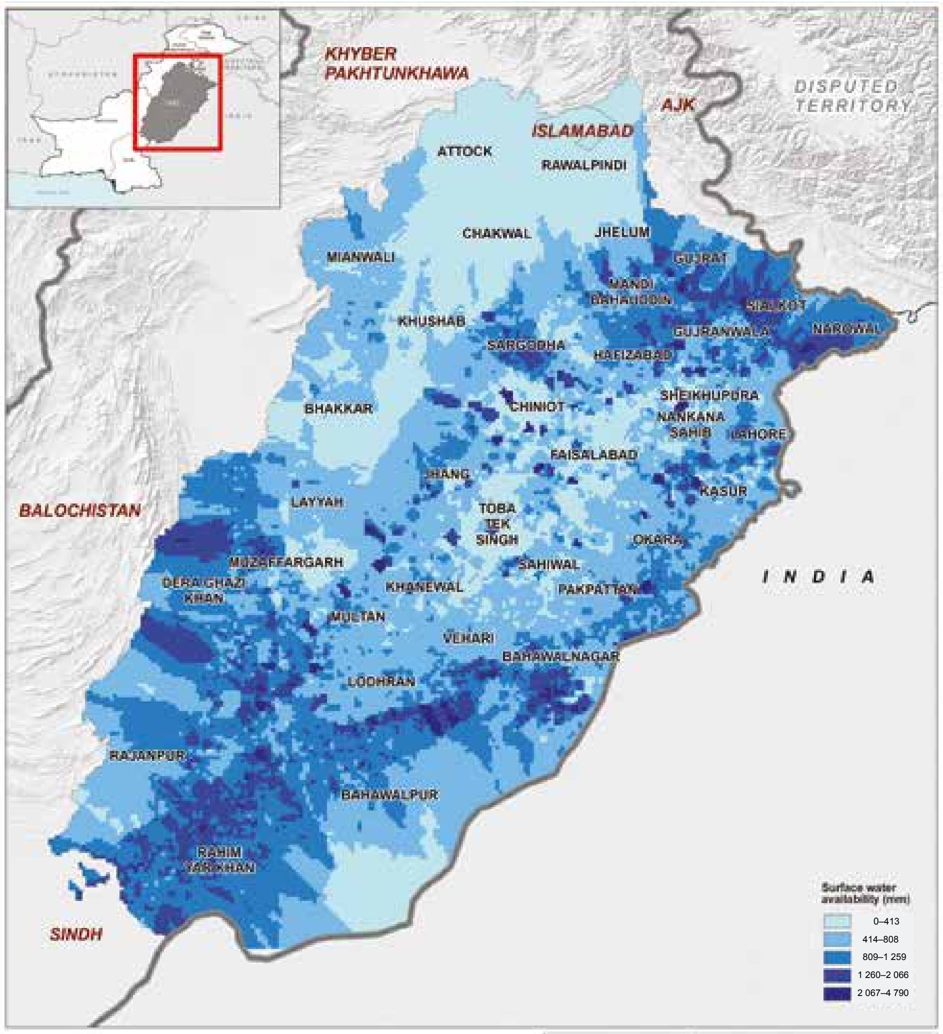
Punjab is dived into two sets of irrigation systems: one in the Barani area and the remainder are irrigated areas. Irrigated areas have a canal-based irrigation system, while in Barani, there is no canal irrigation system. The Barani area includes Chakwal and Rawalpindi, and the remaining irrigated area is under fourteen main canals. The interpolation of the surface water supply resulted in the map on the left. It describes the surface water availability in Punjab that ranges from zero mm up to 4 790 mm. The water availability was zero due to the provision of water outlets and discharge was zero for the whole command area of these watercourses. The results showed greater water availability in the upper and lower part of Punjab. There is no water availability in the Thal and Cholistan areas of Punjab.

GROUNDWATER

Groundwater irrigation is supplementary irrigation for the scarce water delivery under Punjab's high cropping intensity. Groundwater irrigation is used more in the areas where water availability from the canal is less than the irrigation water requirement. Aquifer pumping is used more in areas where rice is cultivated compared to the cotton-growing areas. Estimated groundwater irrigation is shown in the map below. It clearly describes the high groundwater irrigation in the northeast of Punjab and narrows in the center towards Punjab's south. Highest groundwater irrigation is 799 mm. The map also shows zero groundwater irrigation in the Thal and Cholistan areas.

TOTAL AVAILABLE WATER

Total water availability is the sum of all sources of water available in the field: from the surface water supply, groundwater abstraction, and rainfall. Spatial information of all water resources was added to estimate the total water available at the field level. Thus, the maximum water availability in the irrigated area was 4 500 mm, the highest due to the higher canal water allowance, and the higher contribution from the groundwater due to the freshwater availability. The maximum total water availability in Barani area is 1 634 mm.



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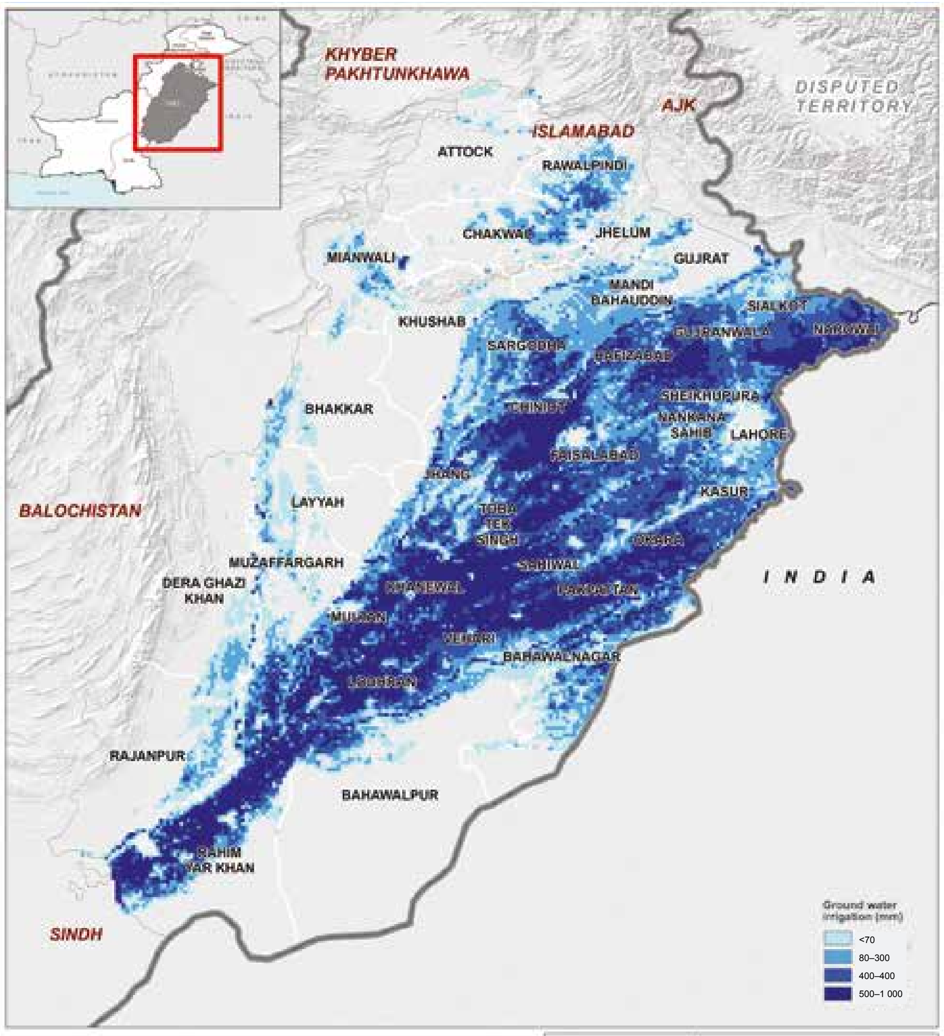
Surface water availability



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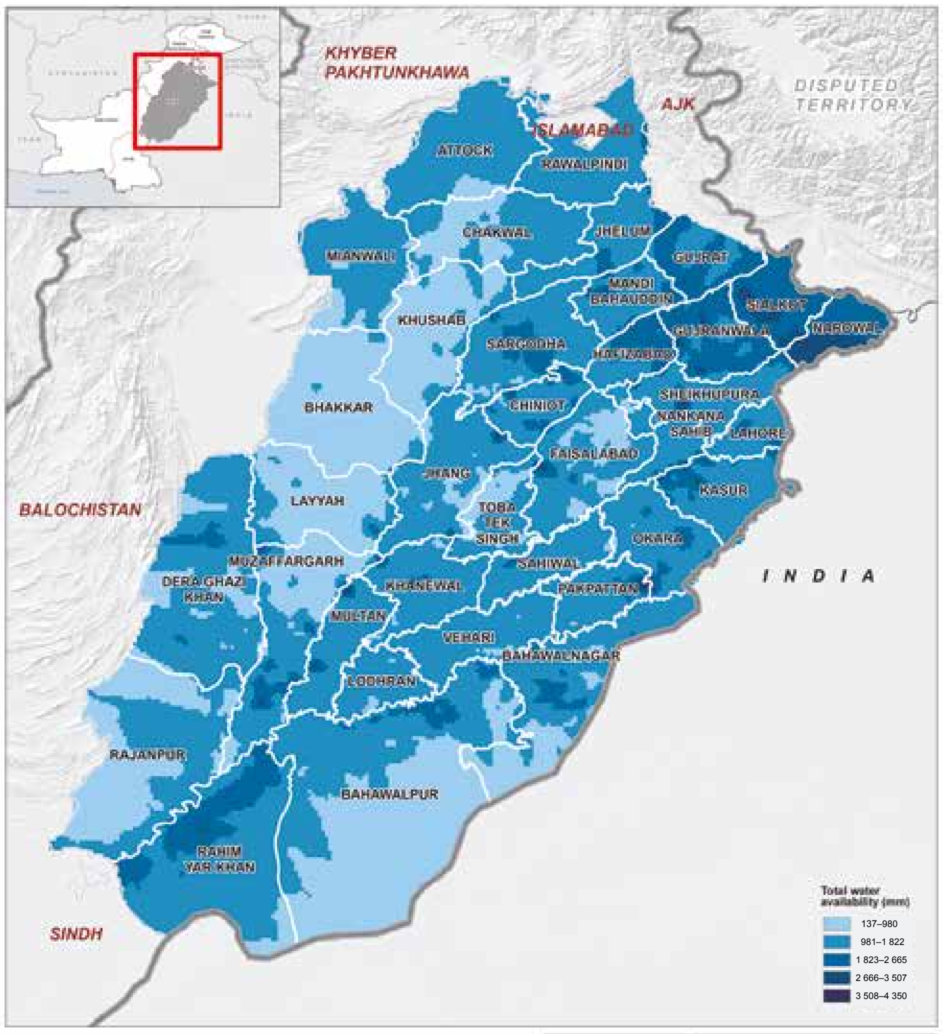
Groundwater irrigation



Map created by: IM Unit, FAO Pakistan. Data sources: FAO, Government of Punjab, GAUL
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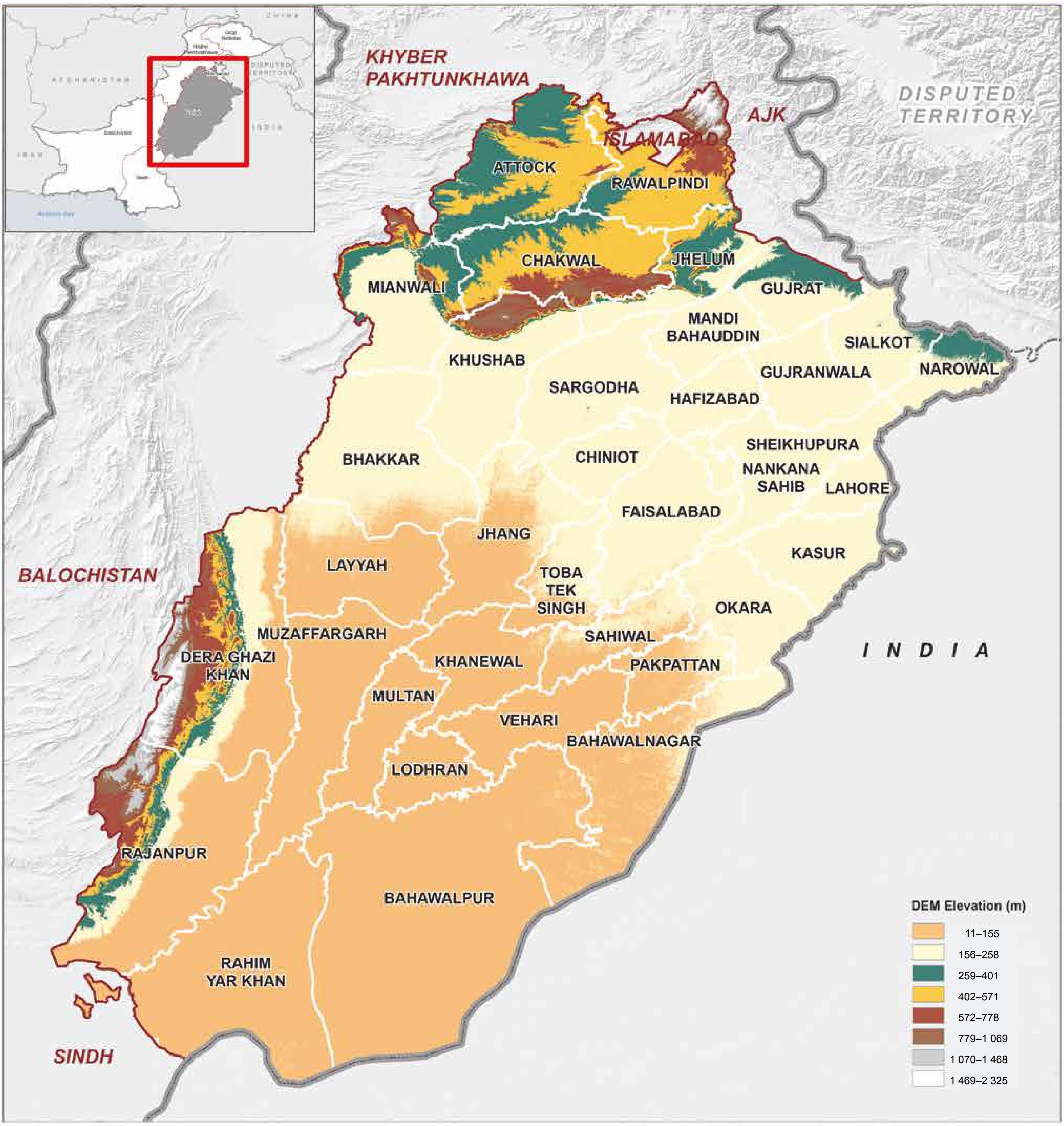
Total water availability

2.12 Elevation, terrain, slope and aspect

In Punjab province, there are two mountainous areas: in Potohar and in Rod-e-Kohi. A digital elevation model shows the range from 11 m to 2 325 m, the slope aspect ranges from 360 to 337.5 m in the mountainous areas of Punjab, and very low values in central Punjab due to its flat surface.



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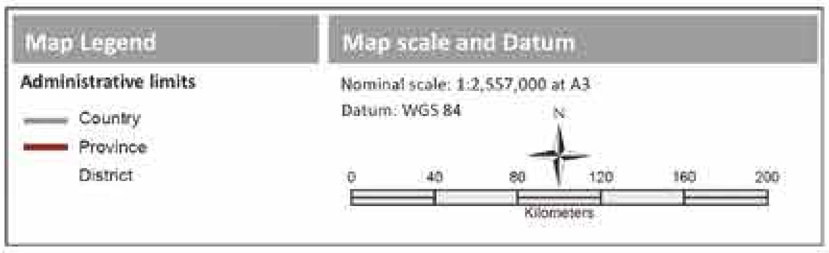


Digital elevation of Punjab

3 Agro-climatic analysis

Identification of agro-climatic regions

After obtaining ET_0 values for each weather station, interpolation was performed in a geographic information system environment. The empirical bayesian kriging interpolation method was used to predict the ET_0 values for the unmeasured points throughout the study area. While executing interpolation, 90 percent of the values were used; the remaining 10 percent was used as the validation data set. The predicted values for the corresponding validation data set were obtained by the overlay function in ArcGIS and scatter plots were made to check the accuracy of the interpolation results for validation purposes.

Further, potential evapotranspiration was used in combination with rainfall data to compute the Thornthwaite moisture index (TMI) using the following formula:

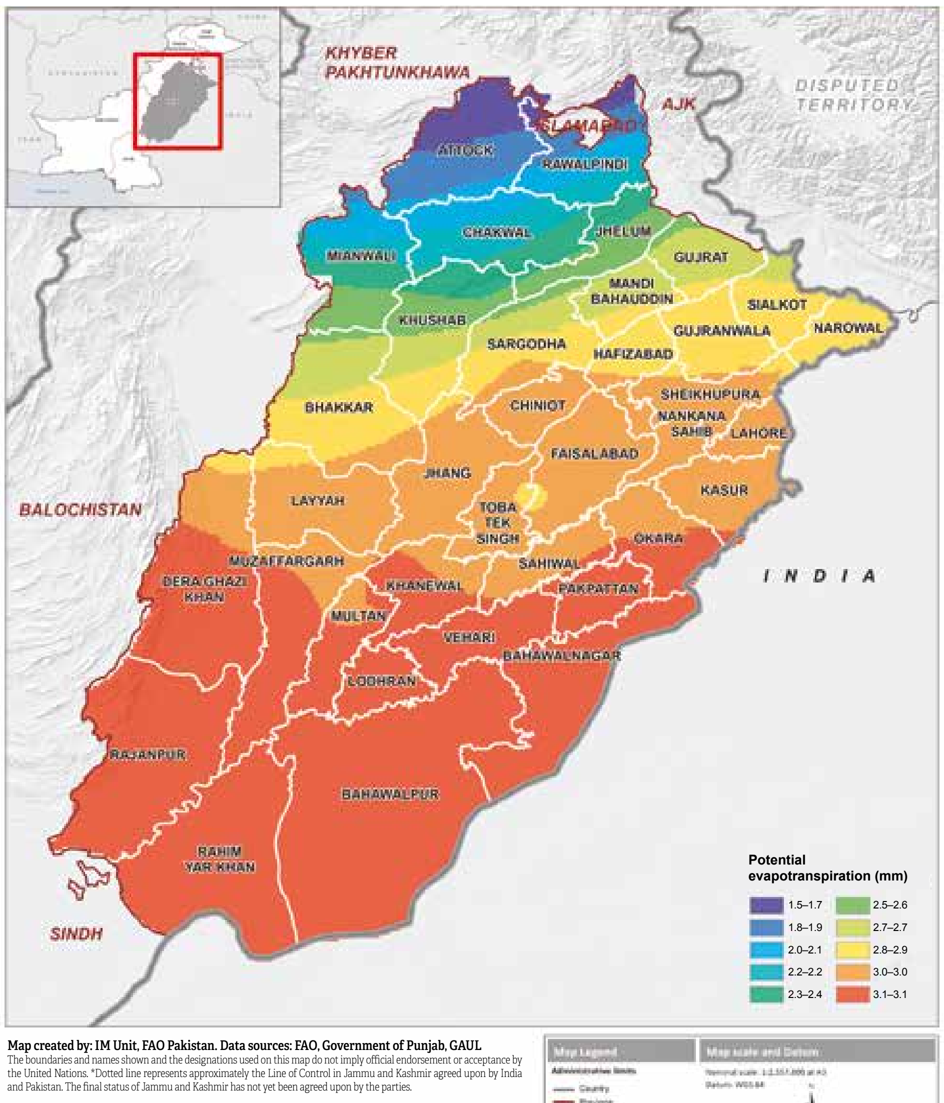
$$TMI = [P - ET_0 / ET_0$$

In the subcontinent, the Thornthwaite moisture index (TMI) has already been used successfully for agro-climatic zoning and allied research. Agro-climatic zones were delineated as land units classified in terms of major climate factors identified as ET_0 and correlated with the moisture availability period as classified in Table 3 (Nabeel & Athar, 2017).

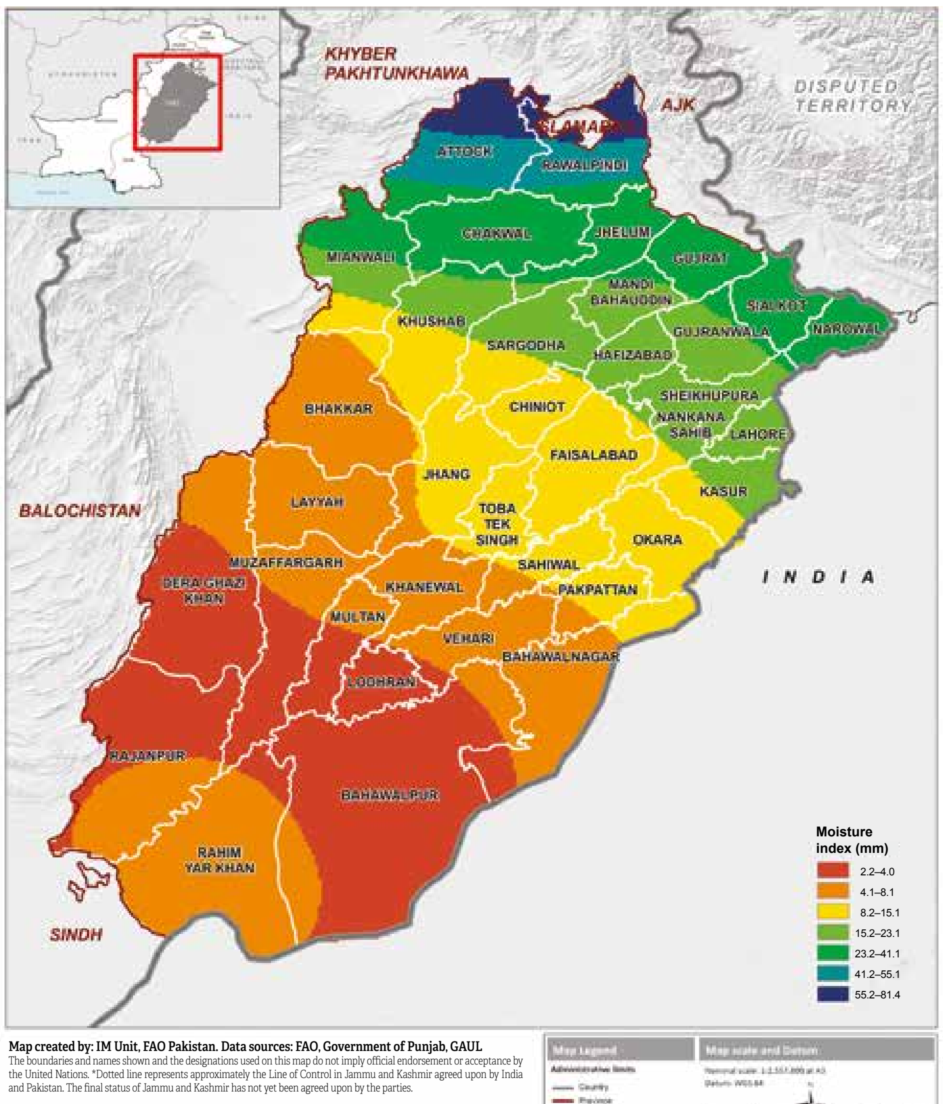
There were seven different agro-climatic zones delineated based on moisture indices with the same climatic characteristics. On the basis of the TMI values, most of the area lies in arid to the semi-arid regions.

Sr. no.	Im	Climate class
1	<8	Hyper arid
2	8–15	Arid
3	15–23	Semi-arid
4	23–40	Dry sub-humid
5	40–55	Humid
6	>55	Very humid

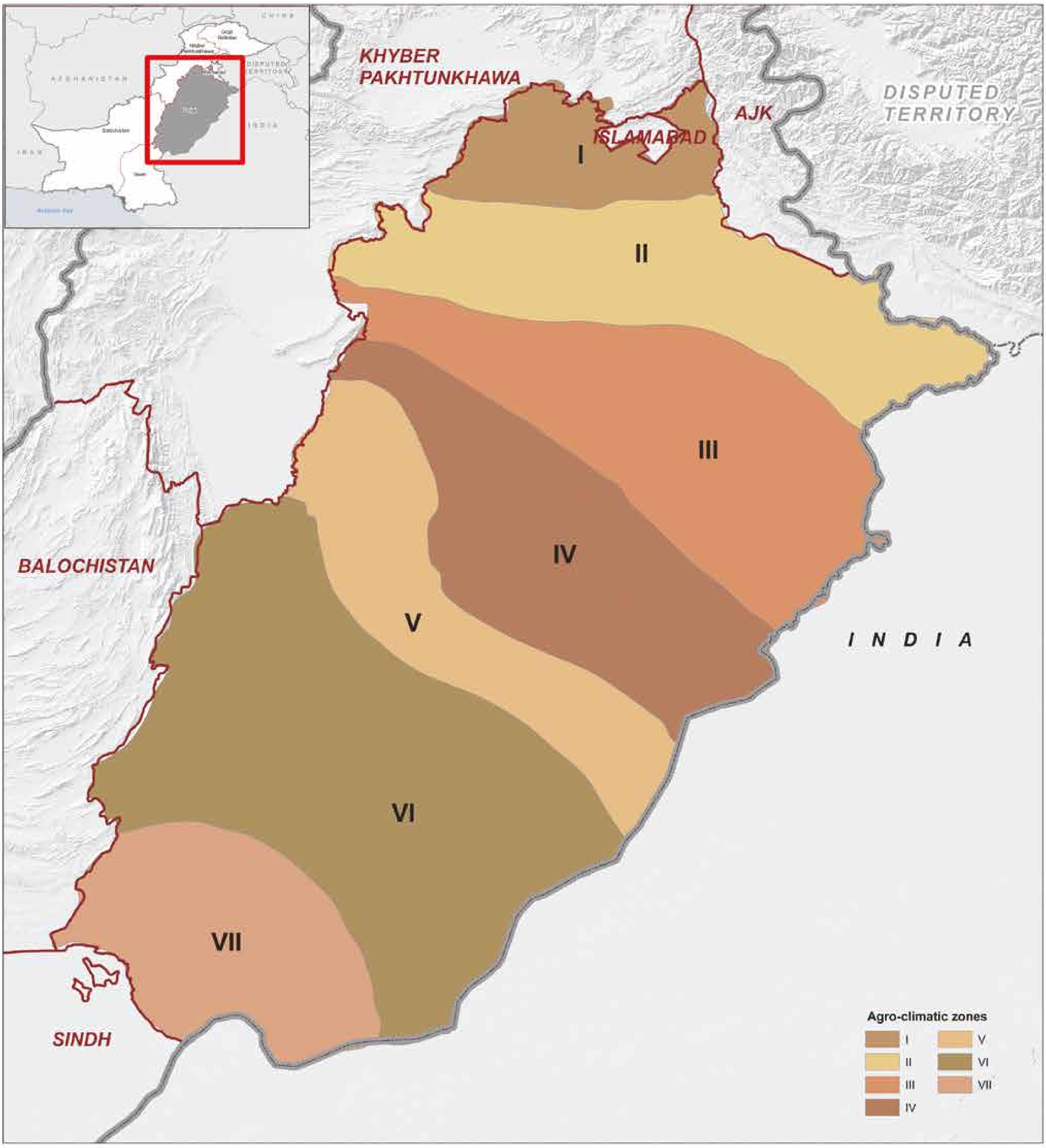
Table 3. Thornthwaite moisture index (TMI) classification



Potential evapotranspiration



Moisture index



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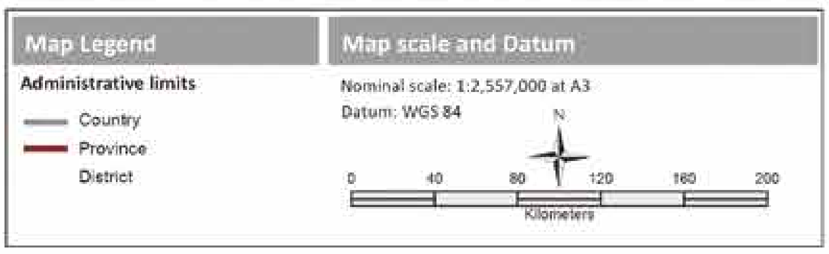
Agro-climatic zones of Punjab



4 Delineation of agro-ecological zones

Agro-ecological zones (AEZs) were delineated using agro-climatic maps and soil type maps of Punjab. Overlay analysis was done in GIS and there were fourteen different agro-ecological zones delineated with the homogeneity of landform and with climatic factors as shown in the maps below. The delineated AEZs differ from the zones identified by PARC in 1980, due to the changing climate from 1980 to 2017. PARC identified 11 zones whereas the present study delineated 14 zones.

Zone ID	Zone name	Avg, rabi max temp (°C)	Avg, rabi min temp (°C)	Avg, kharif max temp (°C)	Avg, kharif min temp (°C)	Rainfall (mm)	ET_o (mm)	Soil type	EC
I	Cholistan desert	28.09	12.31	39.28	27.31	230	3.20	Mostly sandy	0.07–27
II	Arid irrigated	29.20	12.45	40.41	27.59	234	3.10	Loam, sandy loam (9%)	0.07–27
III	Cotton–sugarcane	28.67	12.40	39.93	27.49	243	2.93	Sandy loam, clay loam (10%), loam (35%)	1.73–27
IV	Rod-i-Kohi	27.73	12.61	39.42	27.28	255	3.10	Mostly sandy loam	0.07–27
V	Semi-desert irrigated	27.59	12.38	38.94	27.22	412	2.88	Loam, sandy loam (20%), clay loam (8%)	1–27
VI	Mix cropping	27.38	12.99	39.47	27.30	460	2.62	Sandy loam (55%), loam (45%), clay (5%), loam	0.6–2
VII	Cotton mix cropping	27.39	12.08	38.52	26.72	580	2.71	Loam, sandy loam (5%)	0.07–11.8
VIII	Maize wheat mix cropping	26.97	11.06	37.86	25.58	590	2.64	Loam, sandy loam (3%), clay loam (1%)	0.07–6.83
IX	Thal-Gram crop	27.51	11.35	39.21	26.24	612	2.25	Sandy loam (50%), sandy (35%), loam (10%), clay (5%)	0.07–1.7
X	Rice–wheat	26.34	11.80	36.96	25.74	760	2.74	Loam, clay loam (5%), sandy loam (3%)	0.07–1.79
XI	Thal zone 2	26.84	10.91	37.80	25.73	1 120	2.34	Sandy loam (45%), loam (45%), clay loam (5%)	0.07–3.7
XII	Rice zone	25.03	11.71	35.53	25.20	1 250	1.76	Loam (40%), sandy loam (20%), clay loam (10%)	0.07–1.79
XIII	Groundnut-medium rainfall	24.85	10.27	36.36	24.37	1 620	2.10	Loam (95%), sandy loam (5%)	0.07–6.4
XIV	High rainfall	23.35	9.45	34.50	22.96	1 780	1.95	Loam (95%), sandy loam (5%)	0.07–1.73

Table 4. Agro-ecological zones

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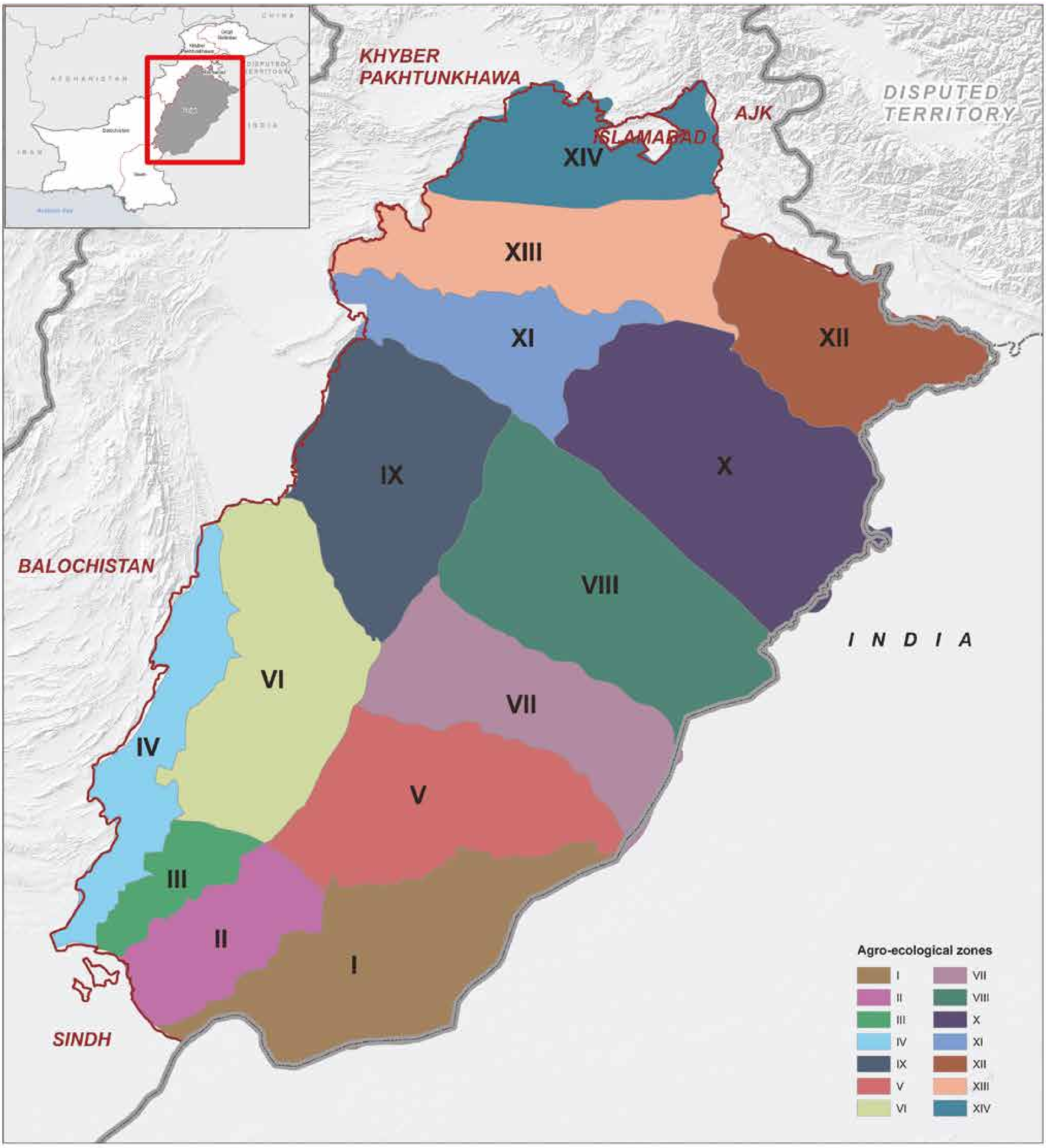

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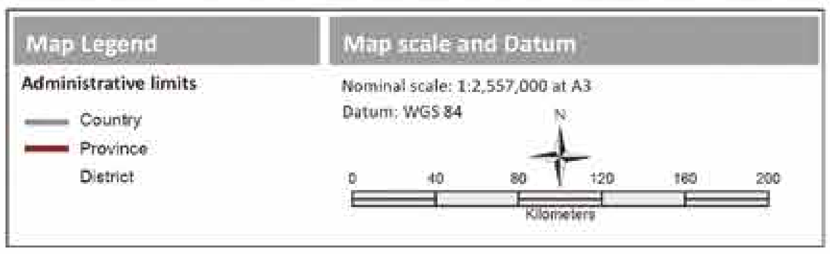
Agro-ecological zones of Punjab



5 Agro-edaphic suitability

5.1 Soil characteristics

The Soil Fertility Research Institute, Lahore–Punjab provided the data of different soil parameters. Almost 0.280 million soil samples were analyzed from all over Punjab. Data related to the soil is a key element of agriculture.

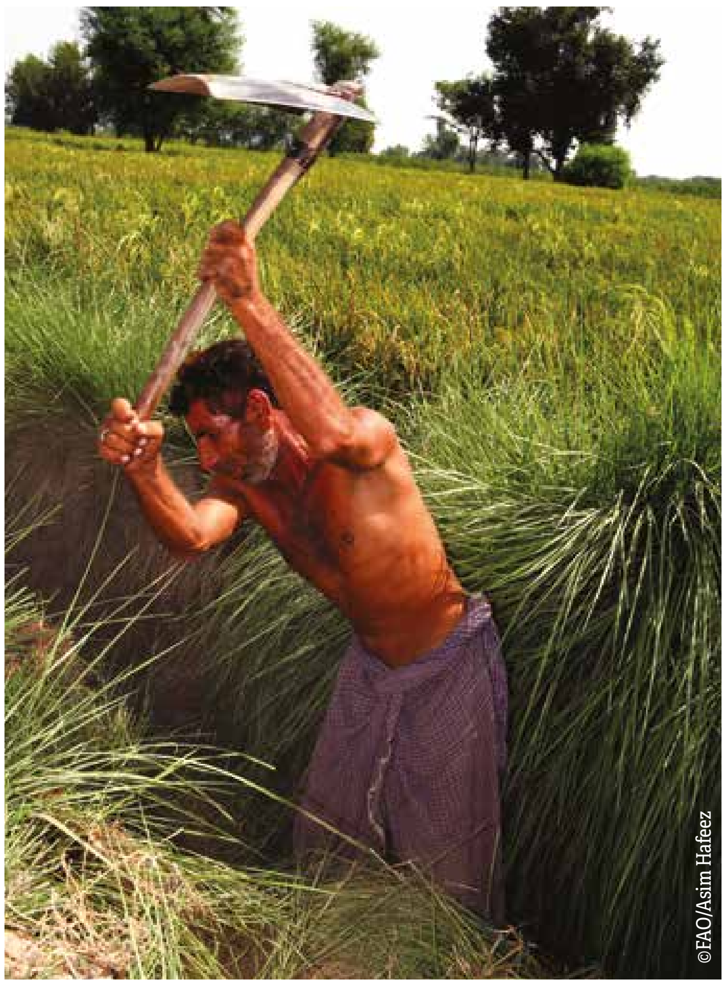
Crop growth is highly dependent on soil texture and type; failure to consider soil type and texture makes it difficult to achieve the best crop growth results. For instance, rice cannot be grown in sandy areas because it requires stagnant water conditions in the field which are based on clay and heavy loam soils. It's clear that every crop requires suitable types of soil.

5.2 Soil quality and soil suitability

Detailed domination by the variation of the soil types in different areas of Punjab:

Soil type	Districts
Clay soil	Sialkot, Narowal, Gujranwala, Hafizabad, Sheikhupura
Loam soil	Lahore, Jhang, Nankana Sahib, Chiniot, Vehari, Multan
Sandy soil	Layyah, Bhakkar, Mianwali, Bahawalpur

Table 5. Soil types in different areas of Punjab



Integration of climatic and edaphic evaluations

Main processing steps

Mindful that redefining agro-ecological zones is based on the crop normal, the AEZ model has been developed using R software based on the data related to climate, soil and water availability.

The data acquired from relevant departments such as climate data from the Pakistan Meteorological Department (PMD); soil data from the soil fertility experts in the Department of Agriculture; and available water data from the Irrigation Department, were not of the same grid size. In order to resolve the lack of uniformity, all data were converted into the same grid size.

The value of using the same grid size is that at each point, there can be information on climate, soil, and water. Therefore, the AEZ model has been developed based on the data availability of all input parameters at each grid. The grid size used in this model is 100 m by 100 m. The procedure for developing a high-resolution database for each input parameter having a grid size of 100 m by 100 m is explained in detail in the geostatistical section.

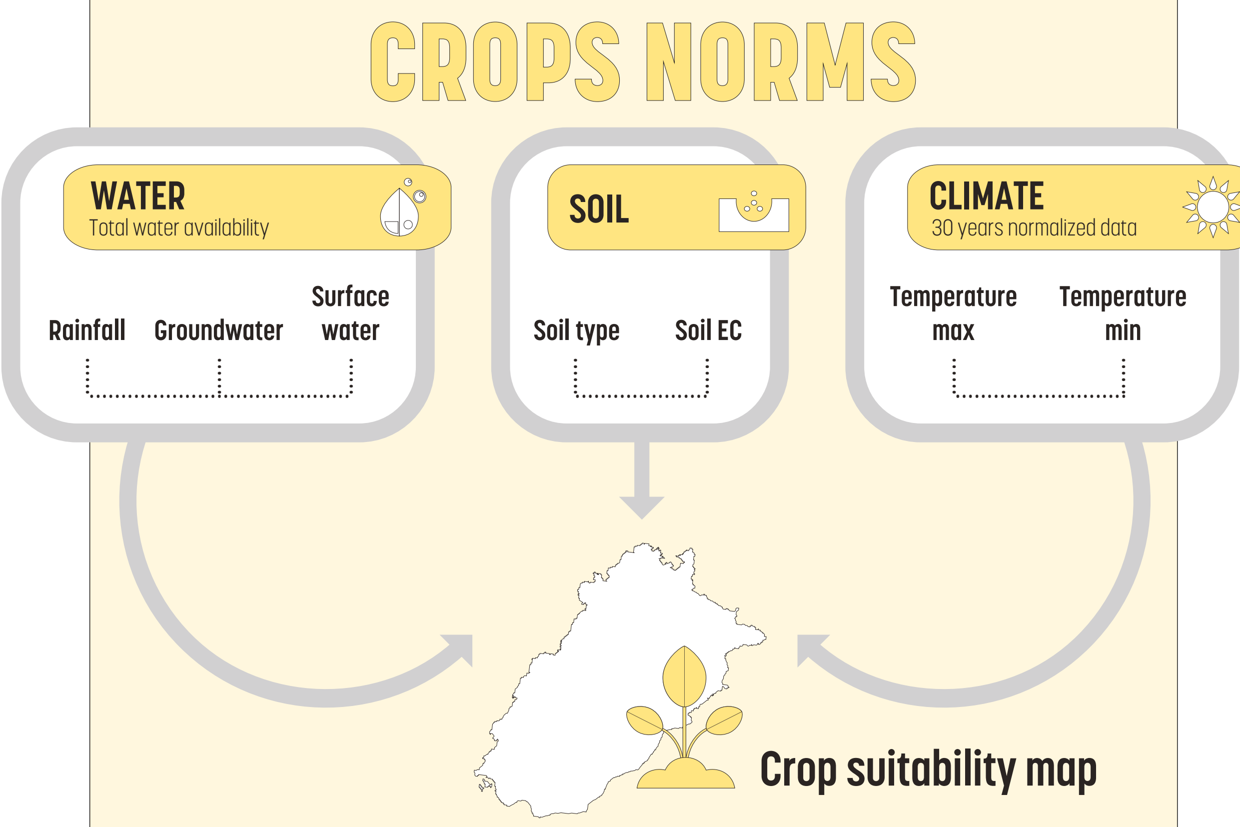


Figure 7. Agro-ecological zones model - Run for each crop with seasonal data

6 Crop norms and suitability maps

6.1 Crop suitability maps

Crop suitability maps were developed based on the following agro-climatic factors.

- **Climatic:** maximum temperature and minimum temperature
- **Soil:** soil EC and texture
- **Water:** rainfall, surface water, groundwater.

Note: Optimum conditions which are required for successful crop production are called crop norms

The following maps show a series of most suitable areas for:

- agronomic crops;
- fruits; and
- vegetables.

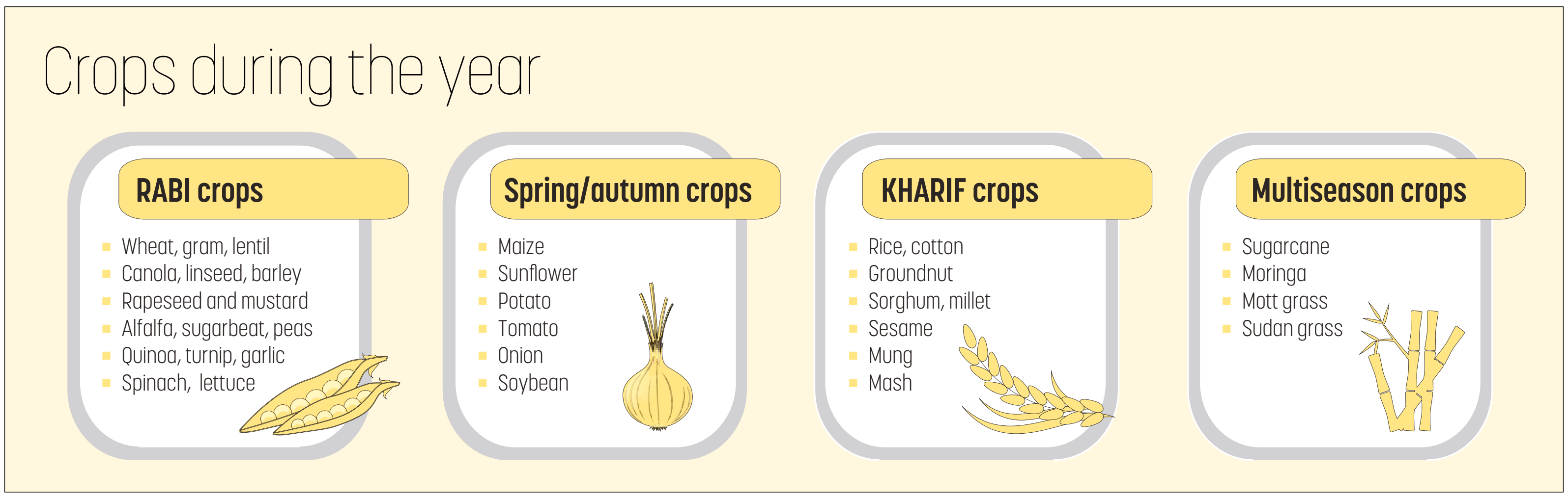


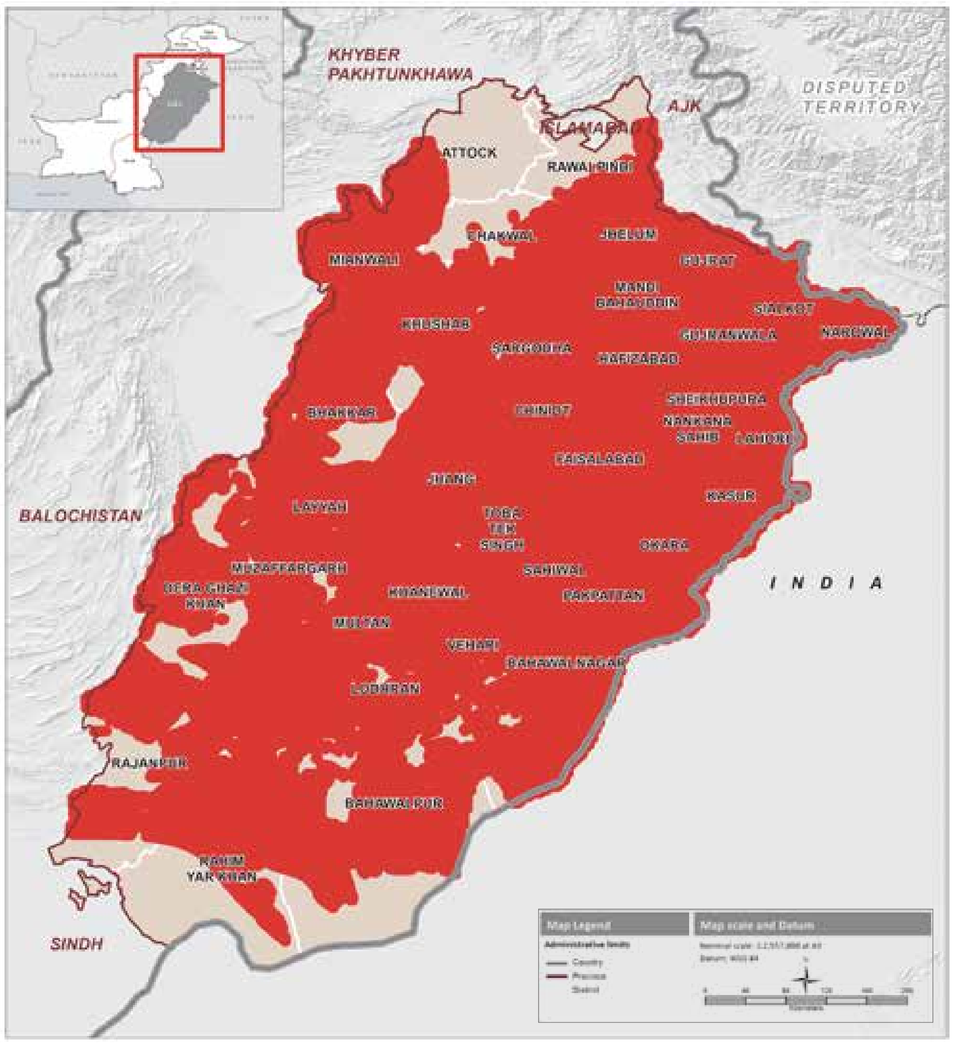
Figure 8. *Crops during the year*

6.2 Crop norms

Sr. no.	Crop	Max temperature (°C)	Min temperature (°C)	Water requirement (mm)	EC	Soil texture
AGRONOMIC CROPS						
1	WHEAT	28	6	300	4	All soil, except for heavy soil
2	RICE	36	20	1200	4	Clay, silty clay, clay loam
3	COTTON	40	26	500–800	4	Loam soil, medium heavy, medium clay, medium loam, silty loam, sandy loam
4	MAIZE	38	20	500–800	4	Silty loam, loamy, medium clay
5	SUNFLOWER	40	20	50–1000	4	Medium clay, silty loam, clay soil
6	GRAM	28	8	200	4	Silty loam, sandy loam
7	SOYBEAN	29	8	500–700	4	Loam, medium clay
8	GROUNDNUT	35	15	600	4	Loam, medium clay
9	SESAME	45	25	250	4	Sandy loam
10	SORGHUM	42	20	300–600	4	Silt, sandy, sandy loam, loam
11	MILLET	42	20	300–600	4	Silt, sandy, sandy loam, loam
12	LENTIL	26	8	260	4	Sandy, sandy loam, loam
13	CANOLA	27	10	250	4	Loam, clay loam, silt loam
14	LINSEED	30	10	350	4	Loamy soil, sandy clay loam
15	RAPESEED & MUSTARD	30	10	200	4	Silt clay loam, sandy clay loam
16	BARLEY	26	8	300	4	Clay loam, silt loam, loam
17	ALFALFA	28	10	350	4	Silt clay, silt clay loam
18	SUGARCANE	40	20	1600–2000	4	Medium clay, heavy loam
19	SUGARBEET	30	12	300	4	Clay loam, silt clay, loam
20	QUINOA	35	15	225	4	Sandy, sandy loam
21	MORINGA	30	12	450	4	Loam, sandy loam
22	SUDAN GRASS	42	18	375	4	Clay, silty clay, sandy clay, loam, sandy loam
23	MOTT GRASS	40	20	200–300	4	Sandy loam, clay loam

Sr. no.	Crop	Max temperature (°C)	Min temperature (°C)	Water requirement (mm)	EC	Soil texture
FRUITS						
24	CITRUS	40	5	1 250–1 850	2	Loam, silt loam, clay loam
25	MANGO	48	15	890–1 060	2	Silt clay, clay loam, sandy loam
26	GUAVA	32	3.8	1 000–2 000	2	Sandy clay, clay loam
27	STRAWBERRY	30	5	300	2	Clay, silt clay loam
VEGETABLES						
28	GARLIC	25	15	400	3.9	Sandy loam, loam, sandy clay loam
29	SPINACH	25	10	250	2	Clay loam, sandy clay loam, silty clay loam
30	CABBAGE	25	10	250	1.8	Silt loam, clay loam, loam, sandy loam
31	PEAS	30	5	300	1.8	Clay loam, silt clay loam, loam, sandy loam
32	CARROT	30	10	250–450	1	Sandy loam, silt loam, loam
33	TURNIP	28	10	250	6.5	Sandy loam, silt loam, loam
34	RADISH	35	10	200–350	1	Sandy loam, silt loam, loam
35	TURMERIC	35	15	1500	1.2	Sandy loam, silt loam, loam
36	CAULIFLOWER	30	10	500	4	Sandy loam, silt loam, clay loam
37	POTATO	29	12	700–1 000	1.7	Sandy loam, sandy clay loam, clay loam, loam
38	TOMATO	29	12	500–1 000	2.5	Clay loam, sandy loam, sandy clay loam. loam, silt loam
39	ONION	35	17	750–1 250	1.4	Loam, silt loam, clay loam, sandy loam
40	CAPSICUM	28	15	600–1 000	1.5	Silt loam, clay loam, loam, sandy loam
41	PUMPKIN	40	20	650–775	2.5	Sandy loam, silt loam
42	SQUASHES	40	20	650–775	2.5	Clay loam, silt loam, sandy clay loam, clay loam
43	GOURDS	40	20	650–775	2.5	Clay loam, silt loam, sandy clay loam, clay loam
44	OKRA	40	25	500–650	2.5	Sandy loam, silt loam, loam, clay loam
45	GINGER	35	25	1 500–2 500	2.5	Silt loam, loam, sandy clay loam

Table 6. Crop norms



Map created by: IM Unit, FAO Pakistan.
Data sources: FAO, Government of Punjab, GAUL

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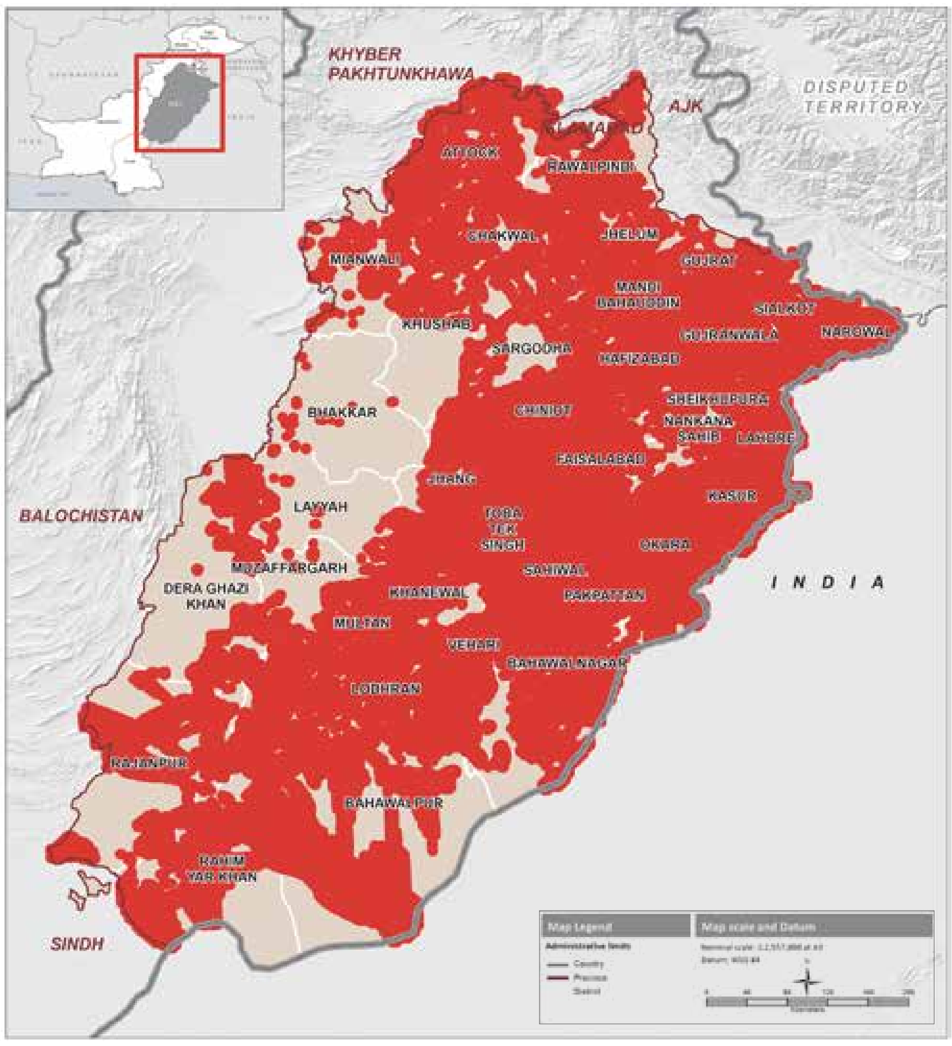
AGRONOMIC CROPS

Most suitable area for **wheat**	
Climate	max 28 °C / min 6 °C
Soil	all, except heavy soils
Water	300 mm



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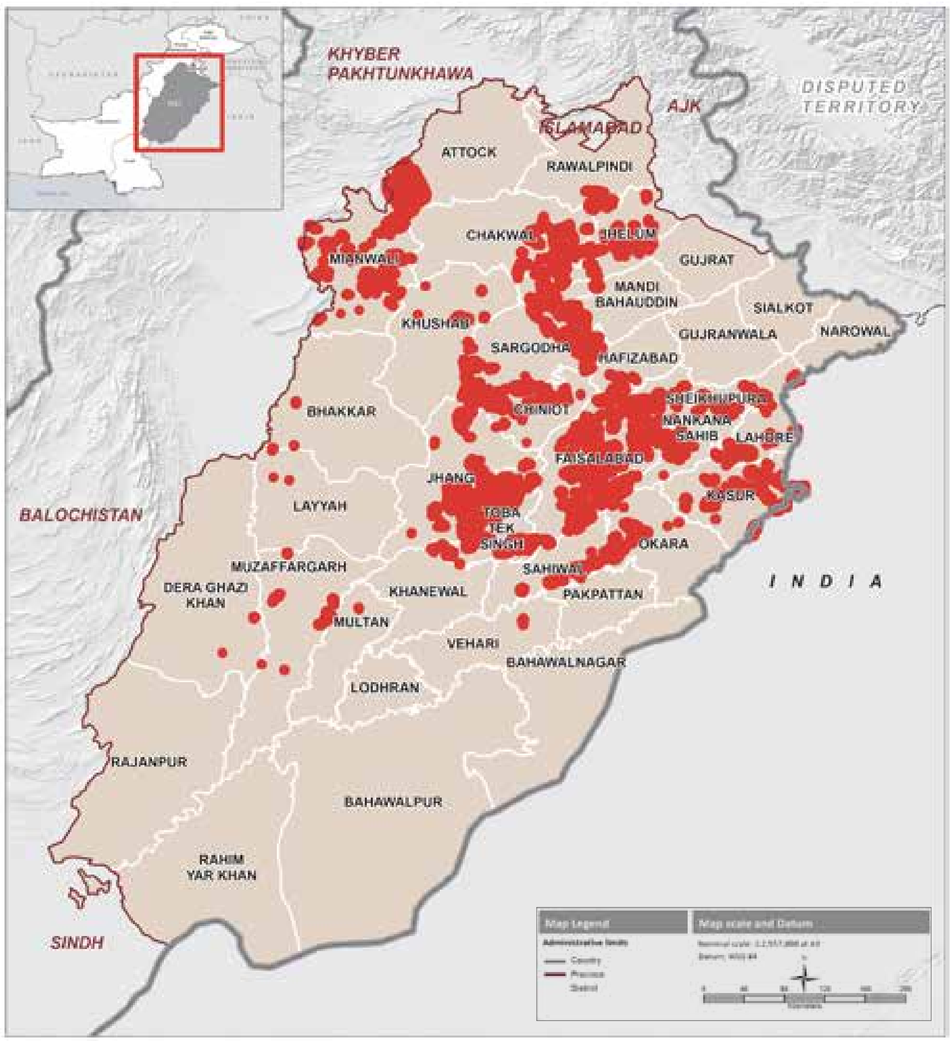
AGRONOMIC CROPS

Most suitable area for **rice**	
Climate	max 36 °C / min 20 °C
Soil	clay, silty clay, clay loam
Water	1200 mm



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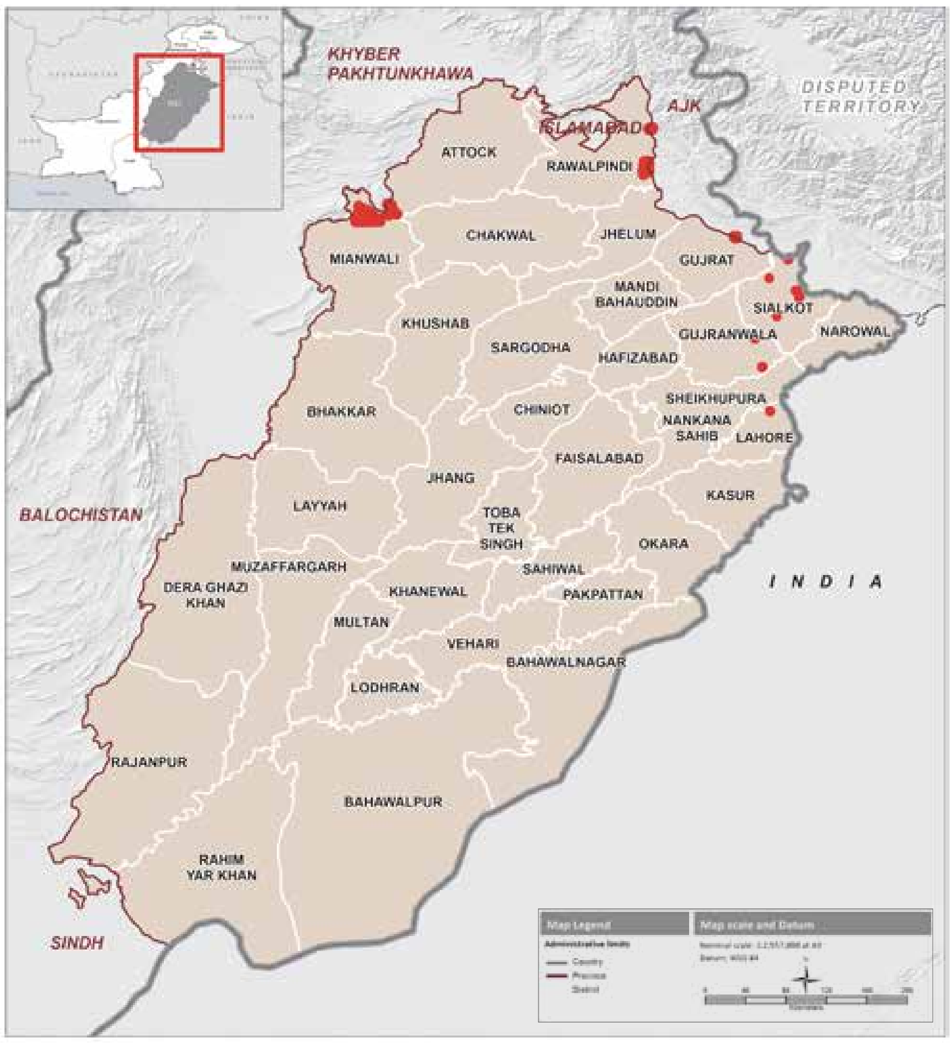
AGRONOMIC CROPS

Most suitable area for **soybean**	
Climate	max 29 °C / min 8 °C
Soil	loam, medium clay
Water	500–700 mm



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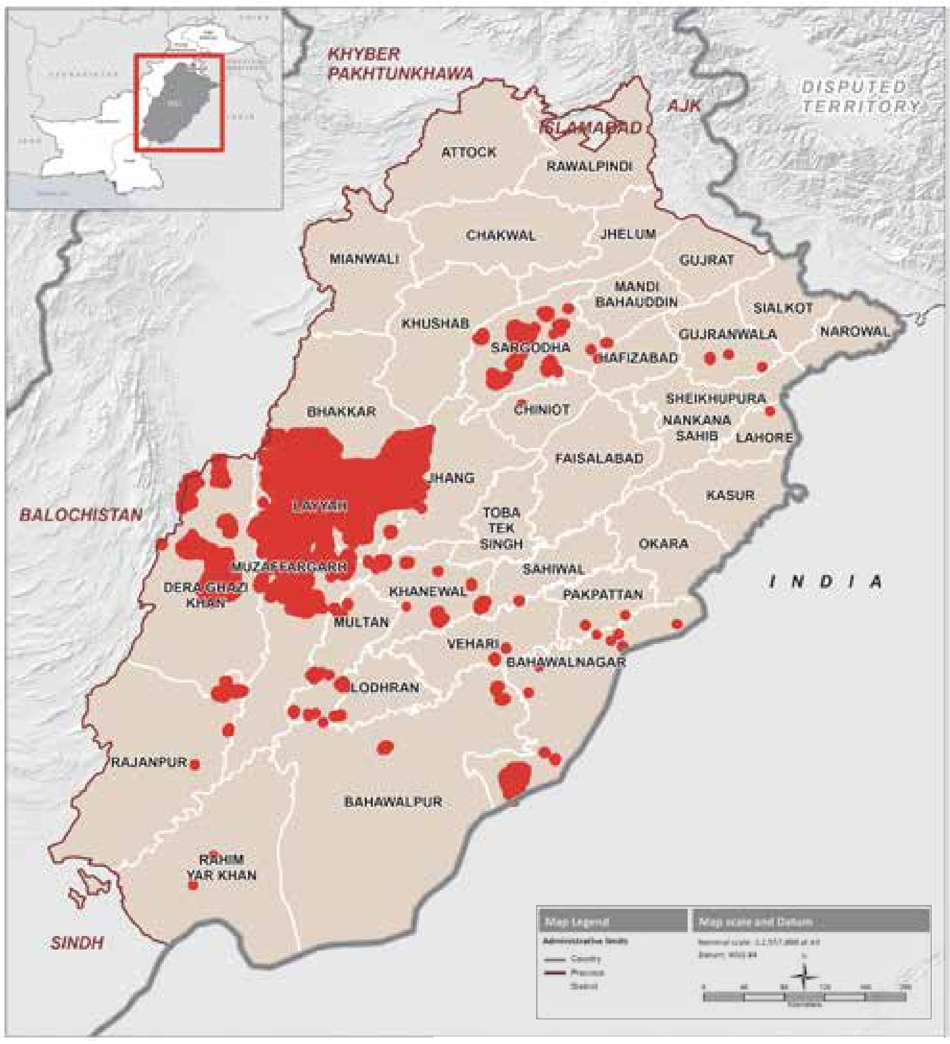
AGRONOMIC CROPS

Most suitable area for **groundnut**	
Climate	max 35 °C / min 15 °C
Soil	loam, medium clay
Water	600 mm



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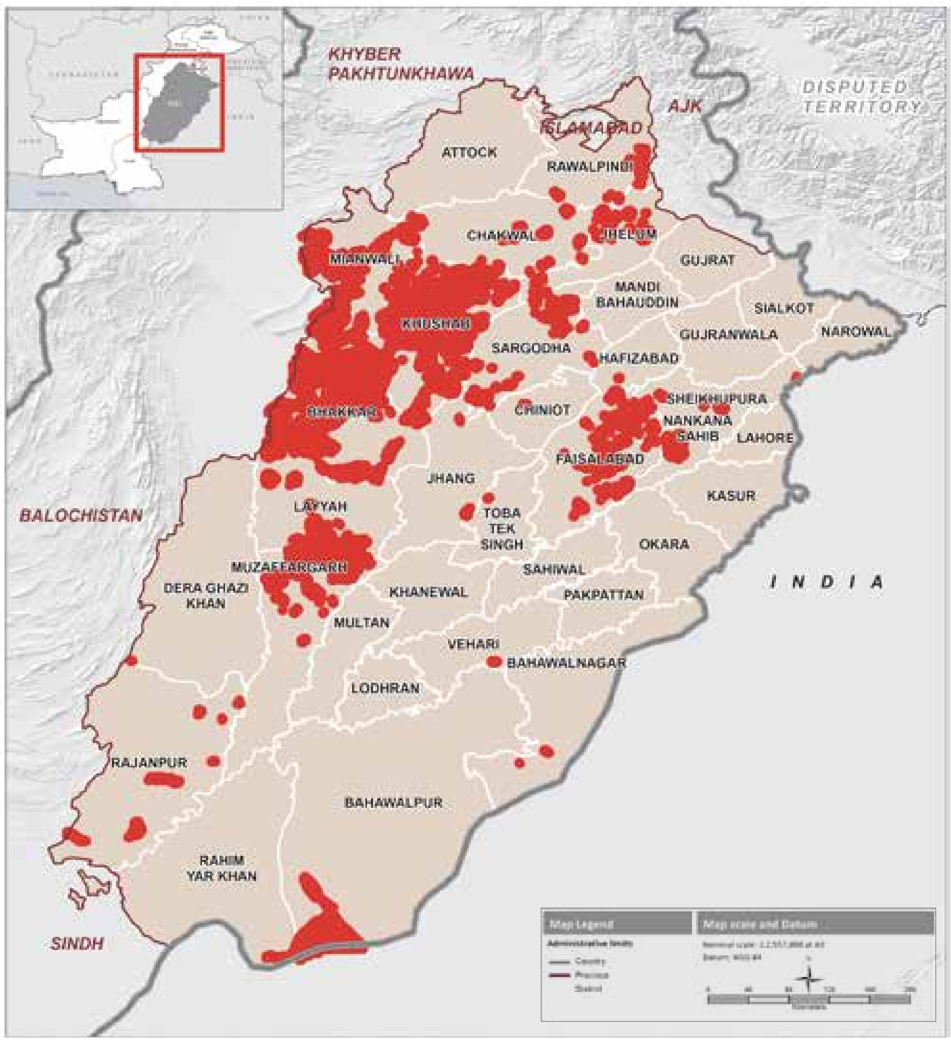
AGRONOMIC CROPS

Most suitable area for **sesame**	
Climate	max 45 °C / min 25 °C
Soil	sandy loam
Water	250 mm



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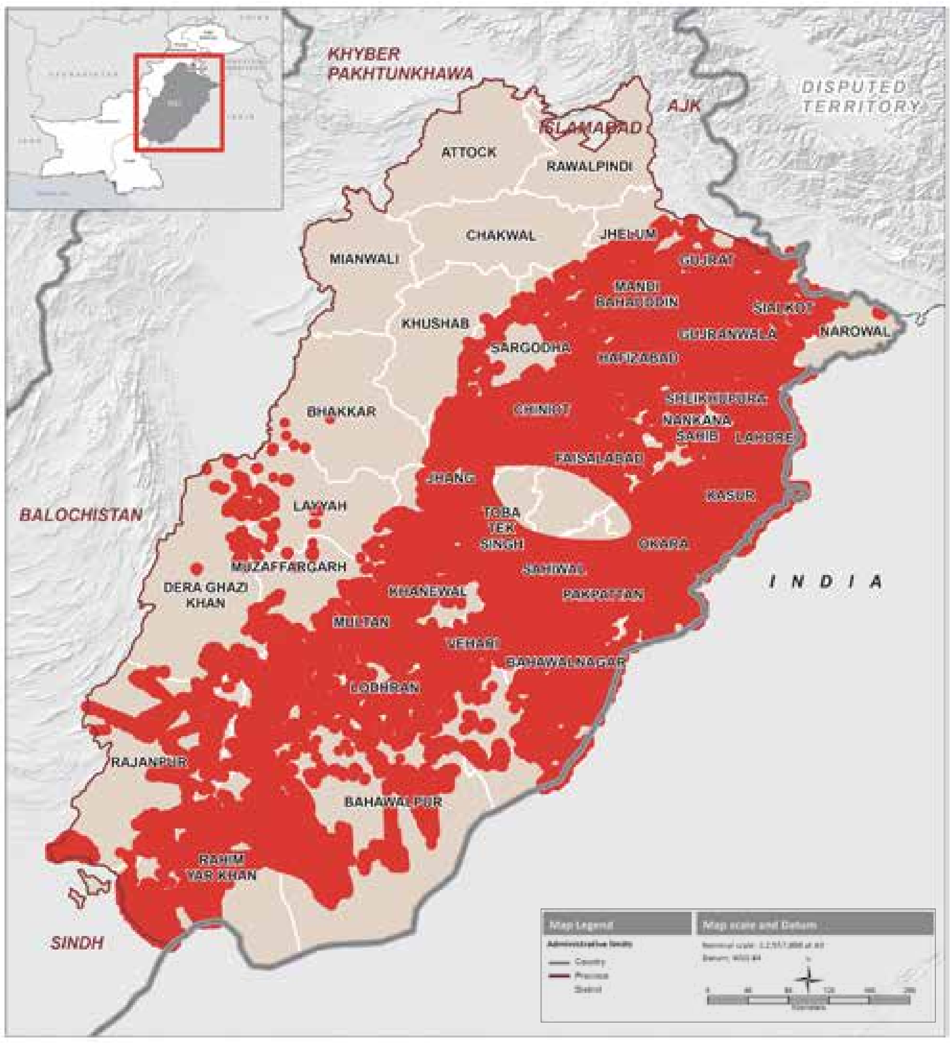
AGRONOMIC CROPS

Most suitable area for **sorghum**	
Climate	max 42 °C / min 20 °C
Soil	silt, sandy, sandy loam, loam
Water	300–600 mm



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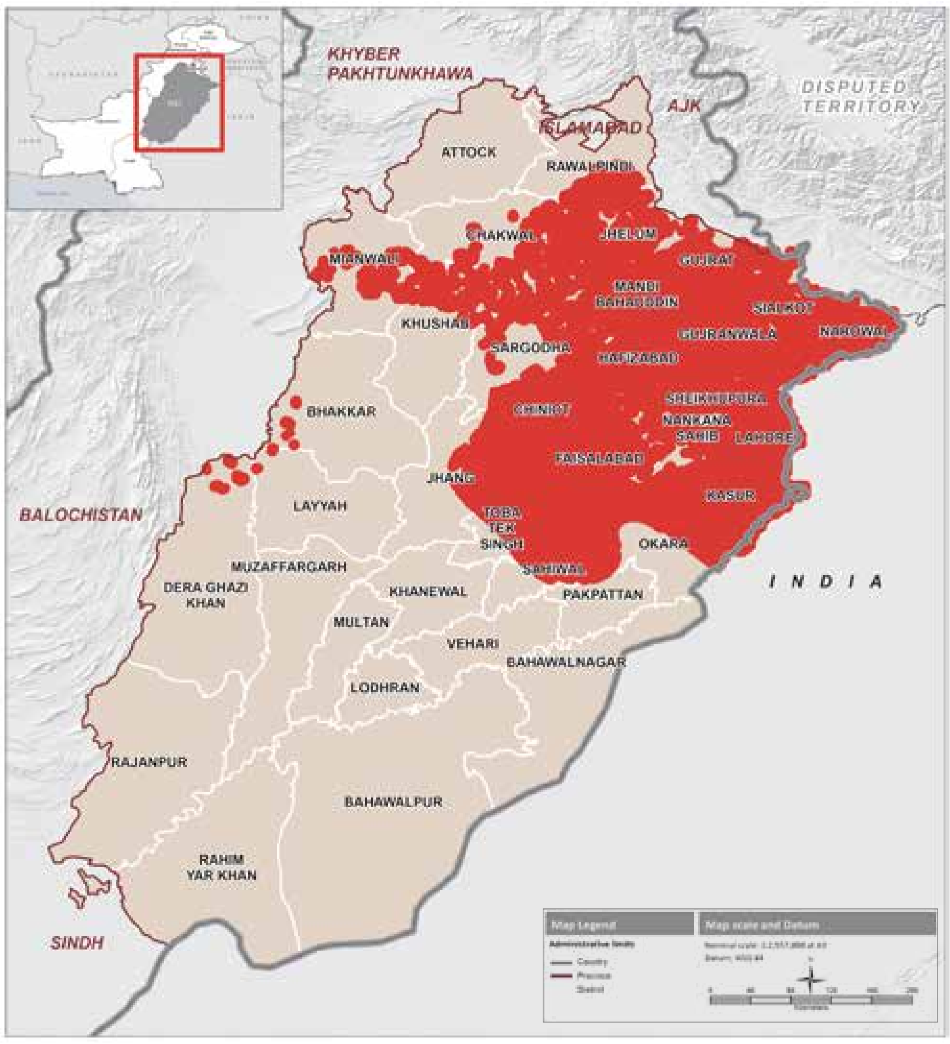
AGRONOMIC CROPS

Most suitable area for **rapeseed and mustard**

Climate	max 30 °C / min 10 °C
Soil	silt clay loam, sandy clay loam
Water	200 mm



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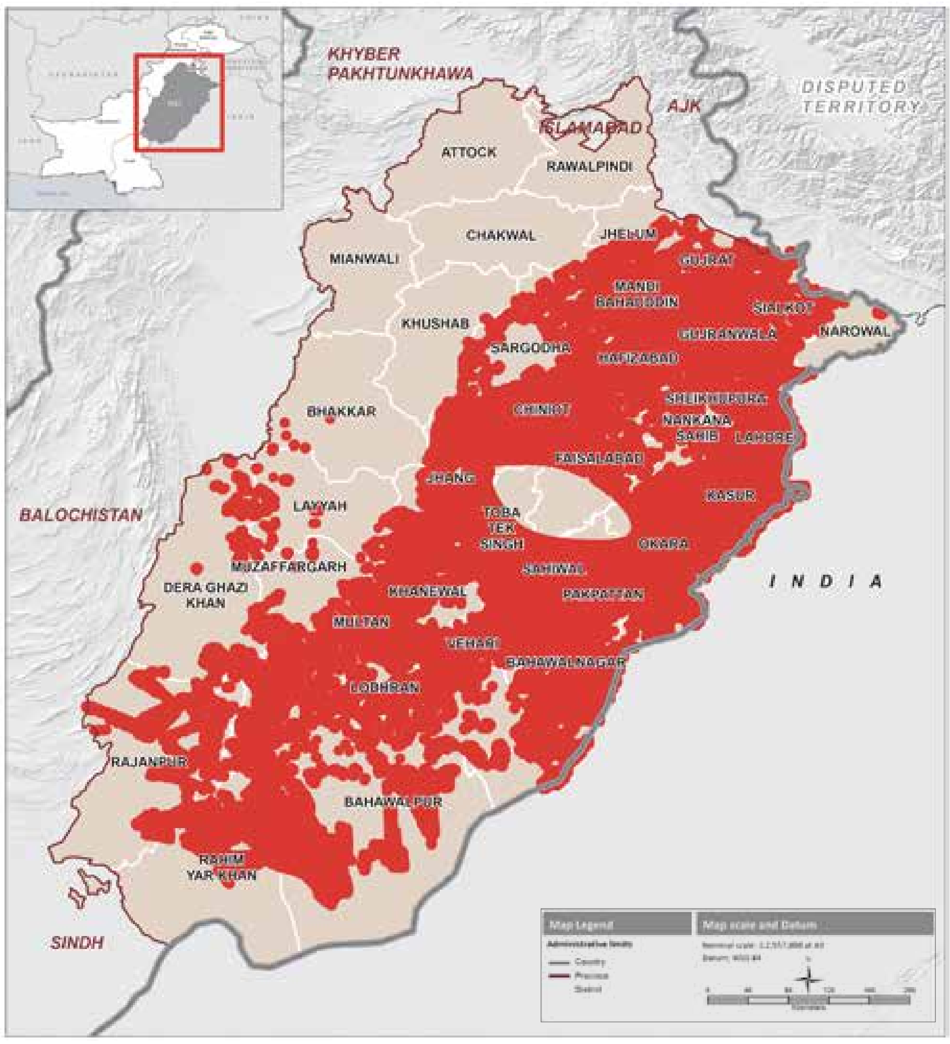
AGRONOMIC CROPS

Most suitable area for **barley**

Climate	max 26 °C / min 8 °C
Soil	clay loam, silt loam, loam
Water	300 mm



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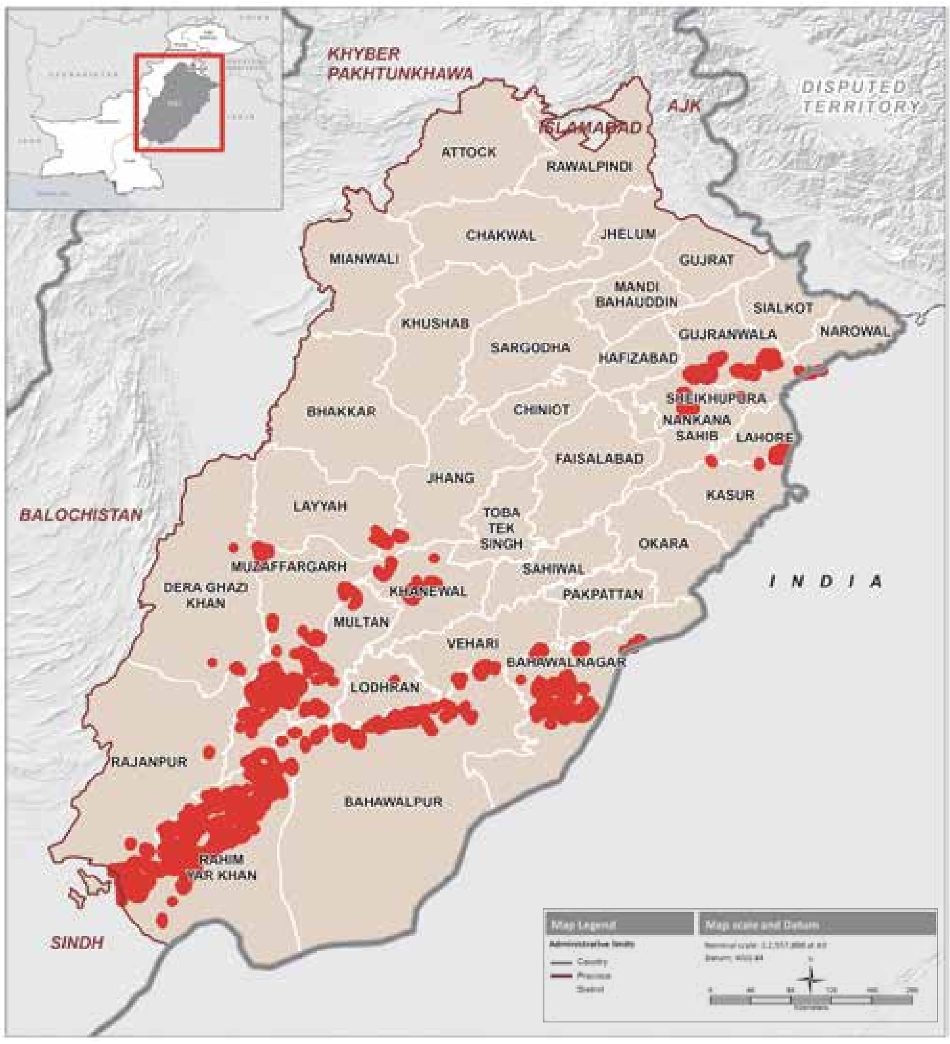
AGRONOMIC CROPS

Most suitable area for **alfalfa**

Climate	max 28 °C / min 10 °C
Soil	silt clay, silt clay loam
Water	350 mm



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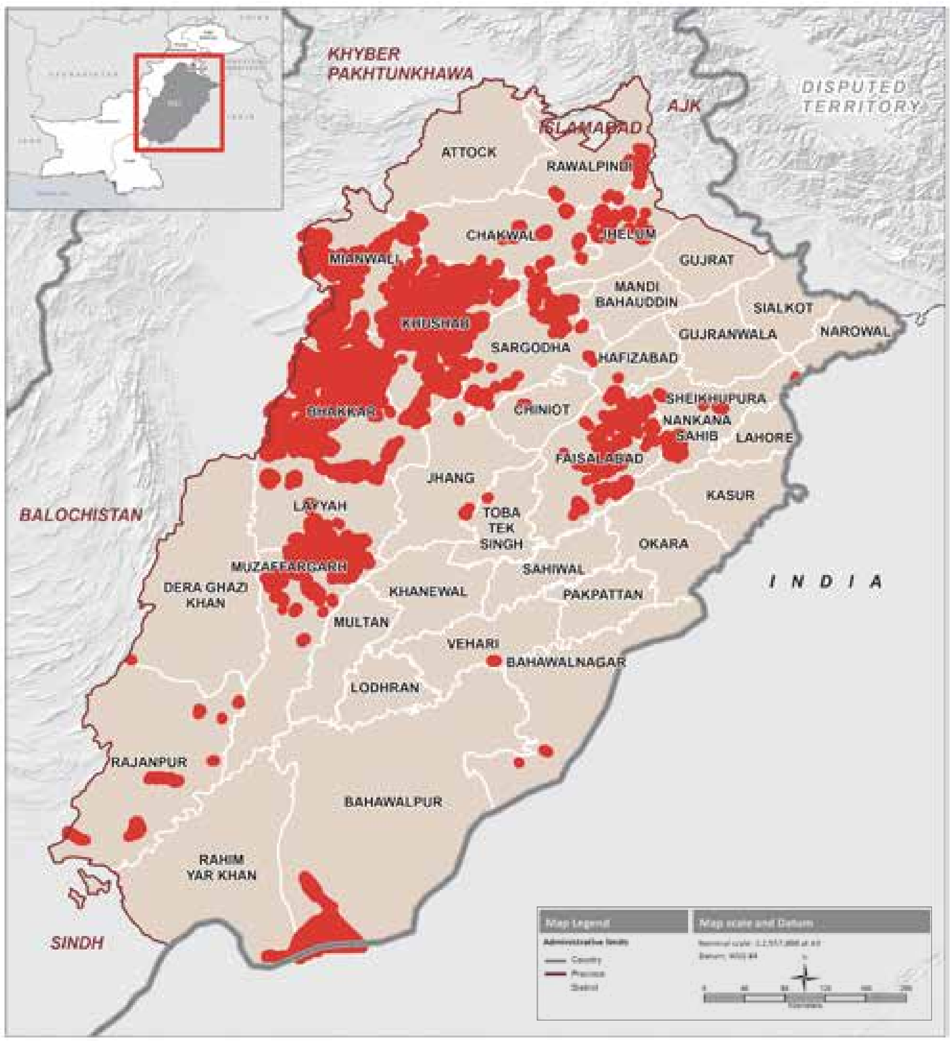
AGRONOMIC CROPS

Most suitable area for **sugarcane**

Climate	max 40 °C / min 20 °C
Soil	medium clay, heavy loam
Water	1 600–2 000 mm



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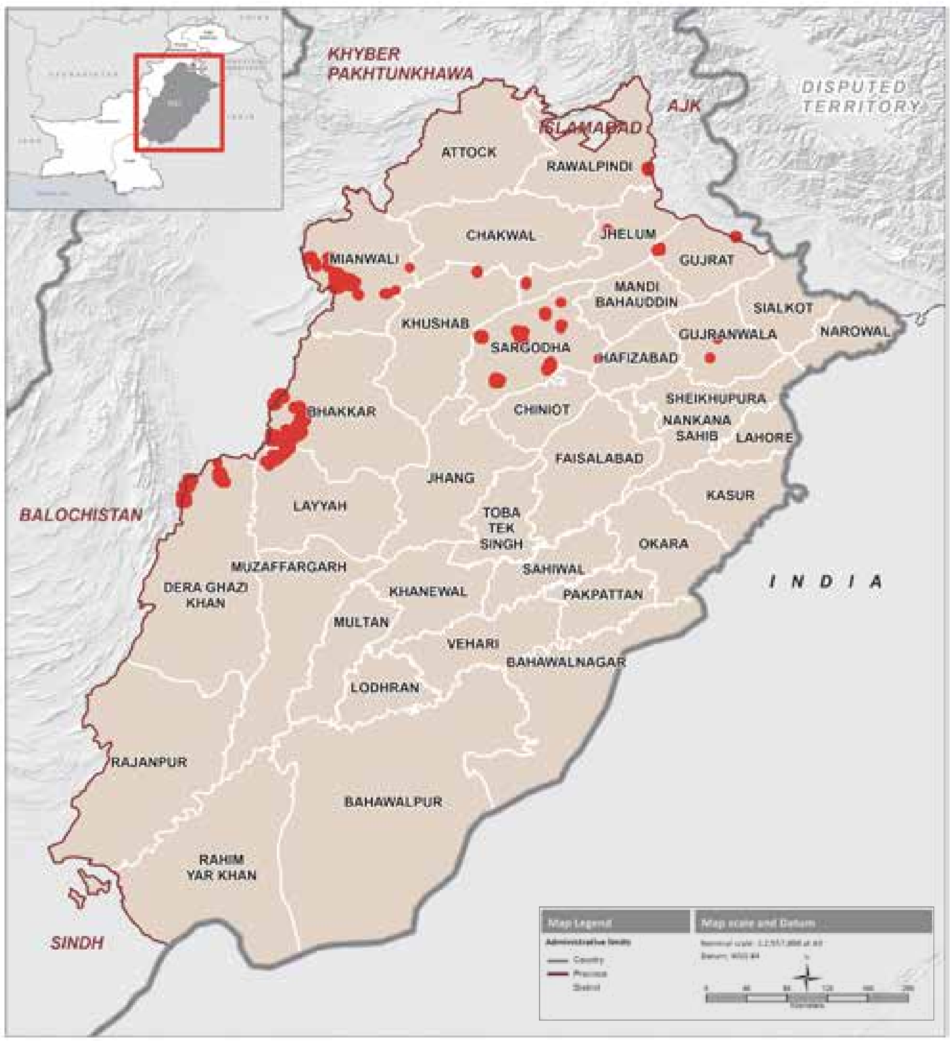
AGRONOMIC CROPS

Most suitable area for **millet**

Climate	max 42 °C / min 20 °C
Soil	silt, sandy, sandy loam, loam
Water	300–600 mm



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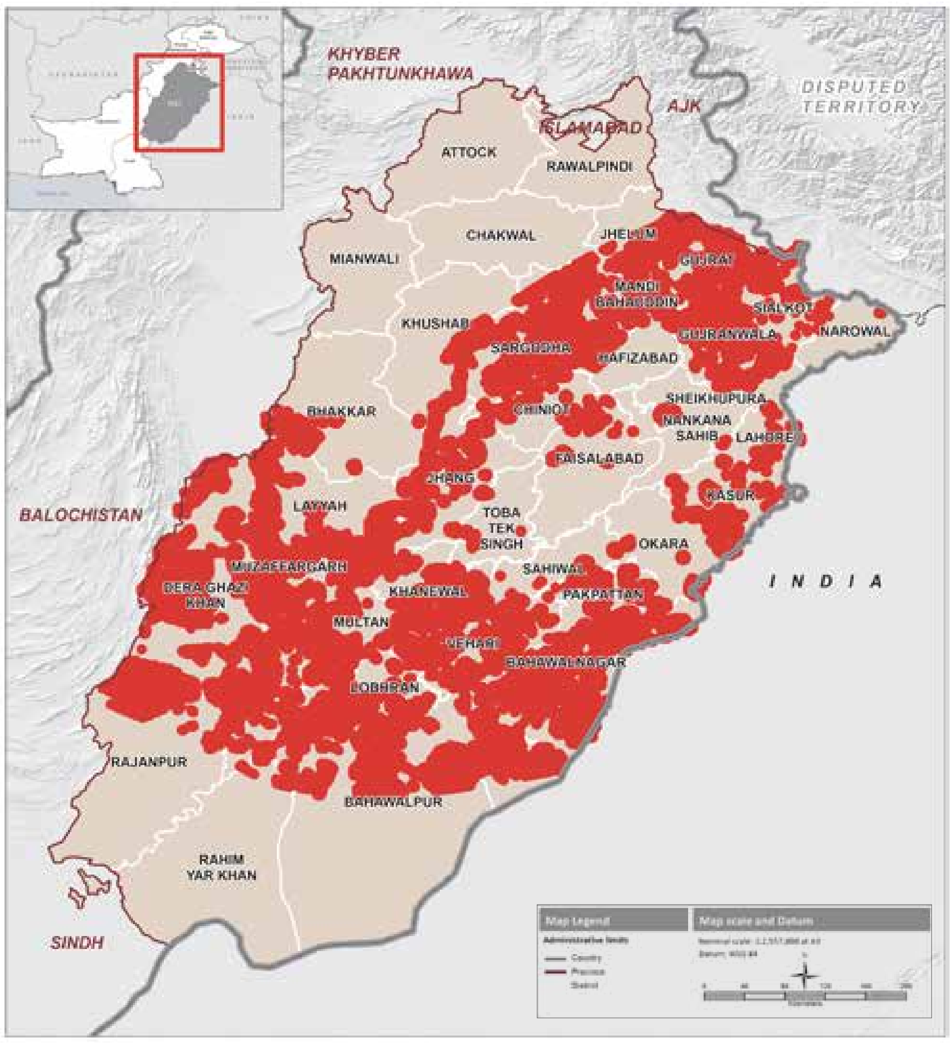
AGRONOMIC CROPS

Most suitable area for **lentil**

Climate	max 26 °C / min 8 °C
Soil	sandy, sandy loam, loam
Water	260 mm



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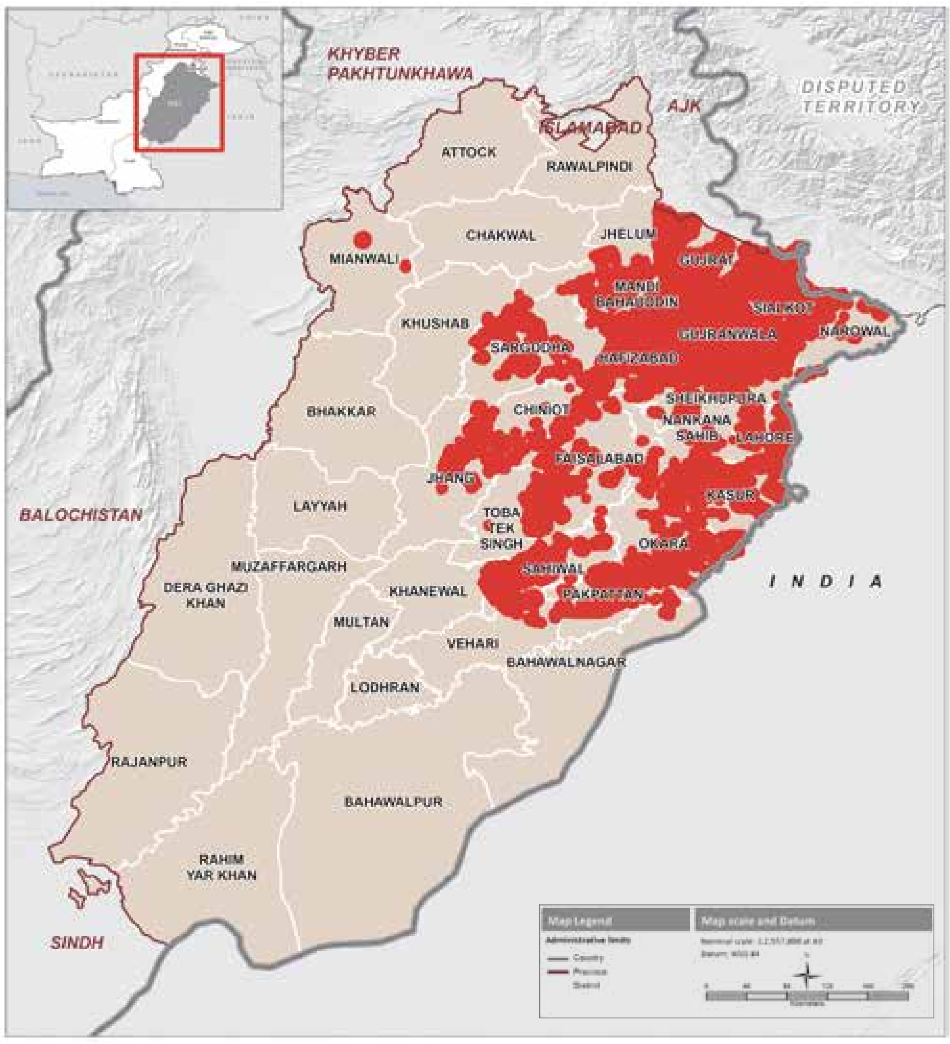
AGRONOMIC CROPS

Most suitable area for **canola**

Climate	max 27 °C / min 10 °C
Soil	loam, clay loam, silt loam
Water	250 mm



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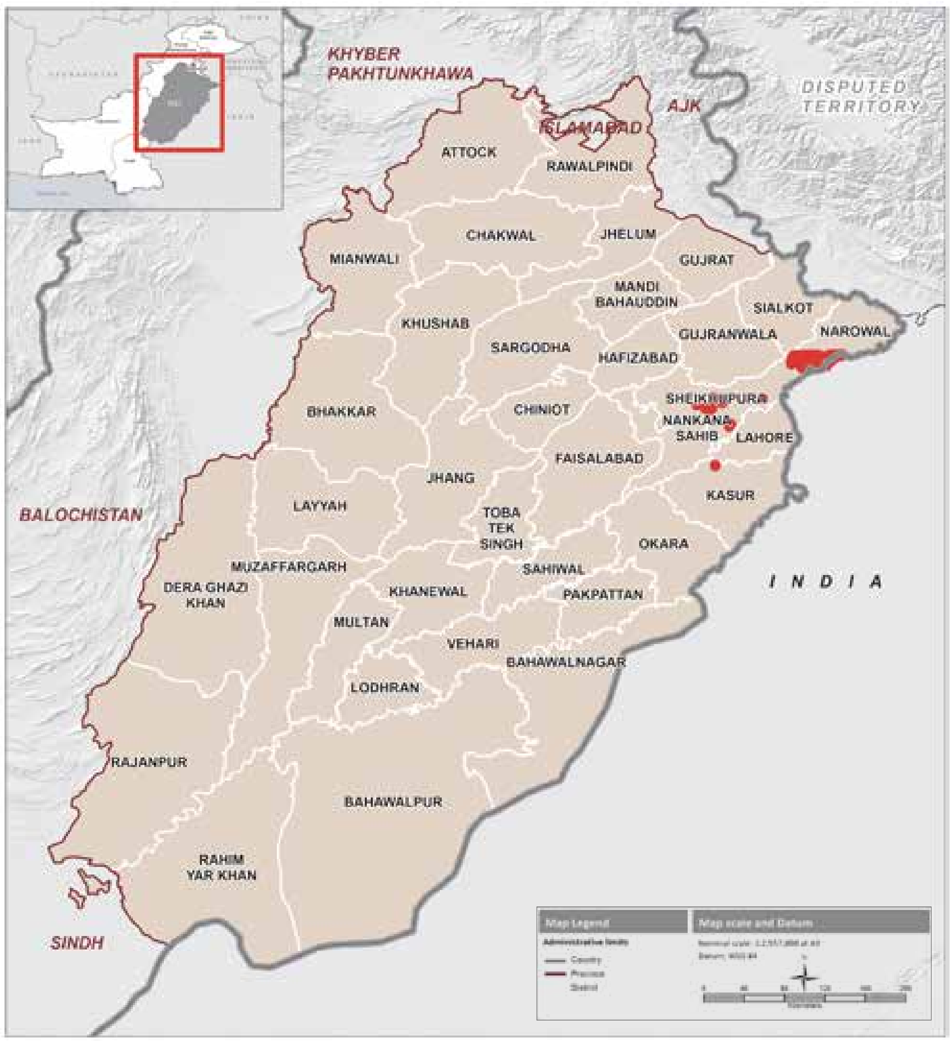
AGRONOMIC CROPS

Most suitable area for **linseed**

Climate	max 30 °C / min 10 °C
Soil	loamy, sandy clay loam
Water	350 mm



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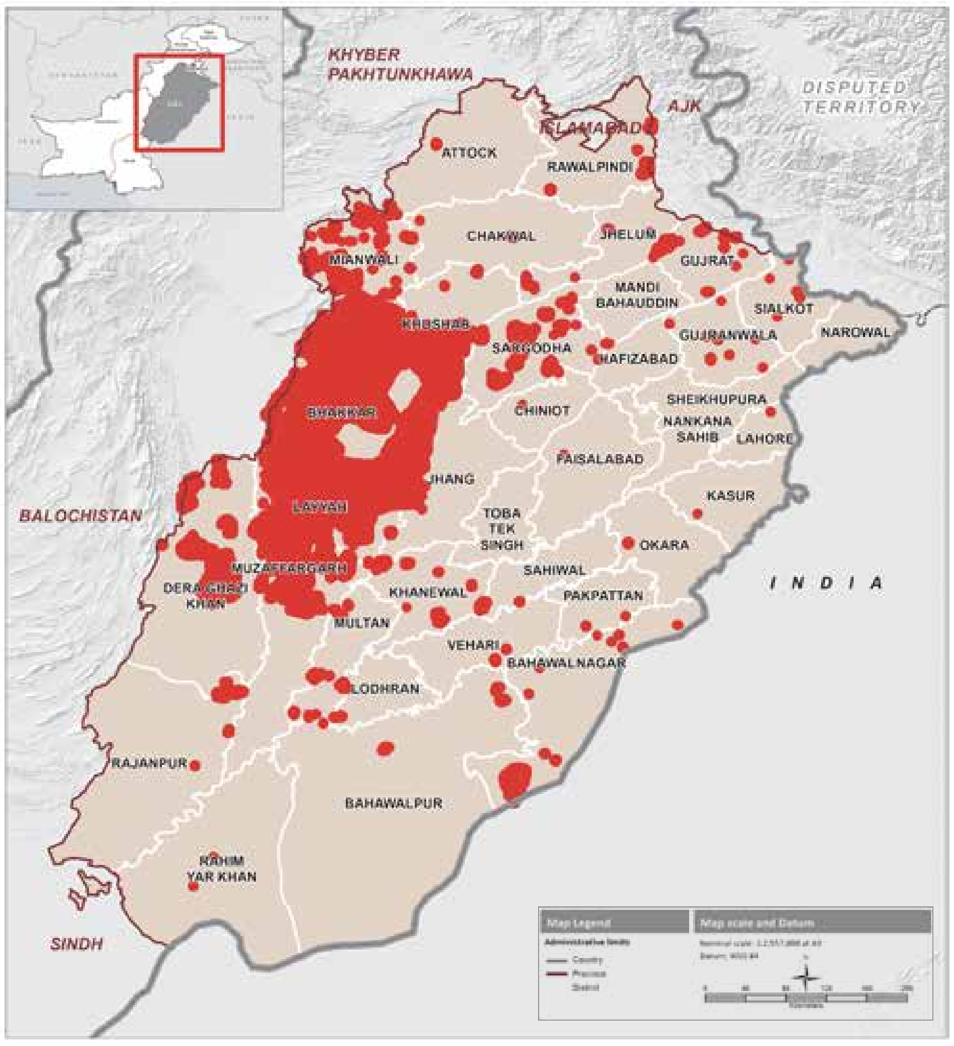
AGRONOMIC CROPS

Most suitable area for **sugarbeet**	
Climate	max 30 °C / min 12 °C
Soil	clay loam, silt clay, loam
Water	300 mm



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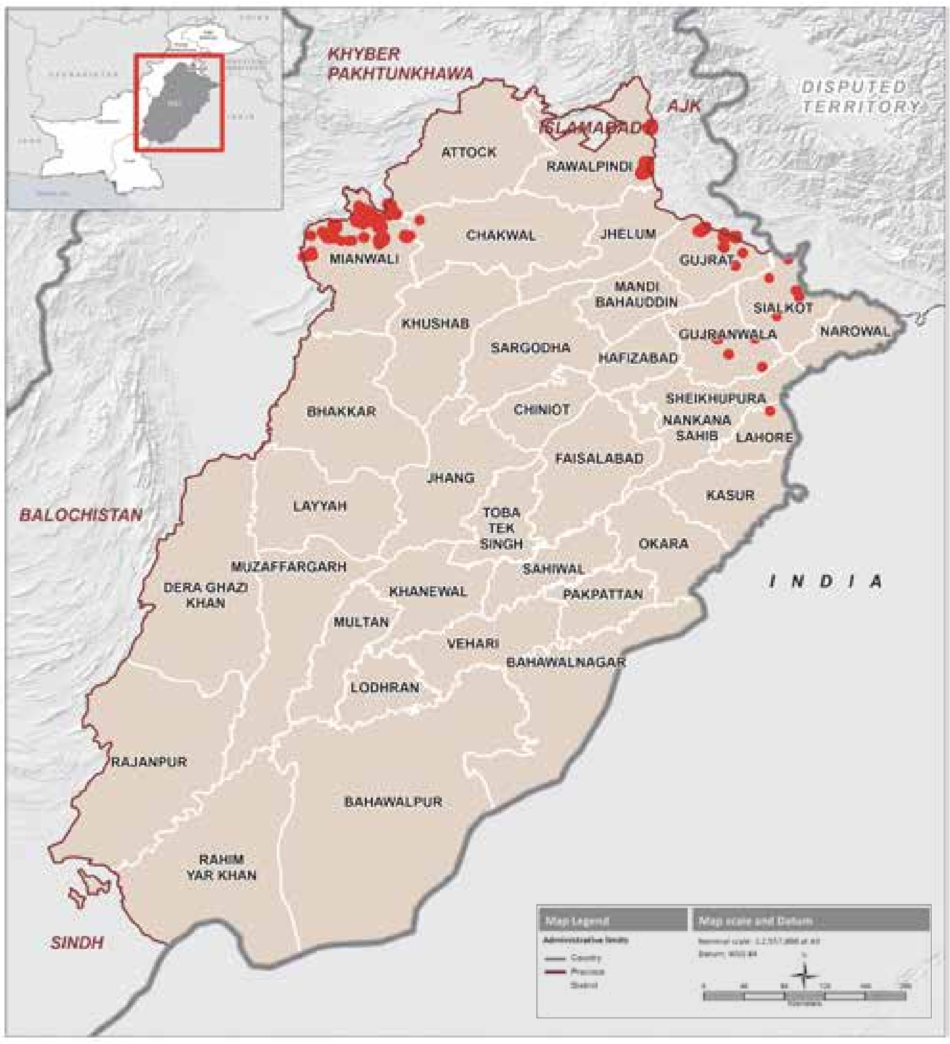
AGRONOMIC CROPS

Most suitable area for **quinoa**	
Climate	max 35 °C / min 15 °C
Soil	sandy, sandy loam
Water	225 mm



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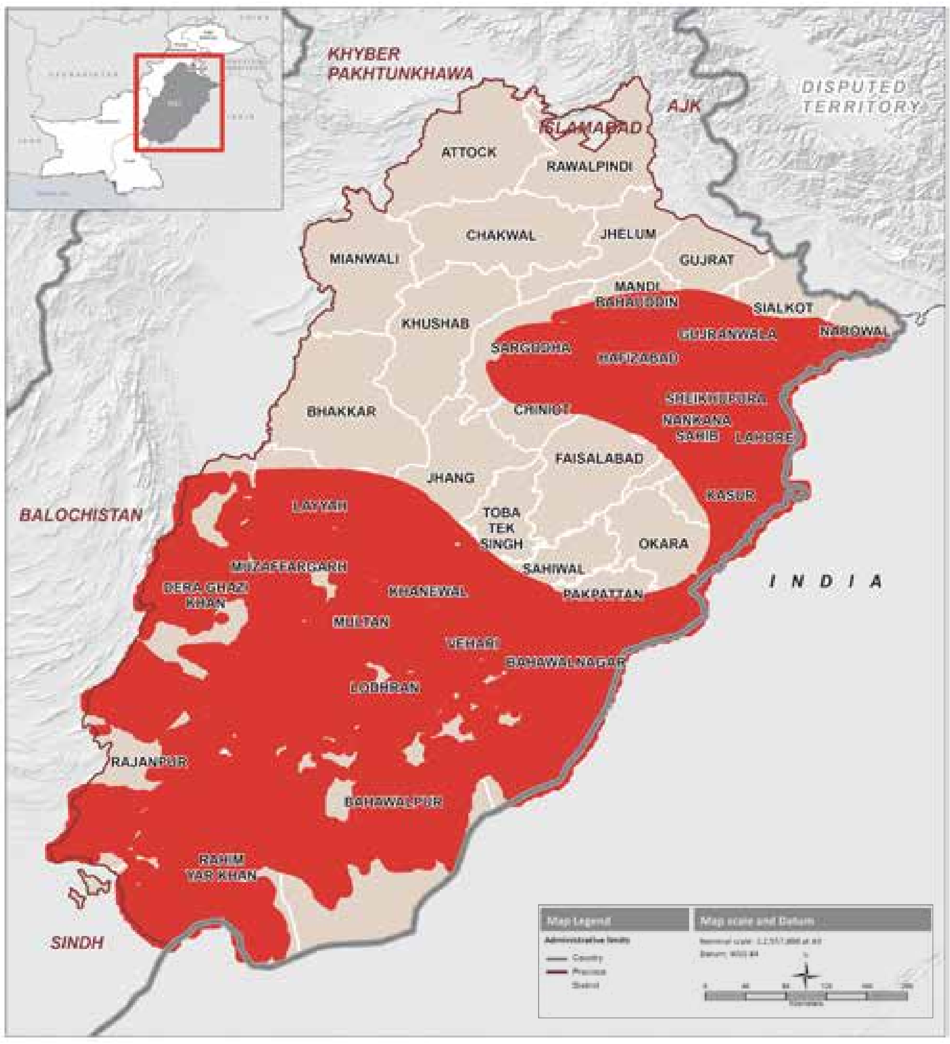
AGRONOMIC CROPS

Most suitable area for **moringa**	
Climate	max 30 °C / min 12 °C
Soil	loam, sandy loam
Water	450 mm



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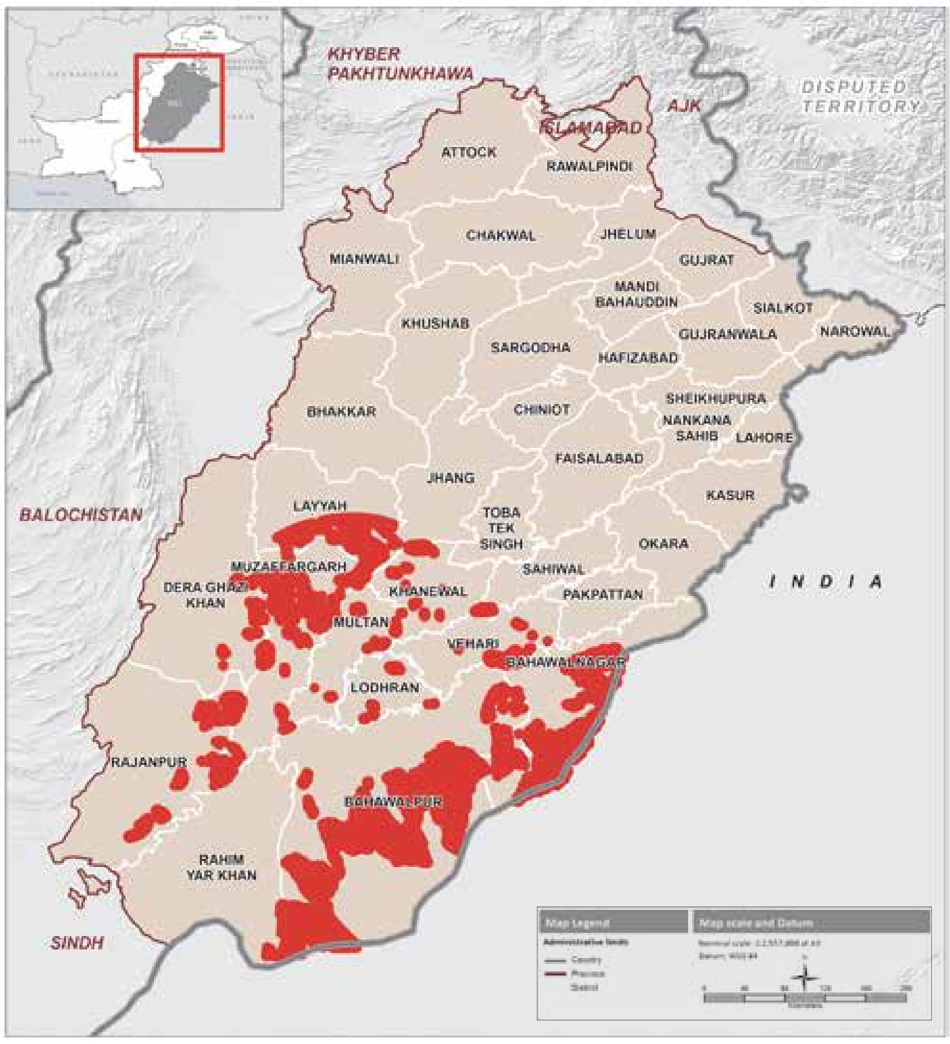
AGRONOMIC CROPS

Most suitable area for **sudan grass**	
Climate	max 42 °C / min 18 °C
Soil	clay, silty clay, sandy clay, loam, sandy loam
Water	375 mm



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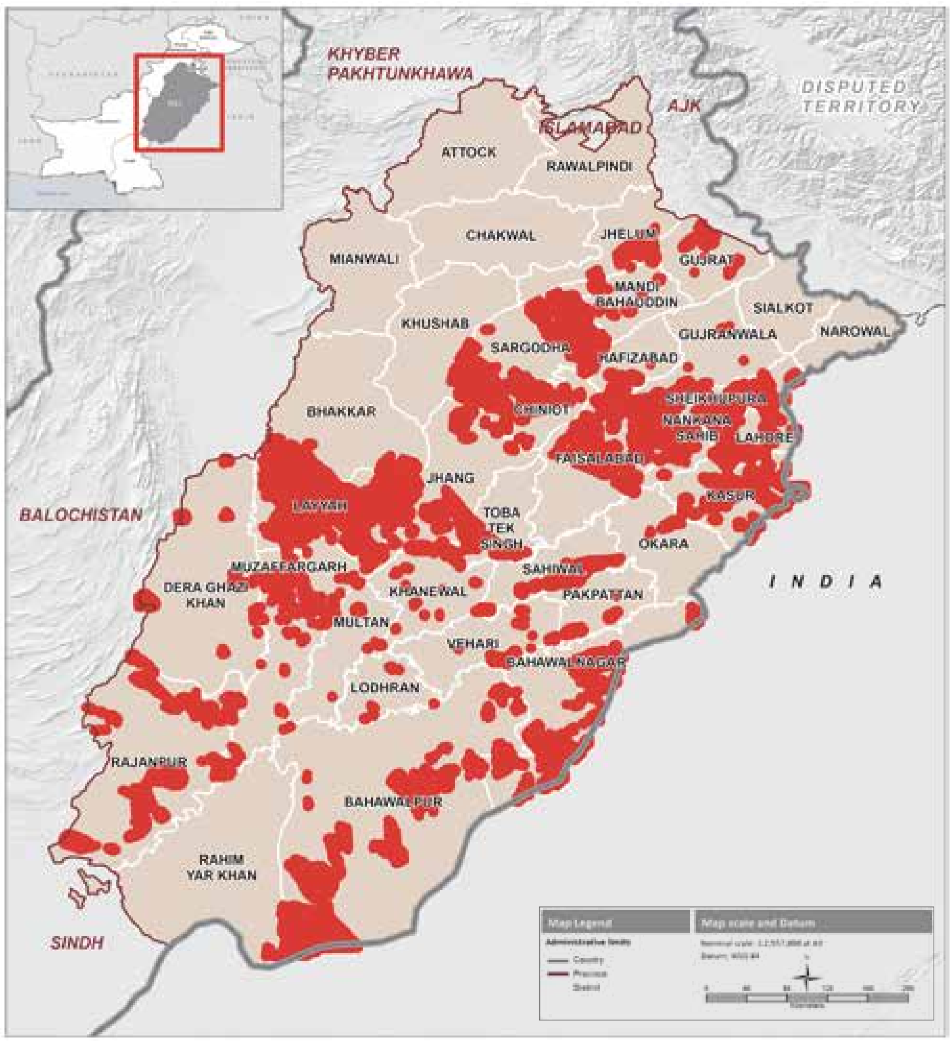
AGRONOMIC CROPS

Most suitable area for cotton

Climate	max 40 °C / min 26 °C
Soil	loam, medium heavy, medium clay, medium loam, silty loam, sandy loam
Water	500–800 mm



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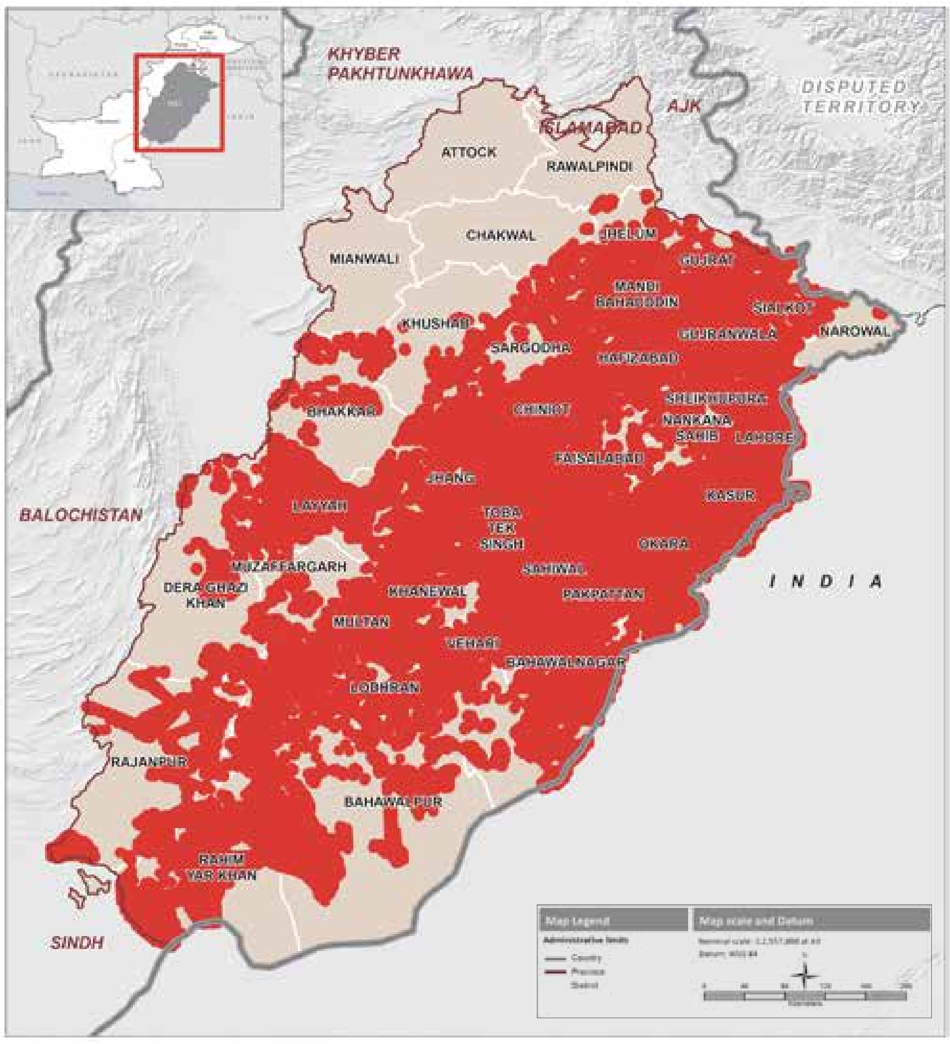
AGRONOMIC CROPS

Most suitable area for maize

Climate	max 38 °C / min 20 °C
Soil	silty loam, sandy loam, loamy, medium clay
Water	500–800 mm



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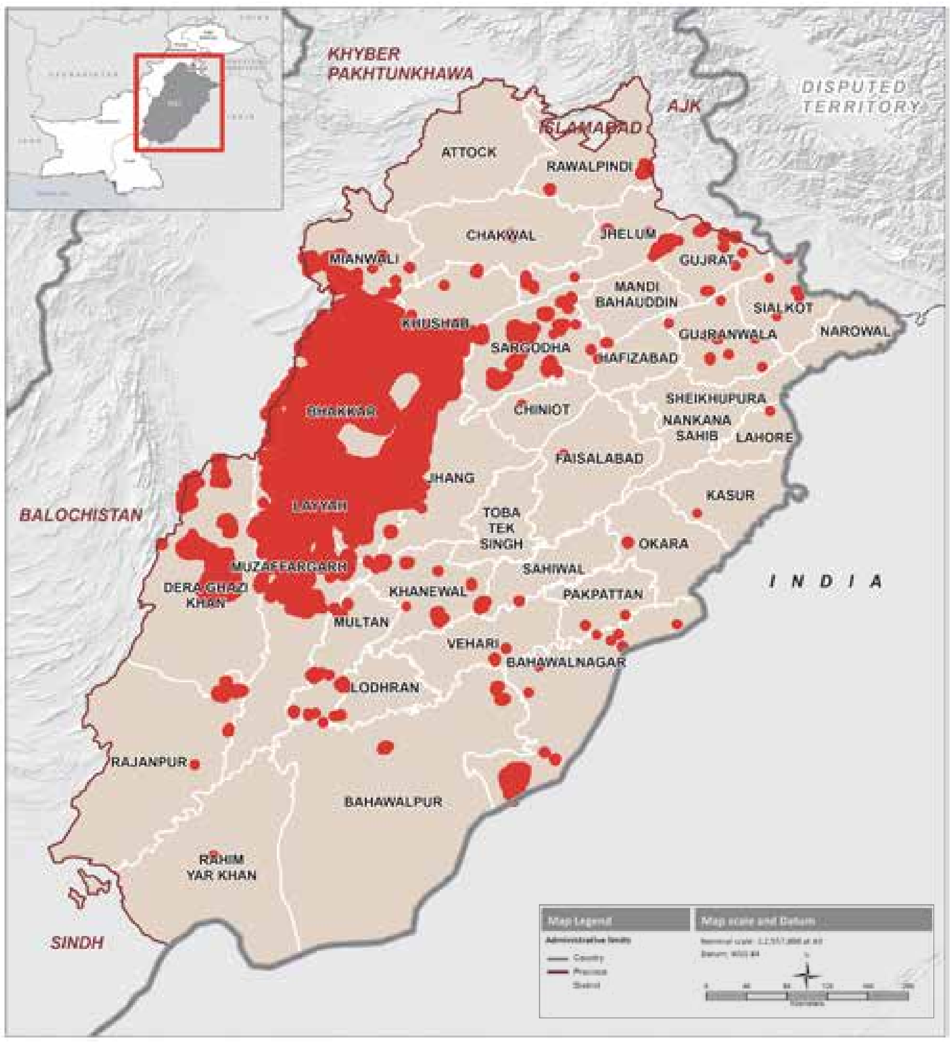
AGRONOMIC CROPS

Most suitable area for sunflower

Climate	max 40 °C / min 20 °C
Soil	medium clay, silty loam, clay
Water	500–1 000 mm



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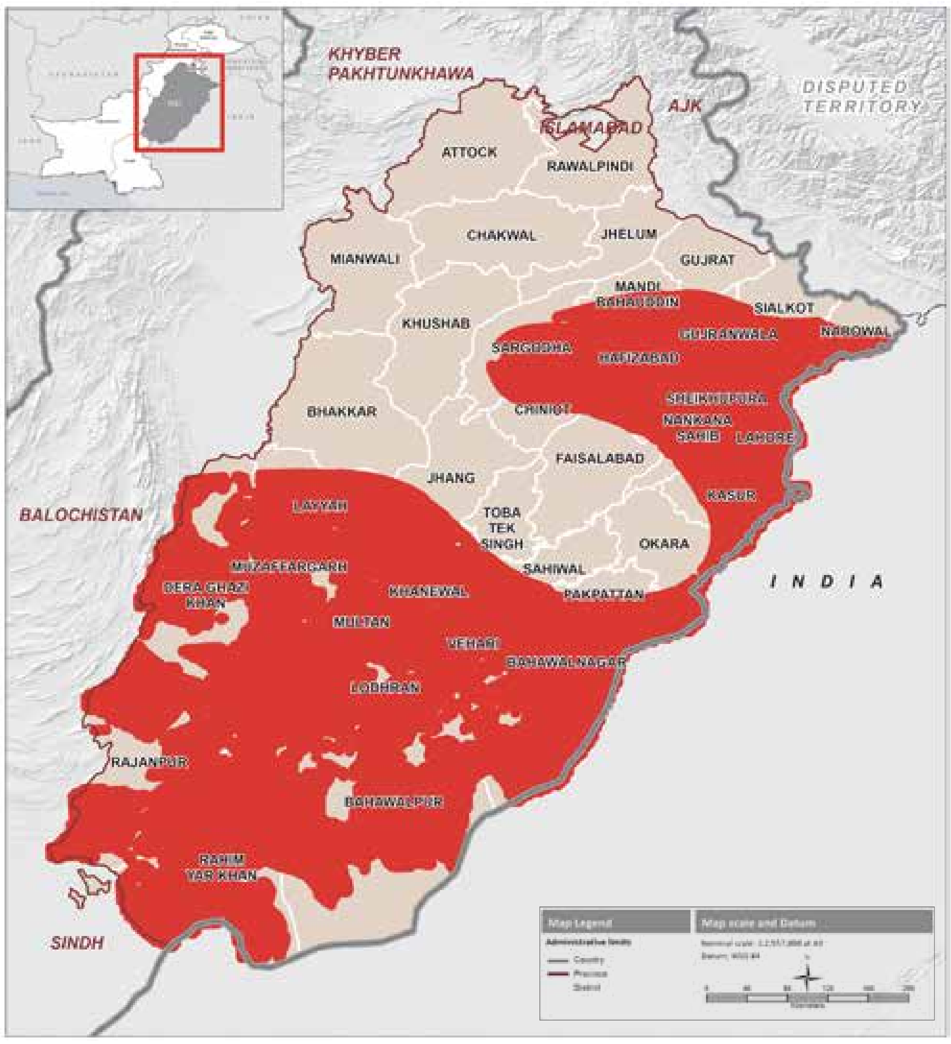
AGRONOMIC CROPS

Most suitable area for gram

Climate	max 28 °C / min 8 °C
Soil	silty loam, sandy loam
Water	200 mm



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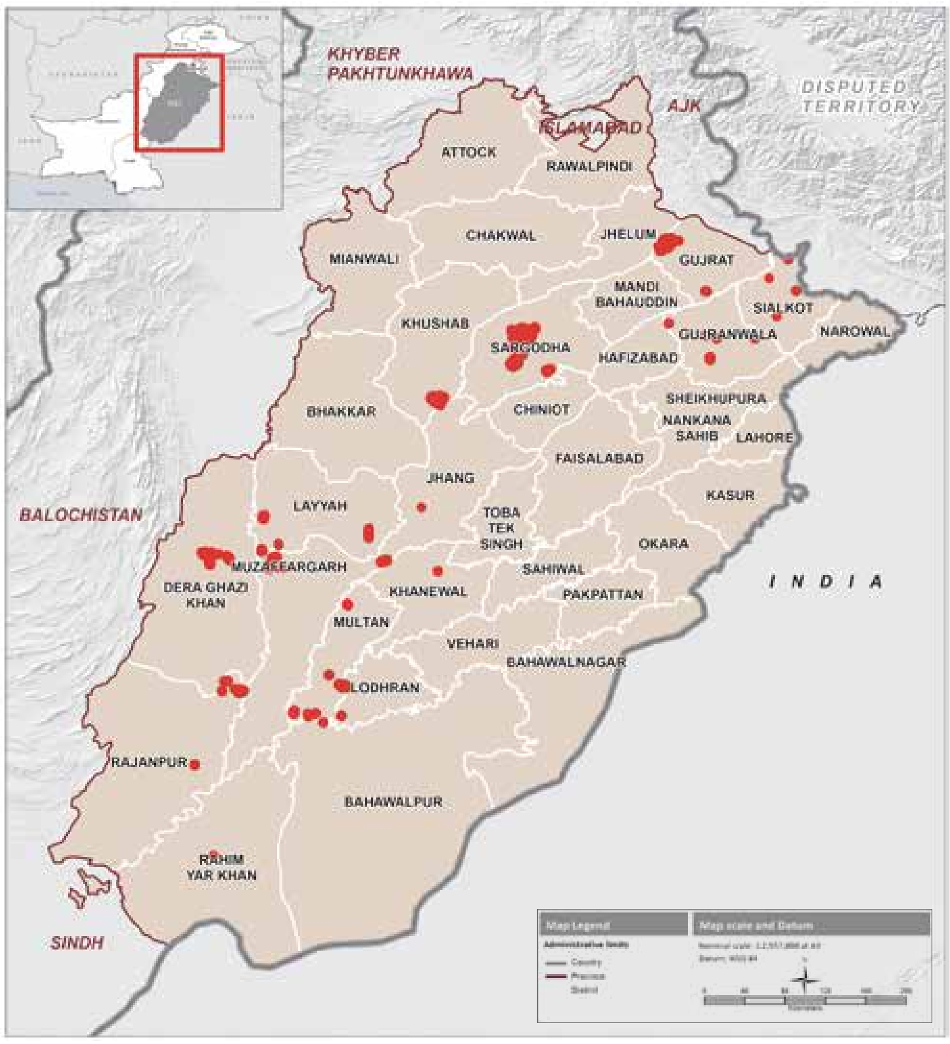
AGRONOMIC CROPS

Most suitable area for **mott grass**

Climate	max 40 °C / min 20 °C
Soil	sandy loam, clay loam
Water	200–300 mm



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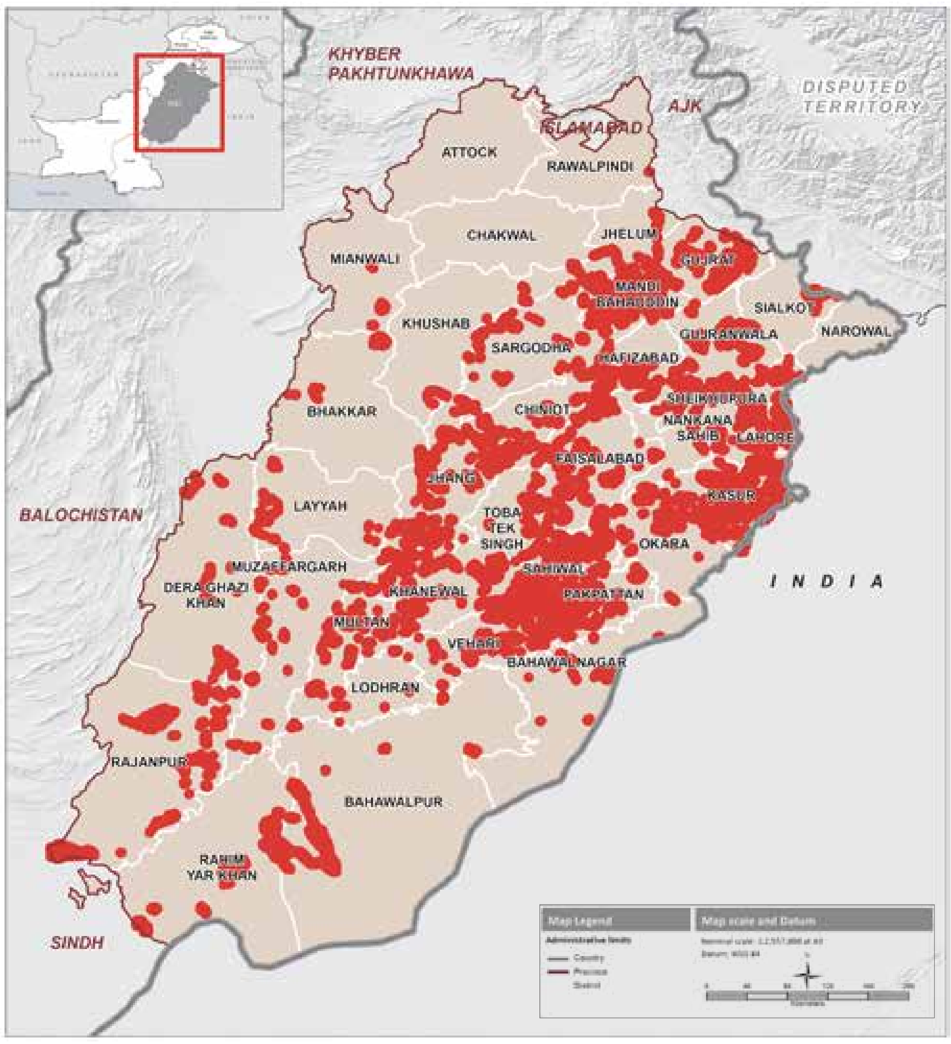
FRUITS

Most suitable area for **citrus**

Climate	max 40 °C / min 5 °C
Soil	loam, silt loam, clay loam
Water	1 250–1 850 mm



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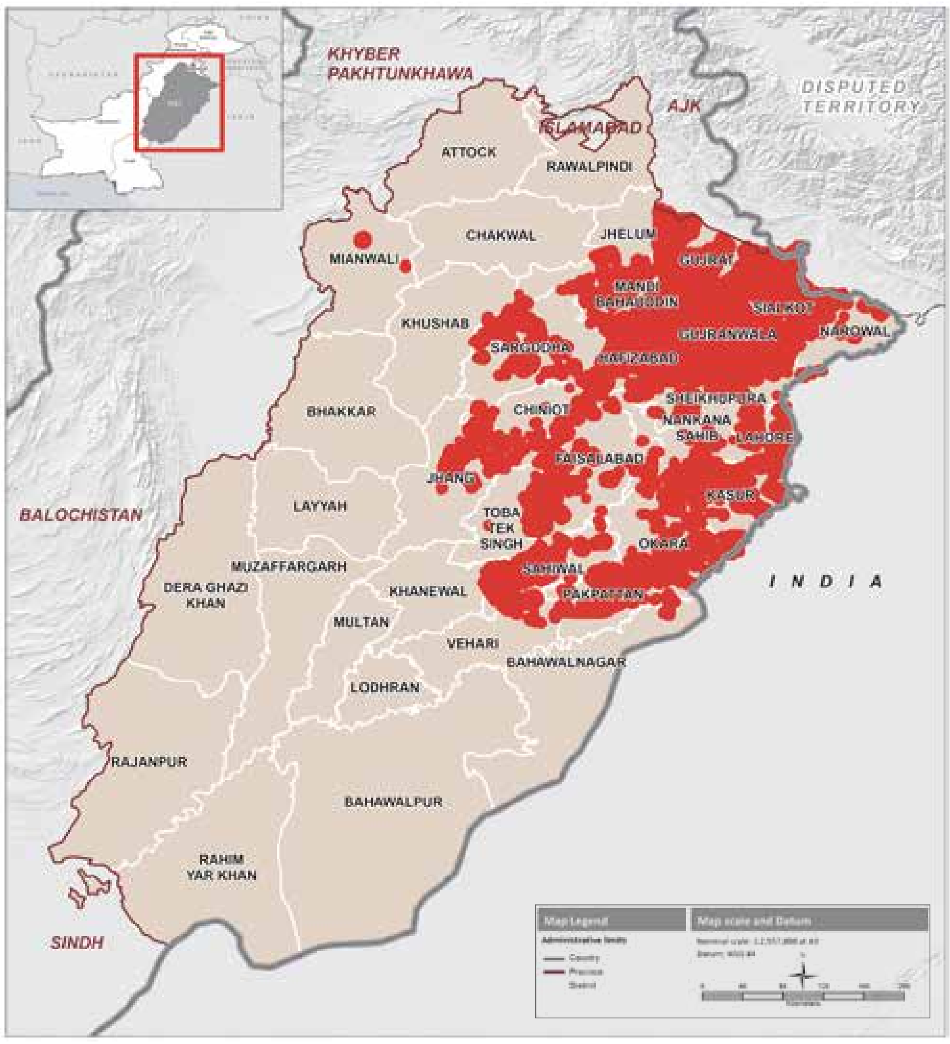
FRUITS

Most suitable area for **mango**

Climate	max 48 °C / min 5 °C
Soil	silt clay, clay loam, sandy loam
Water	892–1 060 mm



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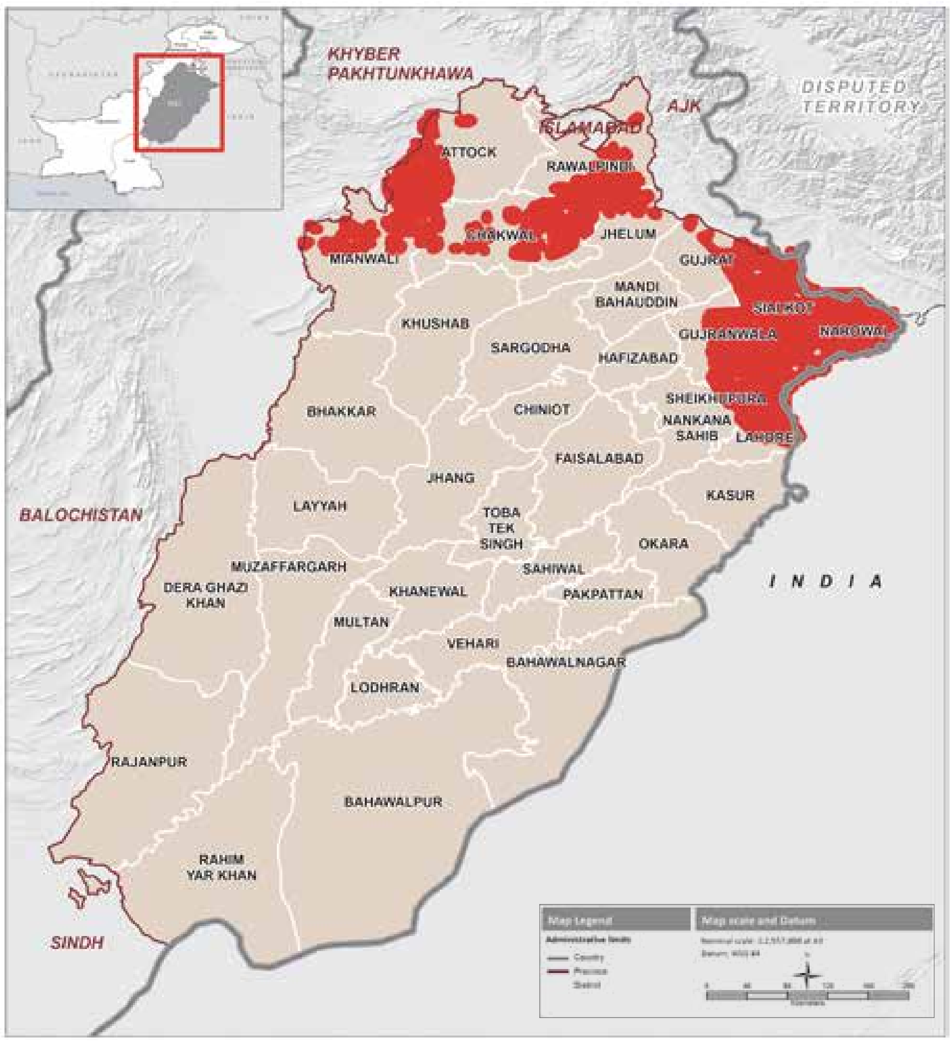
FRUITS

Most suitable area for **guava**

Climate	max 32 °C / min 3.8 °C
Soil	clay, silt clay loam
Water	21 000–2 000 mm



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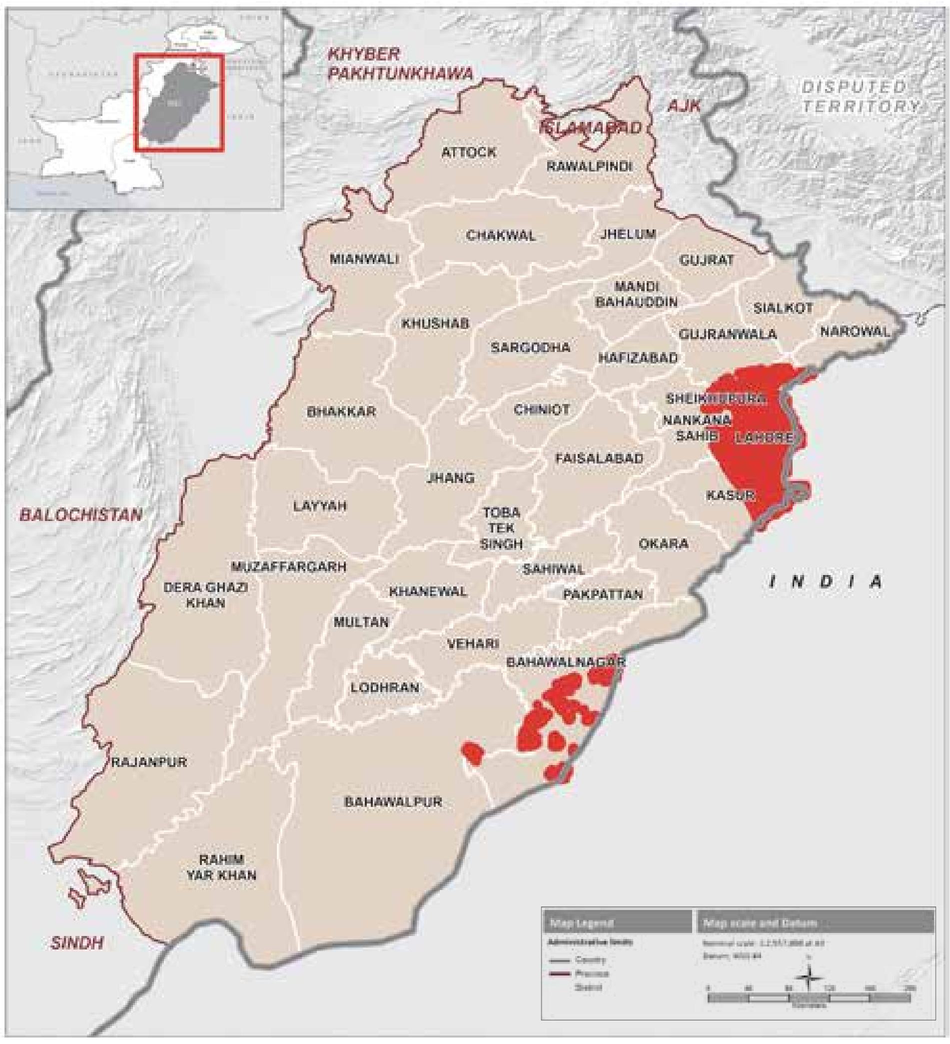
FRUITS

Most suitable area for **strawberry**

Climate	max 30 °C / min -5 °C
Soil	clay, silt clay loam
Water	300 mm



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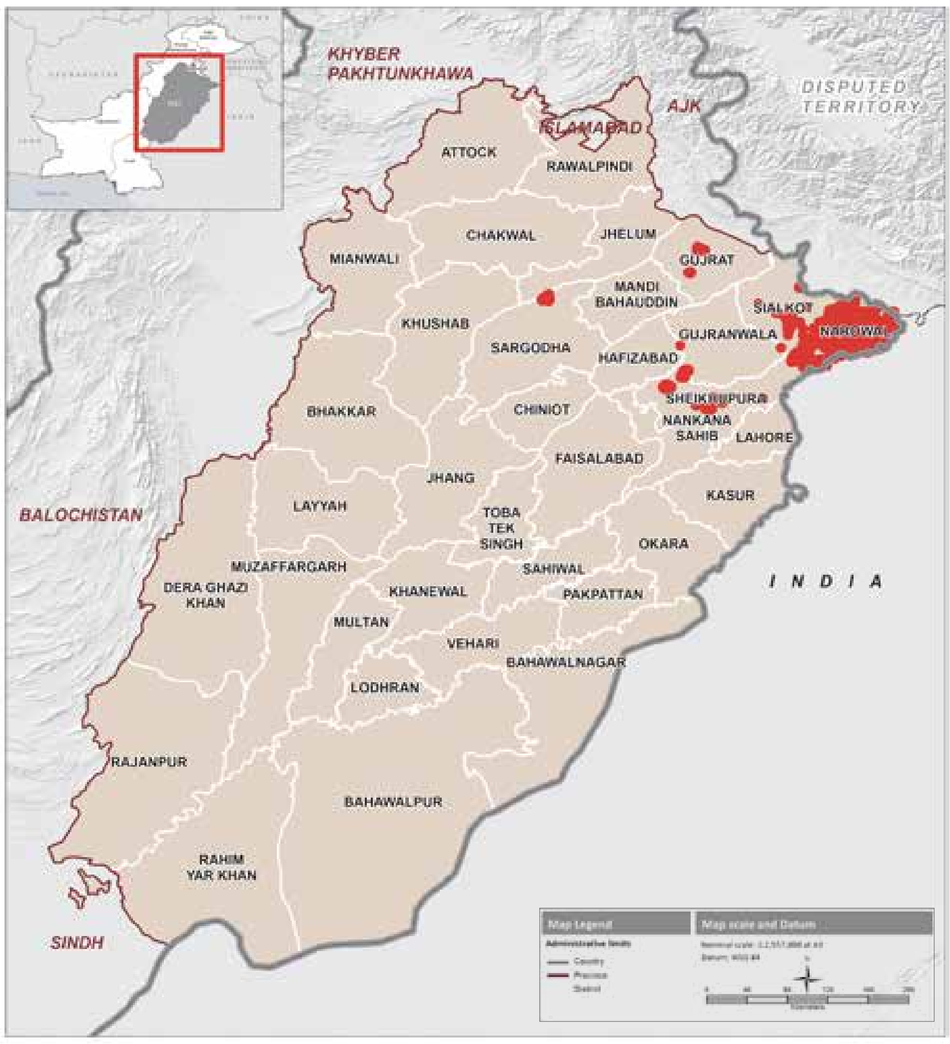
VEGETABLES

Most suitable area for **squashes**

Climate	max 40 °C / min 20 °C
Soil	clay loam, silt loam, sandy clay lom, lay loam
Water	650–775 mm



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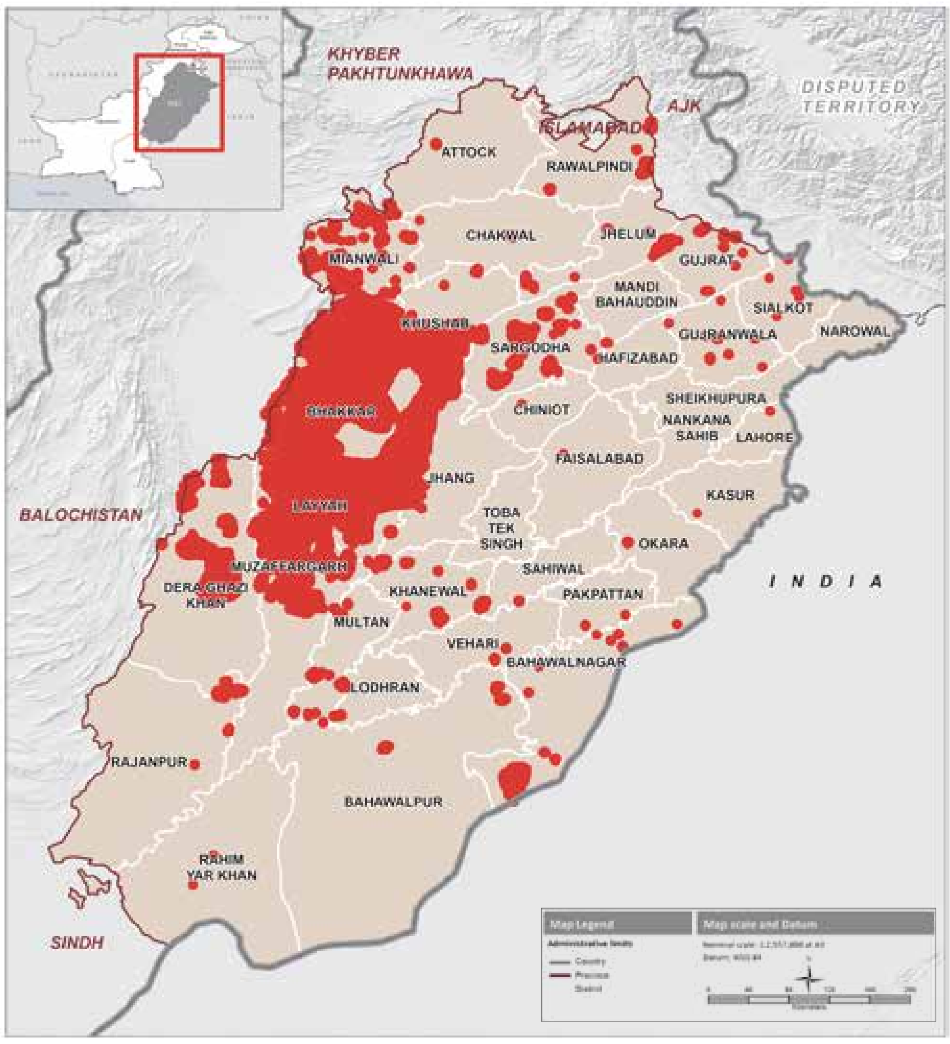
VEGETABLES

Most suitable area for **spinach**

Climate	max 25 °C / min 10 °C
Soil	clay loam, sandy clay loam, silty clay loam
Water	250 mm



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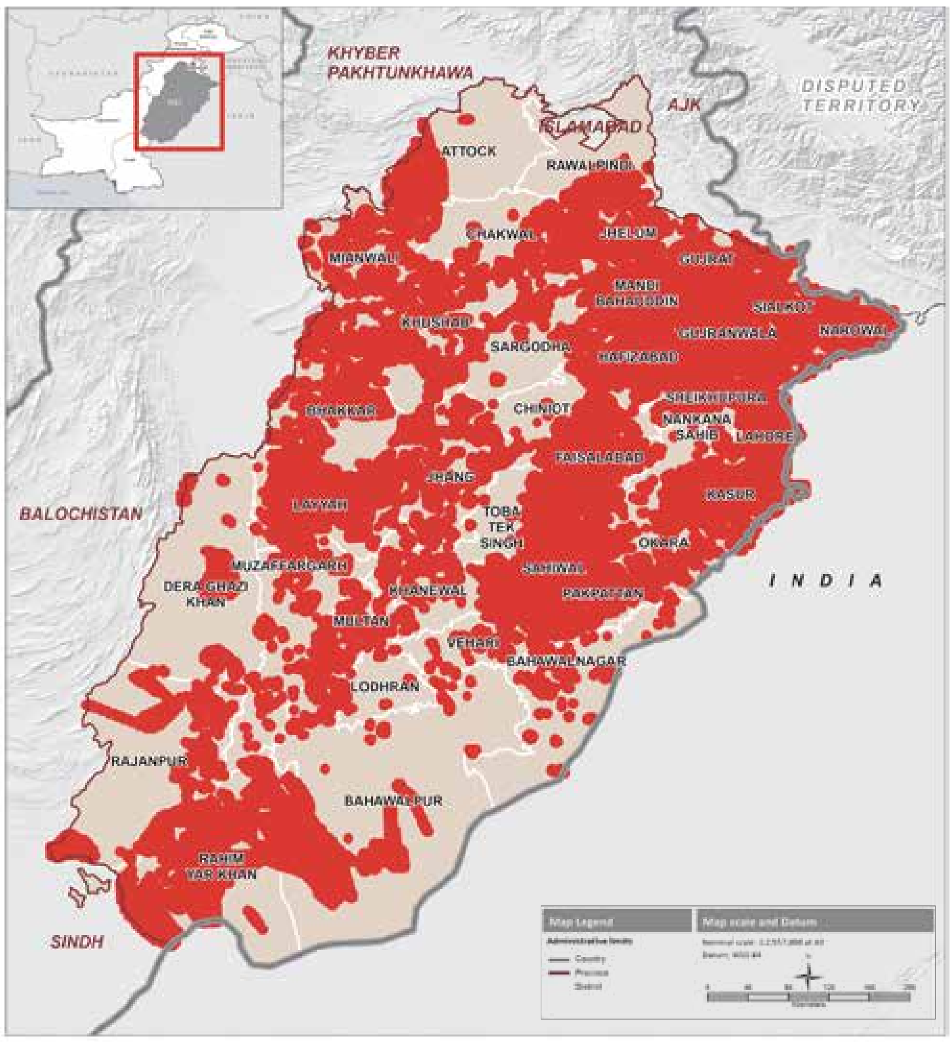
VEGETABLES

Most suitable area for **garlic**

Climate	max 25 °C / min 15 °C
Soil	sandy loam, loam, sandy clay loam
Water	400 mm



Map created by: IM Unit, FAO Pakistan.
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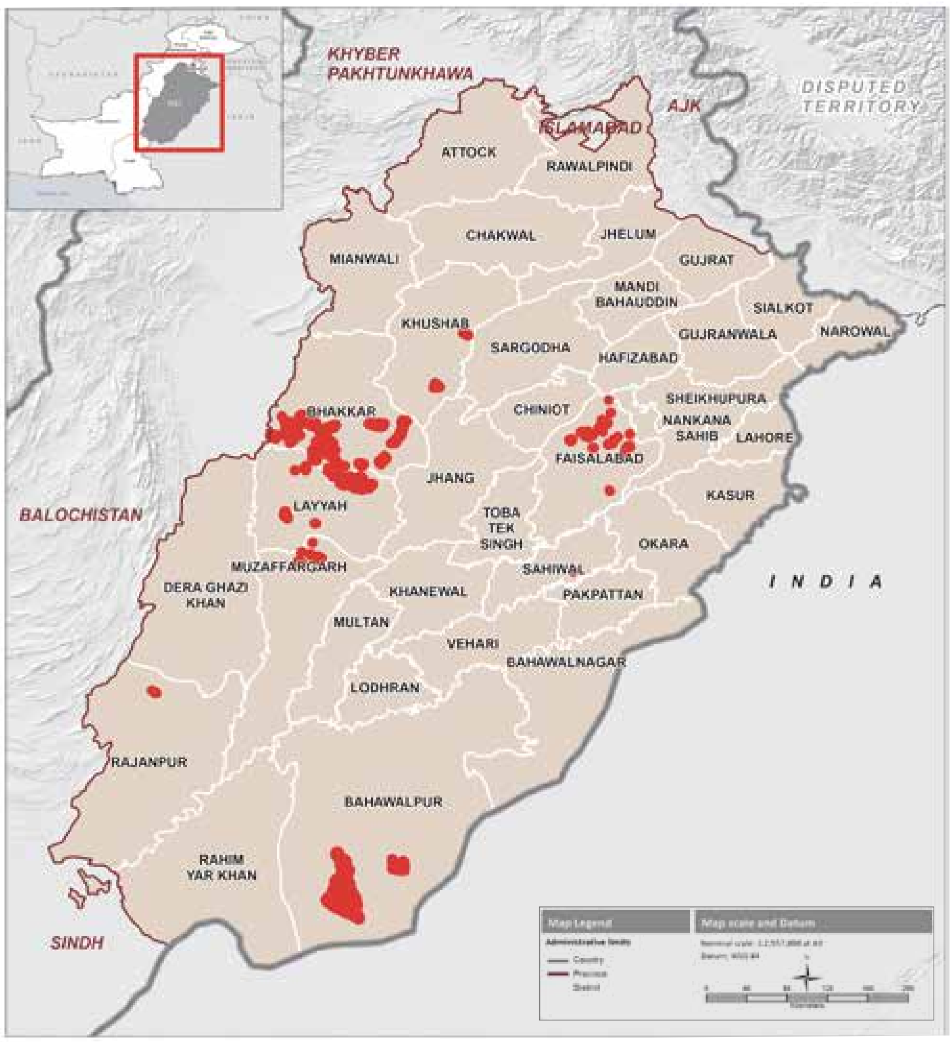
VEGETABLES

Most suitable area for **peas**

Climate	max 30 °C / min 5 °C
Soil	clay loam, silt clay loam, loam, sandy loam
Water	300 mm



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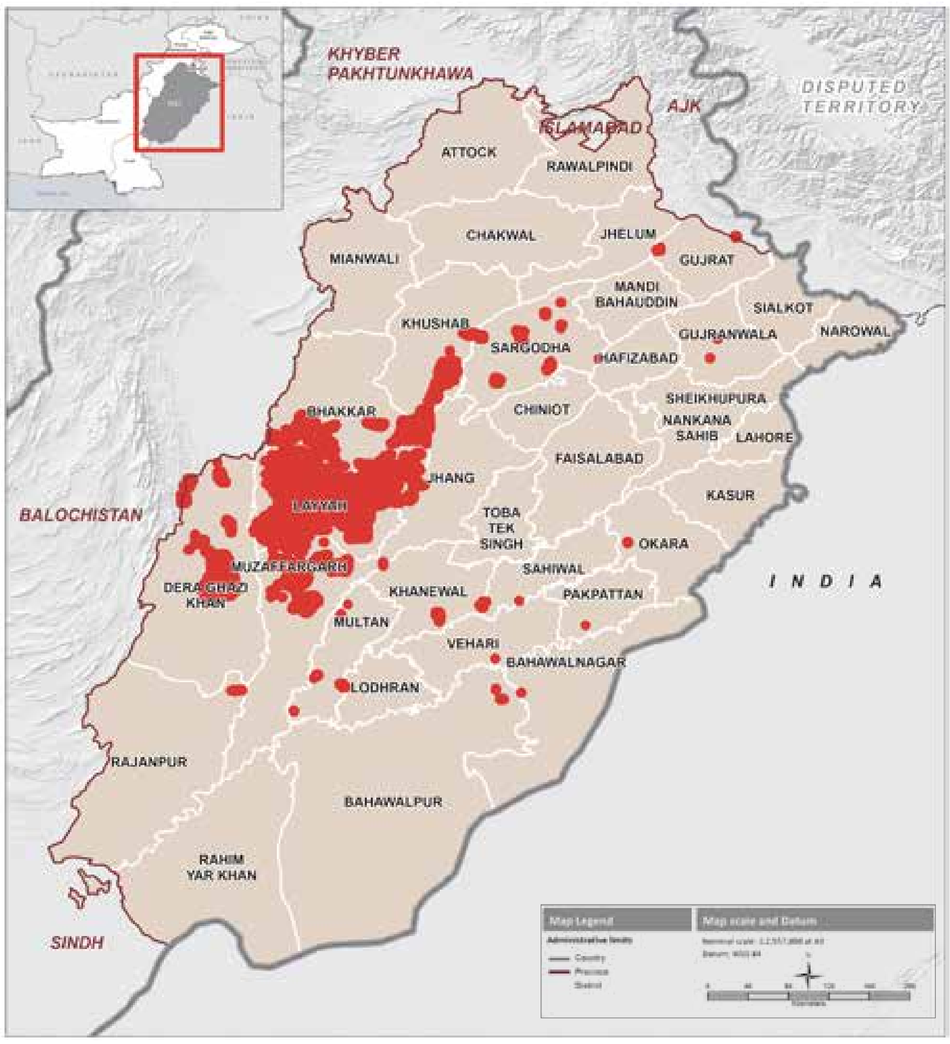
VEGETABLES

Most suitable area for **carrots**

Climate	max 30 °C / min 10 °C
Soil	sandy loam, silt loam, loam
Water	250–450 mm



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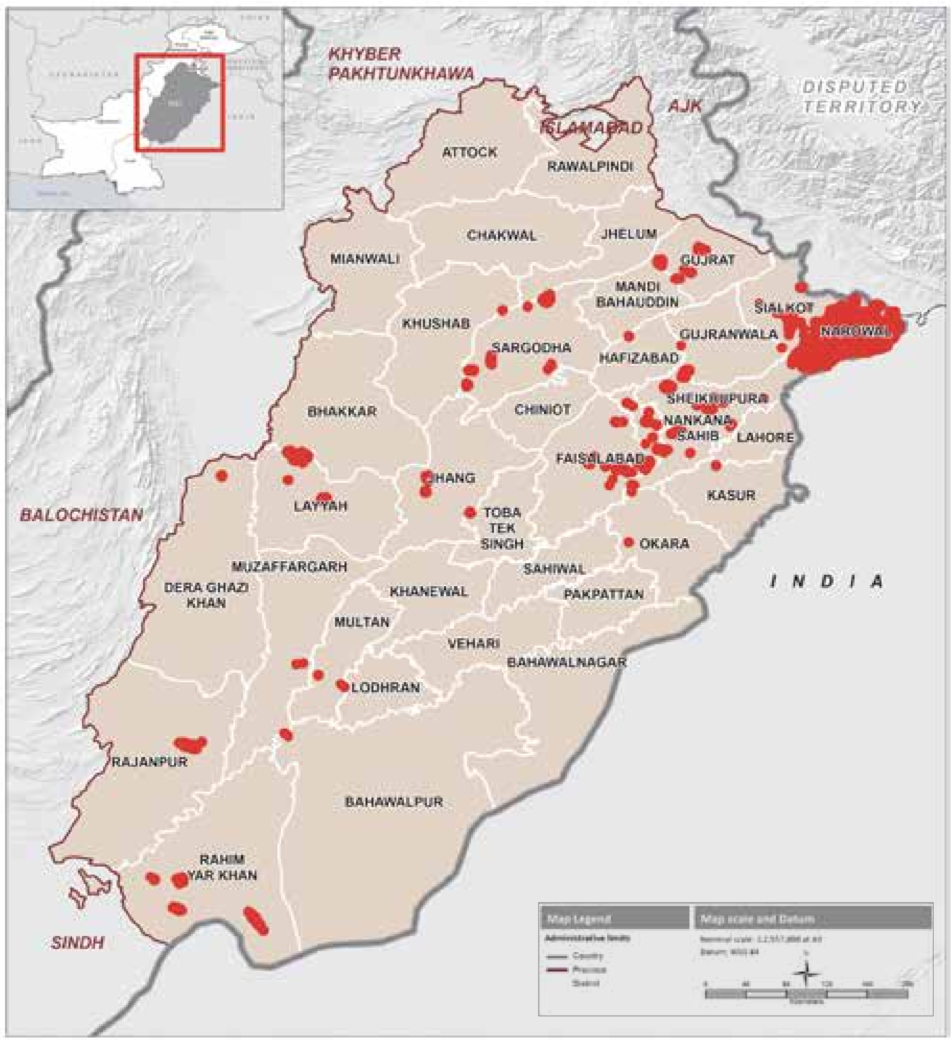
VEGETABLES

Most suitable area for **turnip**

Climate	max 28 °C / min 10 °C
Soil	sandy loam, silt loam, loam
Water	250 mm



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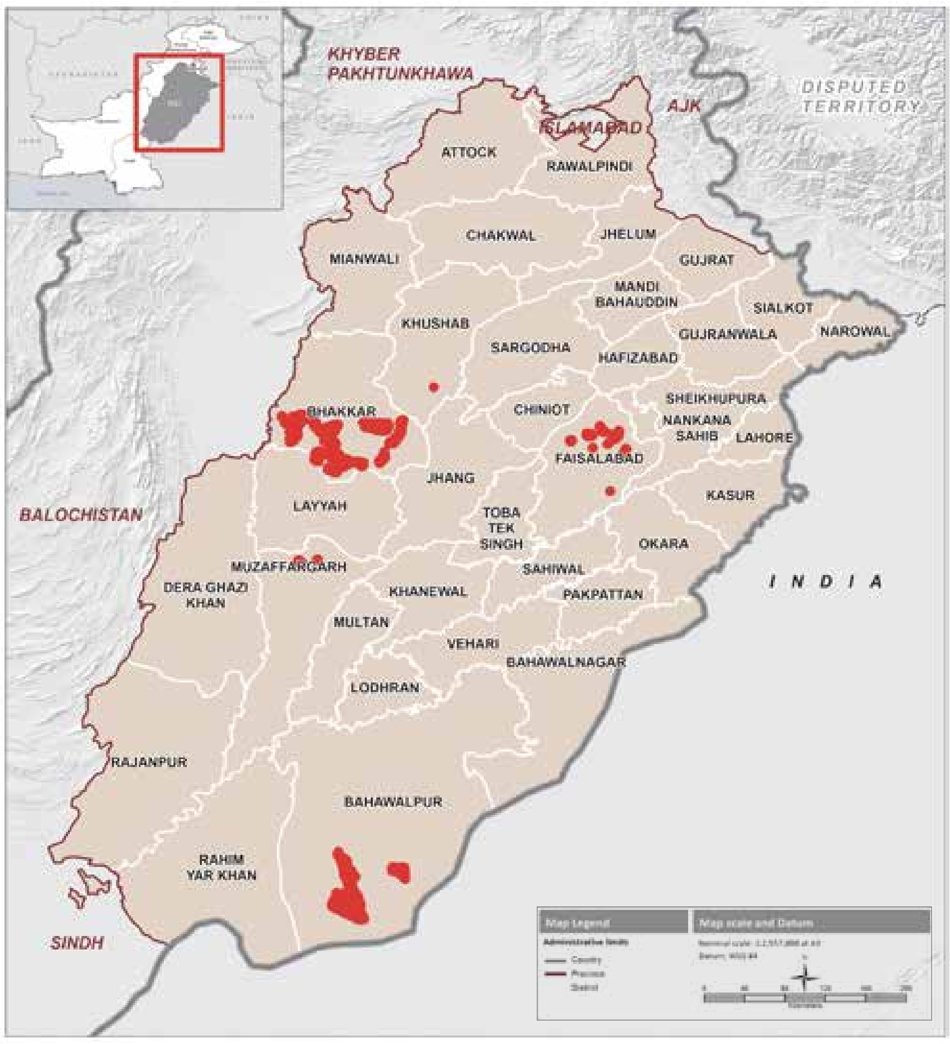
VEGETABLES

Most suitable area for **cabbage**

Climate	max 25 °C / min 10 °C
Soil	silt loam, clay loam, loam, sandy loam
Water	250 mm



Map created by: IM Unit, FAO Pakistan.
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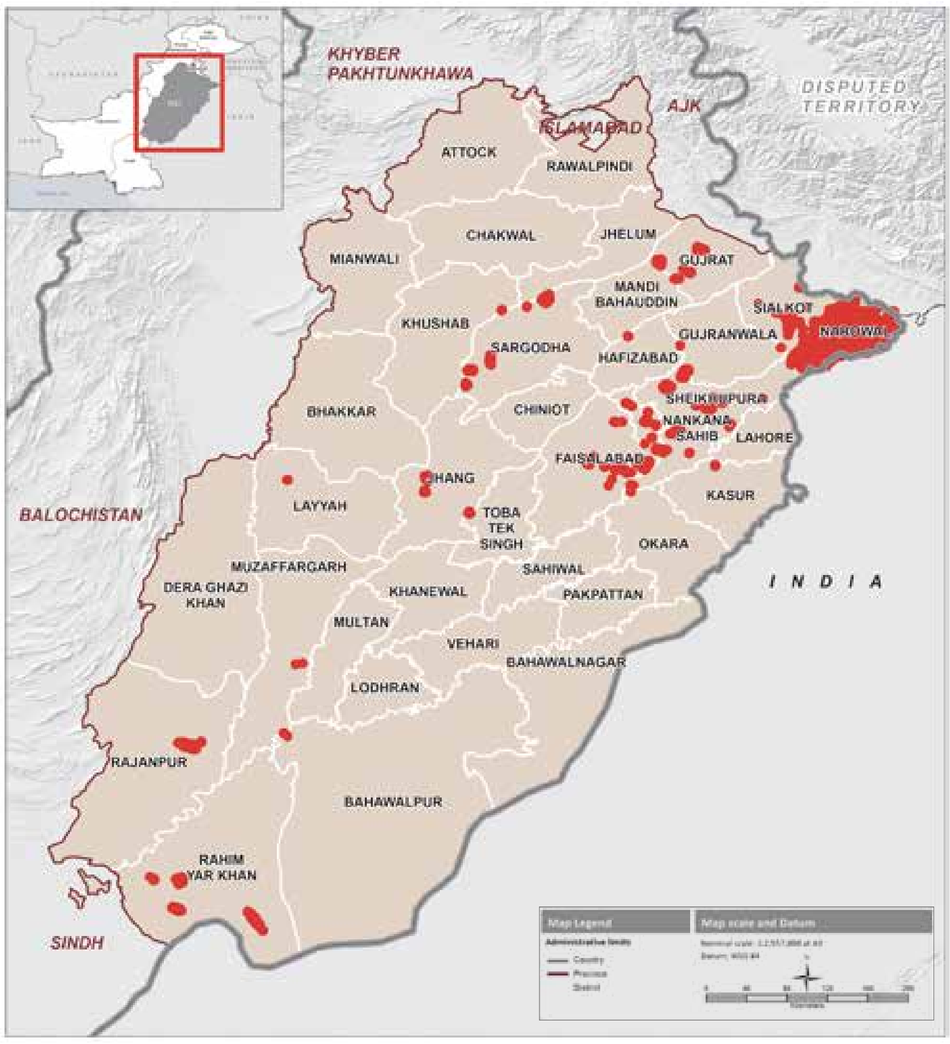
VEGETABLES

Most suitable area for **turmeric**

Climate	max 35 °C / min 15 °C
Soil	sandy loam, silt loam, loam
Water	1 500 mm



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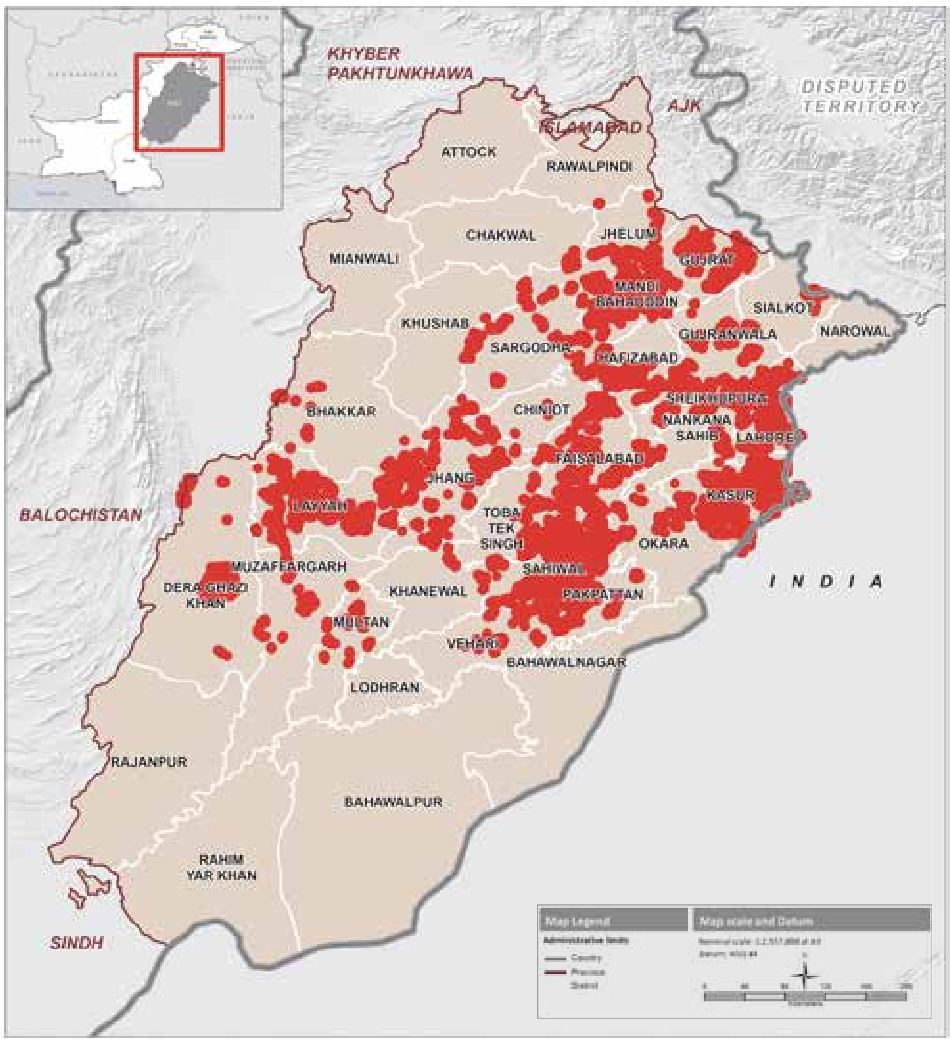
VEGETABLES

Most suitable area for **cauliflower**

Climate	max 30 °C / min 10 °C
Soil	sandy loam, silt loam, clay loam
Water	500 mm



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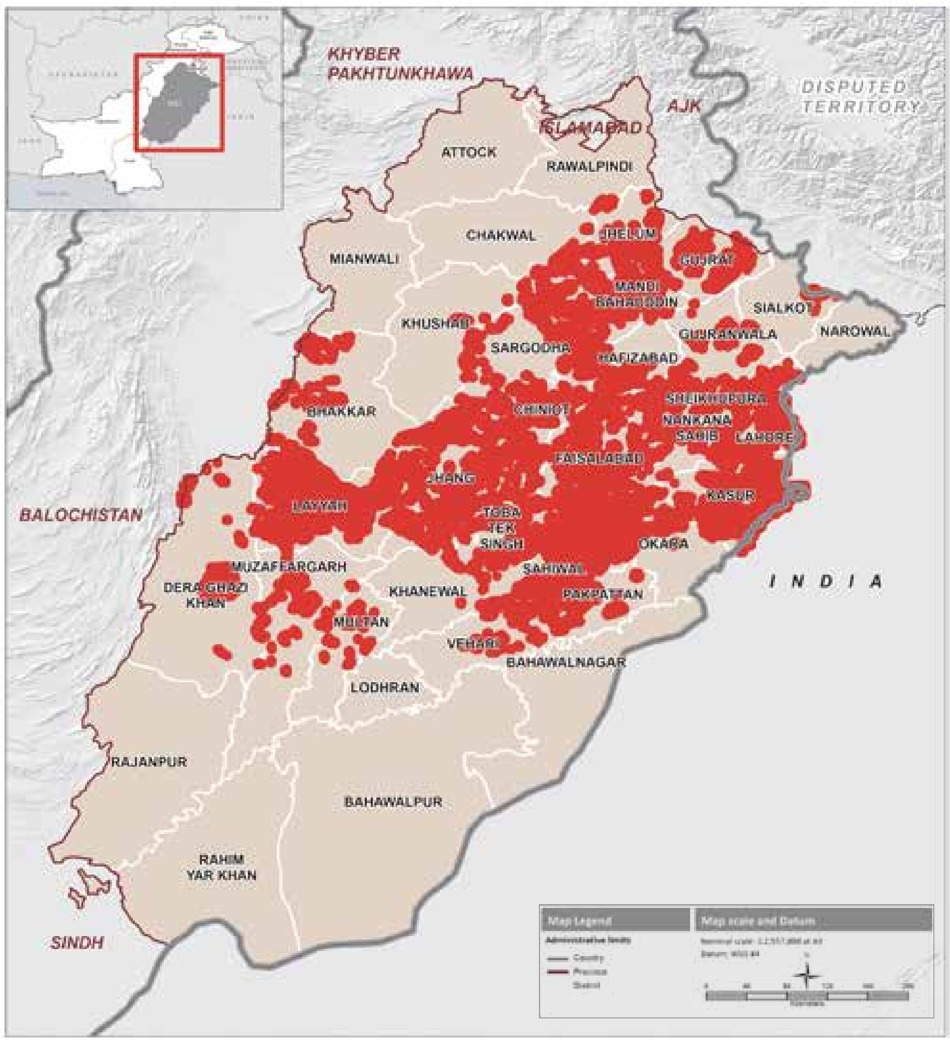
VEGETABLES

Most suitable area for **potato**

Climate	max 29 °C / min 12 °C
Soil	sandy loam, sandy clay loam, clay loam, loam
Water	700–1 000 mm



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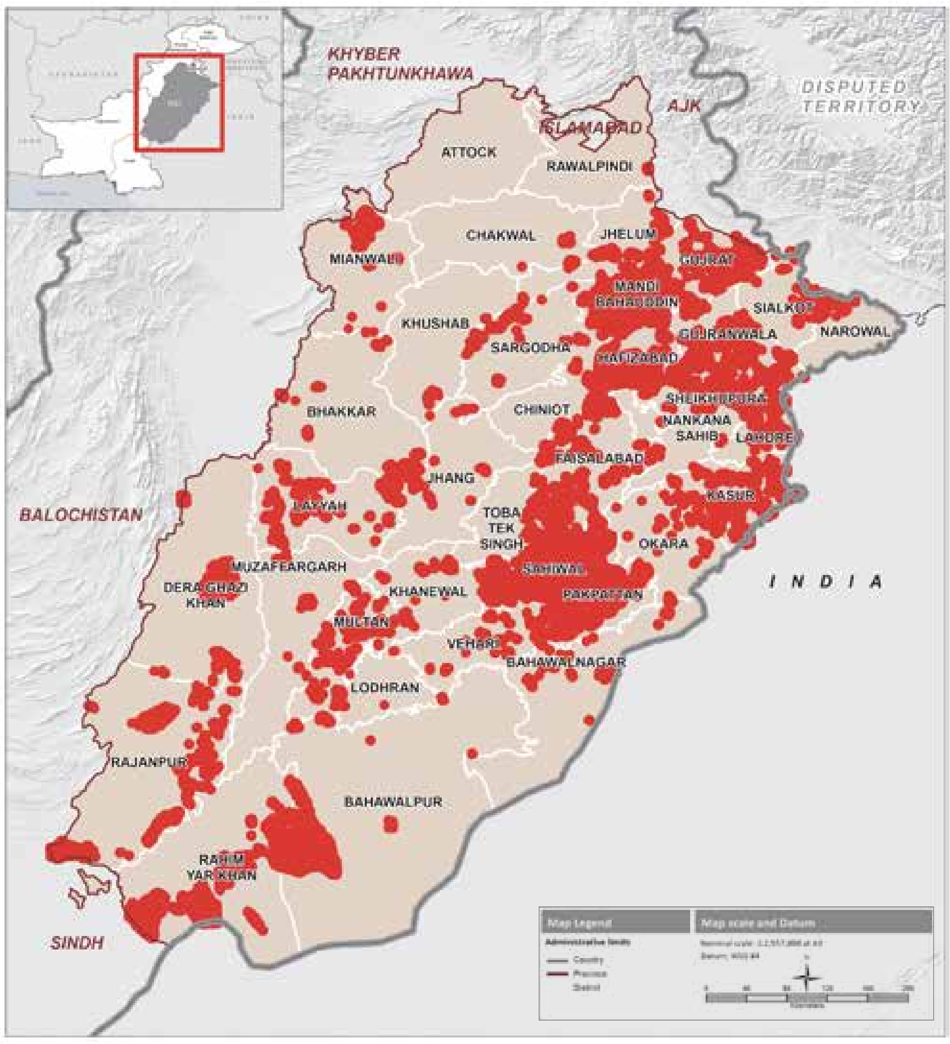
VEGETABLES

Most suitable area for **tomato**

Climate	max 29 °C / min 12 °C
Soil	clay loam, sandy loam, sandy clay loam, loam, silt loam
Water	500–1 000 mm



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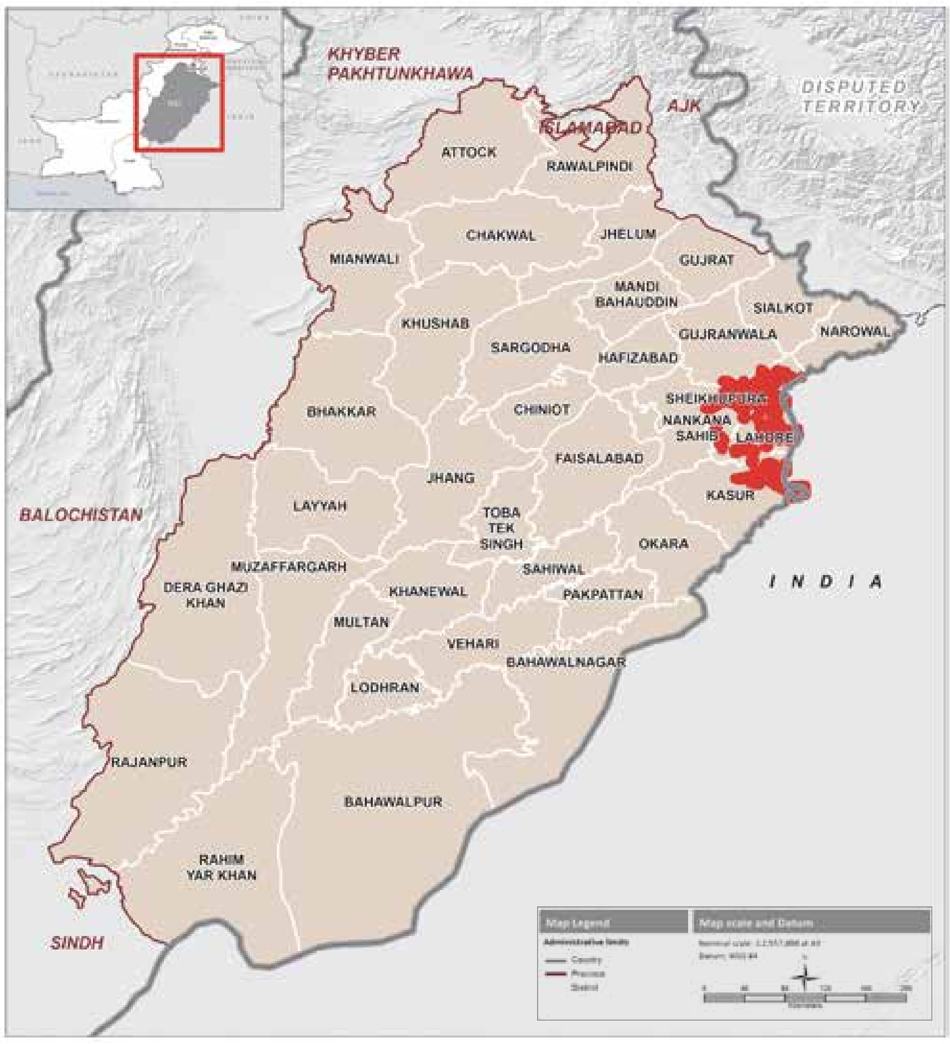
VEGETABLES

Most suitable area for **onion**

Climate	max 35 °C / min 17 °C
Soil	loam, silt loam, clay loam, sandy loam
Water	600–1 000 mm



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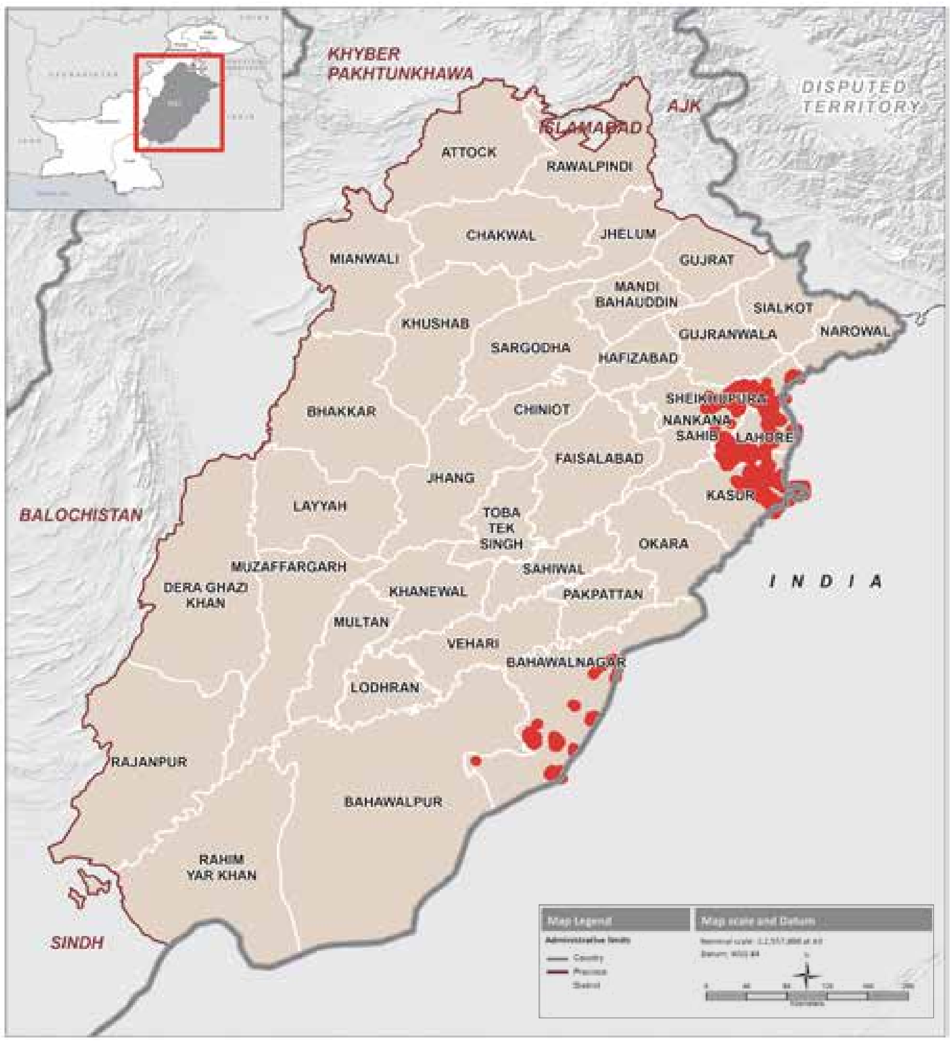
VEGETABLES

Most suitable area for **capsicum**

Climate	max 28 °C / min 15 °C
Soil	silt loam, clay loam, loam, sandy loam
Water	600–1 000 mm



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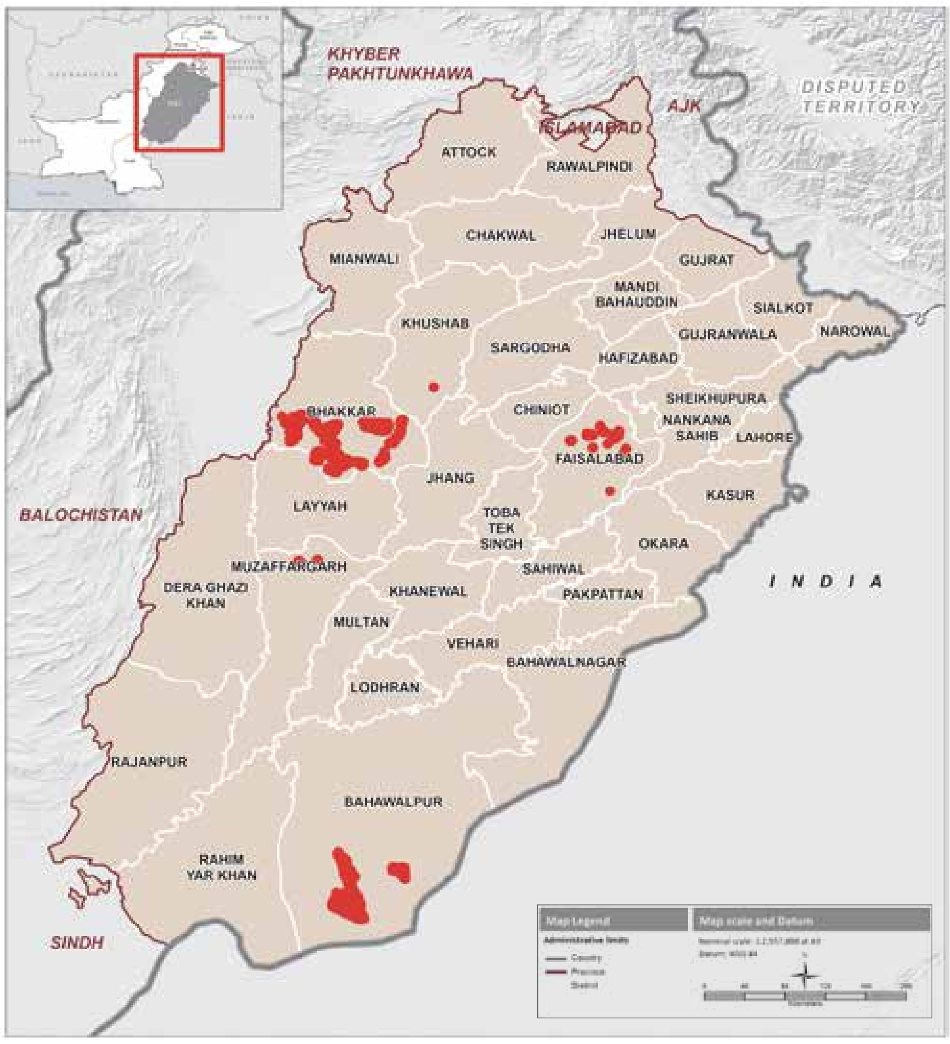
VEGETABLES

Most suitable area for **pumpkins**

Climate	max 40 °C / min 20 °C
Soil	sandy loam, silt loam
Water	650–775 mm



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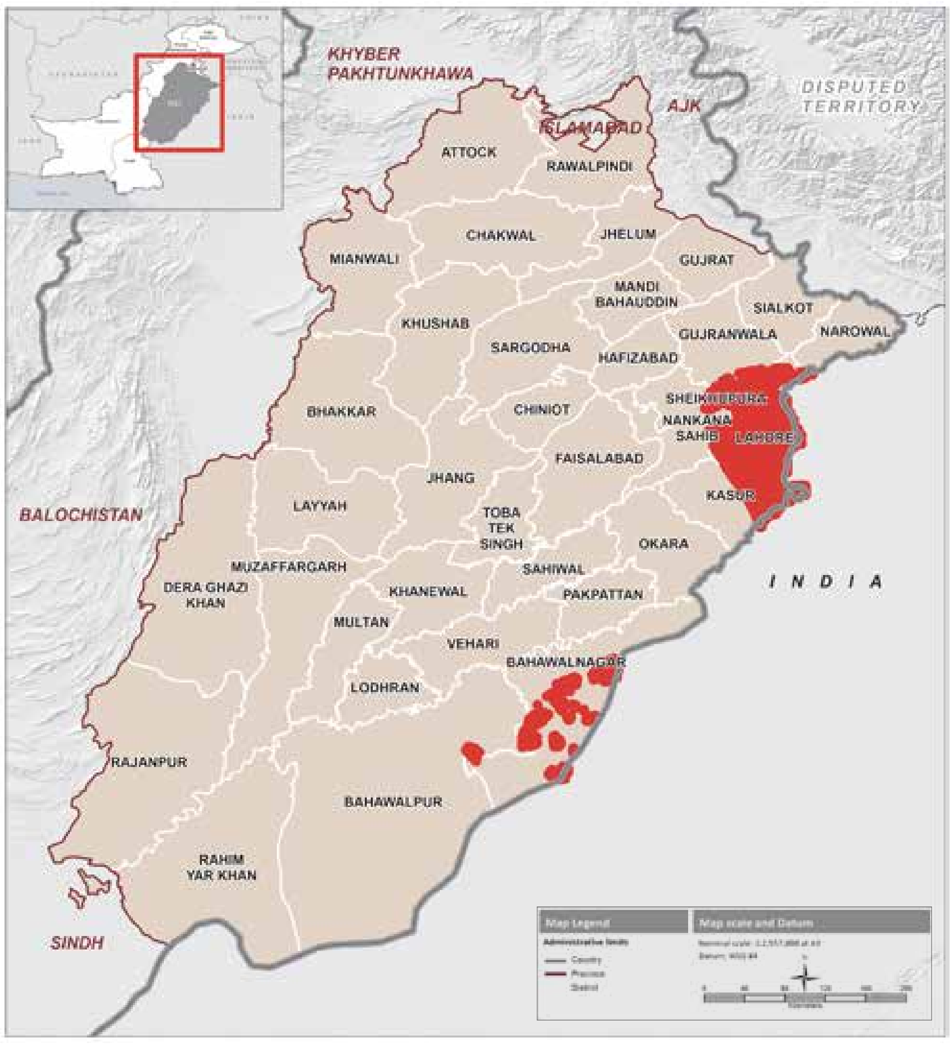
VEGETABLES

Most suitable area for **radish**

Climate	max 35 °C / min 10 °C
Soil	sandy loam, silt loam, loam
Water	200–350 mm



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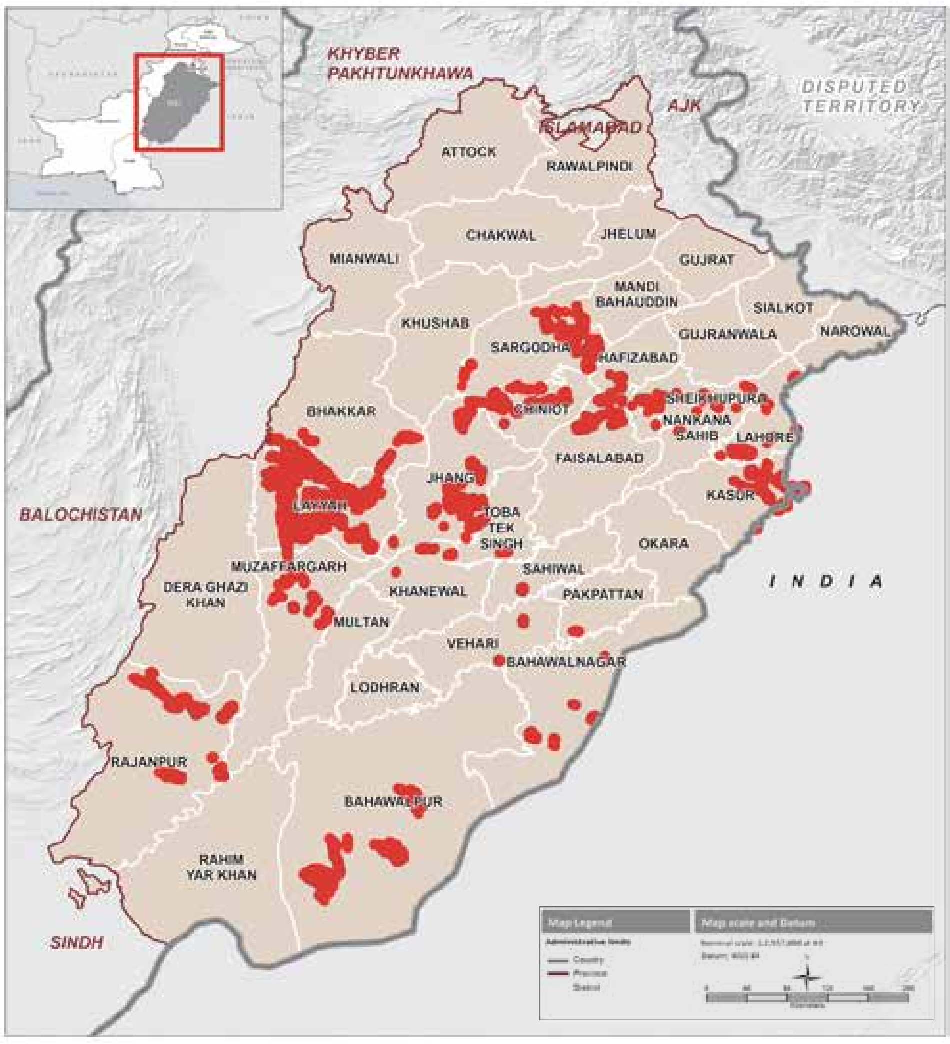
VEGETABLES

Most suitable area for **gourds**	
Climate	max 40 °C / min 20 °C
Soil	clay loam, silt loam, sandy clay loam
Water	1 650–775 mm



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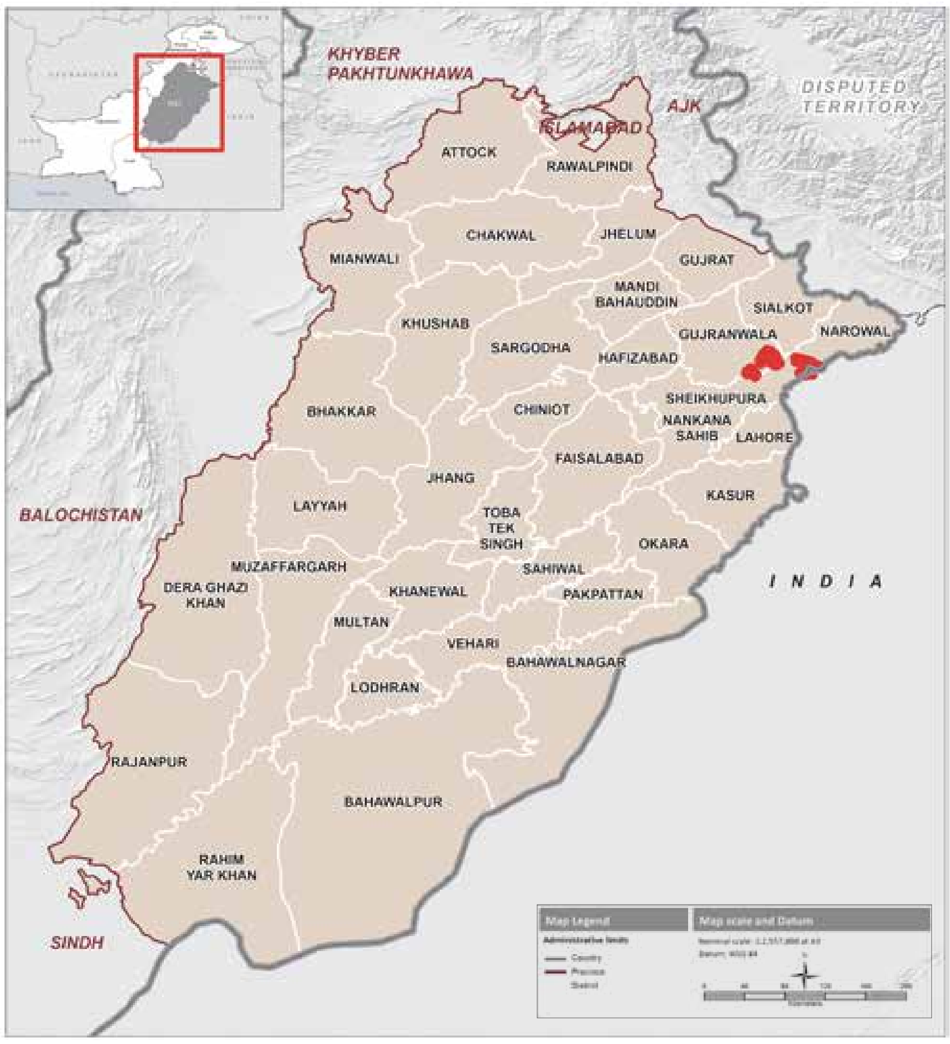
VEGETABLES

Most suitable area for **okra**	
Climate	max 40 °C / min 25 °C
Soil	sandy loam, silt loam, loam, clay loam
Water	500–650 mm



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VEGETABLES

Most suitable area for **ginger**	
Climate	max 35 °C / min 25 °C
Soil	silt loam, loam, sandy clay loam
Water	1 500–2 500 mm

7 Agro-economic zoning

7.1 Cost of production and economic suitability

The earlier section of this report discussed agro-climatic zones and crop suitability maps based on crop norms. The decision criteria for the practical suitability of growing crops depend on economic returns on investment. The analysis of the cost of production and returns of enterprises shows the weak and strong points for farming communities and associated farm enterprises and helps in deciding which crops to grow in a particular agro-ecological setting. In order to conduct an economic analysis, district data on crop yields, farmgate prices for produce and the costs of production are needed. The AEZ study included currently cultivated and future crops in crop suitability mapping; however, it was not possible to include all crops for economic feasibility studies because of missing data due to non-cultivation of some crops in some districts. Moreover, the cost of production is officially calculated by the Crop reporting service (CRS) on a provincial basis and therefore, the cost data are currently not available at the district level. This leaves only the possibility of using crop yield and market price information (i.e. revenue and provincial cost data) to calculate gross margins for use for agro-economic zoning. The analyses can be helpful in the formulation of effective price policy and agro-economic zoning and extension. Resolving the following data issues could help in developing refined information regarding agro-economic zones.

CONSTRAINTS

- Data by district or Tehsil for the cost of production are not available from any department; therefore, only yield data by district and cost of production data by province are used in the calculations.
- Economic data coverage of crops/vegetables is limited.
- Intra-district variation (agro-ecological) is not considered in collecting information.
- Farm size data are not collected.
- Variation in technology (tunnel farming, etc.) is not considered while collecting information.

7.2 Gross margins and cost of production

The cost of production per hectare for each crop in each district is calculated by multiplying the per kilogram cost (calculated at the provincial level by the CRS) by the yield in a specific district. Revenue figures are generated by taking the product of yield and its respective product price. The product prices are obtained from the Agricultural marketing information services (AMIS) website. By definition, net revenue (NR) is arrived at by subtracting total cost (TC) from total revenue (TR). Hence,

$$NR = TR - TC \quad (1)$$

Where, $TR = P * Q$; $TC = TVC + TFC$ and $TVC = \sum(P_{xi} * Q_{xi})$

TVC	= total variable cost
TFC	= total fixed cost
P	= price of crop
Q	= quantity of crop
Pi_{xi}	= input price
Q_{xi}	= quantity of input

7.3 Selection of suitable districts based on minimum cultivated area for a given crop

The cost of production data shows that almost all crops are grown in different districts. However, some crops were grown in very small patches for some local needs, or on some exceptionally suitable locations in otherwise non-suitable districts for those crops. Using data for districts with very small cultivated areas for a crop can result in outliers which can be misleading. In order to resolve this issue, a baseline of a 20 percent area under a crop, compared to the maximum area under that crop in another district, is selected as criteria for including districts in economic suitability comparison (i.e. high, medium, low suitability/profitability comparisons).

7.4 Economic suitability criteria

In order to develop an economic suitability map from the existing crop suitability maps, subjective criteria were developed. The 66th percentile, using districts with maximum returns for a crop as criteria, is considered highly suitable; the 33rd percentile is moderately suitable and the remainder is a marginally suitable district.

Highly suitable:	> 66th percentile of maximum profit district
Moderately suitable:	> 33rd percentile of maximum profit district
Marginally suitable:	< 33rd percentile of maximum profit district

7.5 District net returns on crops

Net returns (Rs./ha) on each crop in each district are calculated using the equation provided above (arranged in descending order), and are presented in the following figures. We have selected 25 crops for which data on the cost of production and output prices were available from the Agricultural Marketing Information Services (AMIS). The crop information with profitability classes was calculated based on a 66th and 33rd percentile source, and are as follows:

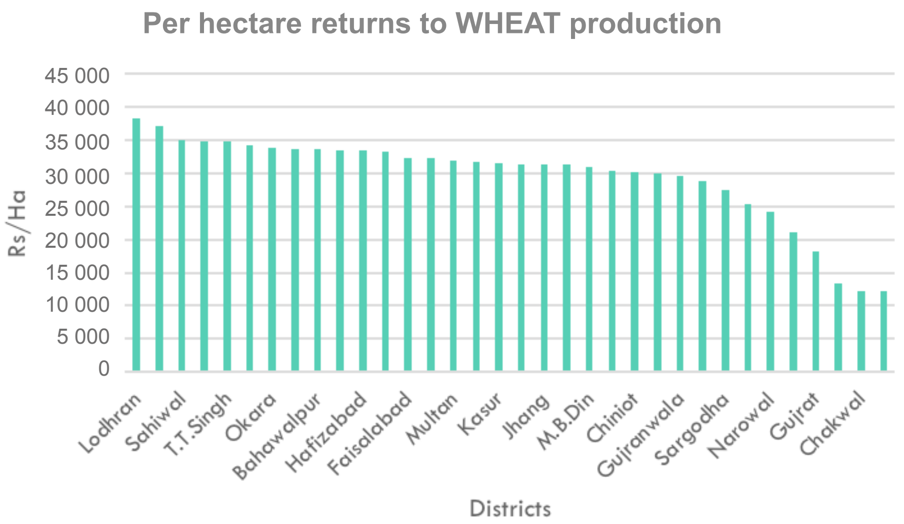
No.	Crop	Low profit (< 33%)	Moderate profit (< 66%)	High profit (> 66%)
1	WHEAT	< 12 654	12 654–25 306	12 654–25 306
2	COTTON	< 4 451	4 451–8 901	8 902–13 487
3	RICE	< 4 131	4 131–8 263	8 263–12 519
4	SUGARCANE	< 25 992	12 996–25 992	25 993–39 383
5	MAIZE	< 10 435	10 435–20 871	20 872–31 624
6	BITTER GOURD	< 139 119	139 119–278 238	278 238–421 574
7	BRINJAL	< 52 505	52 505–105 010	105 011–159 107
8	CUCUMBER	< 86 081	86 081–172 162	172 163–260 852
9	CAULIFLOWER	< 60 583	60 583–121 166	121 167–183 586
10	GARLIC	< 375 218	375 218–750 436	750 437–1 137 026
11	LADY FINGER	< 31 476	31 476–62 951	62 952–95 382
12	ONION	< 26 028	26 028–52 055	52 056–78 873
13	PEAS	< 2 917	2 917–5 833	5 834–8 840
14	POTATO	< 36 327	36 327–72 653	72 654–110 081
15	TOMATO	< 62 629	62 629–125 257	125 258–189 785
16	MOONG BEAN	< 5 379	5 379–10 756	10 757–16 299
17	MASH	< 3 761	3 761–7 521	7 522–11 396
18	CANOLA	< 14 755	14 756–38 964	38 965–56 158
19	GRAM	< 10 777	10 777–21 552	21 553–32 657
20	RAPESEED & MUSTARD	< 23 315	23 315–46 630	46 631–70 653
21	SUNFLOWER	< 4 081	4 081–8 162	8 163–12 368
22	CARROT	< 59 092	59 092–118 183	118 184–179 067
23	TINDA	< 14 388	14 388–28 775	28 776–43 600
24	CHILI	< 10 369	10 369–20 738	20 739–31 422
25	WATER MELON	< 116 186	116 186–232 371	232 372–352 079

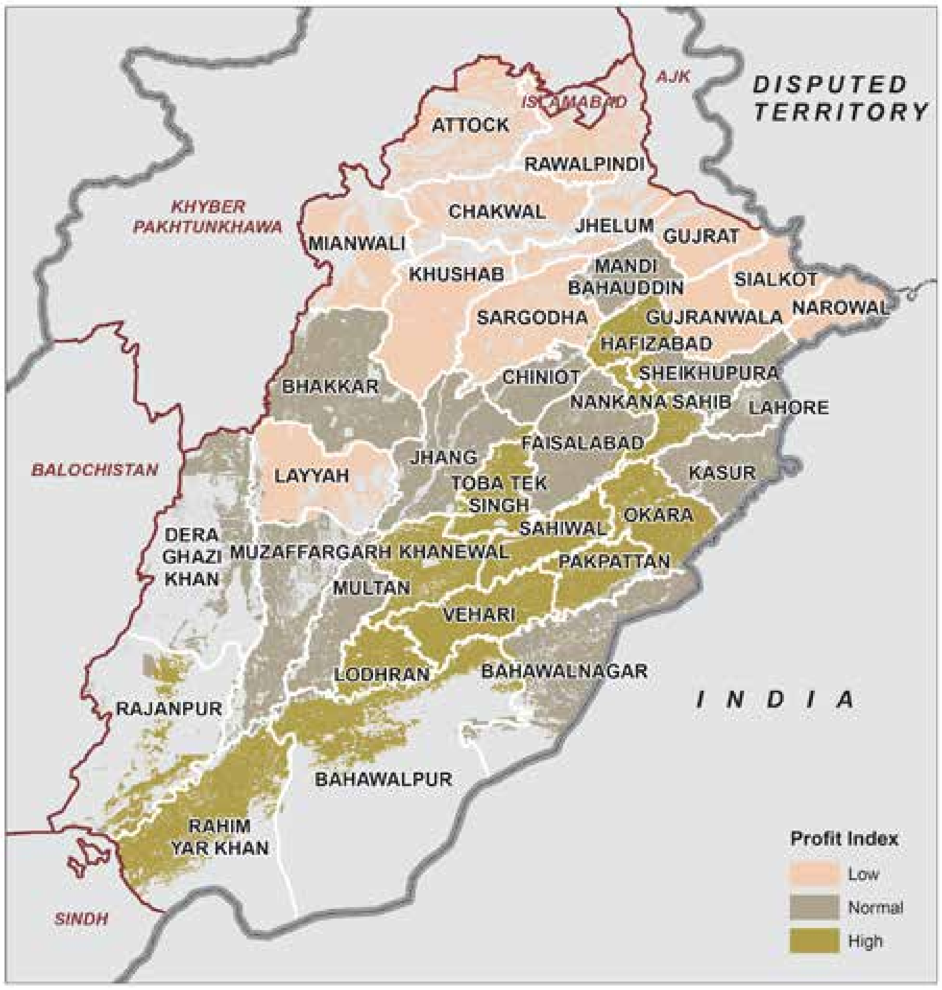
Table 7. Profitability classes and percentiles

ECONOMIC SUITABILITY OF WHEAT

Based on district-wide net returns for wheat production, district Lodhran has the highest net returns per hectare (Rs. 38 344.63 per hectare) in the province, followed by Sahiwal, TT Singh, and Okara districts, respectively.

The economic suitability map reveals that wheat has wider adaptability and economic viability (in relative terms and in comparison to different districts) in the majority of the zones. The greater part of zones XI and XII is moderately suitable, and parts of zones XIII and XIV are low and moderately suitable for wheat production.





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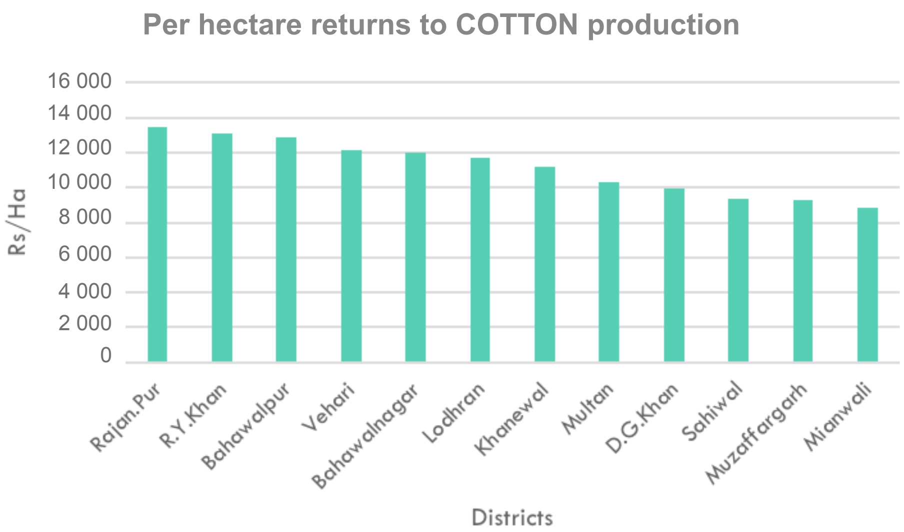
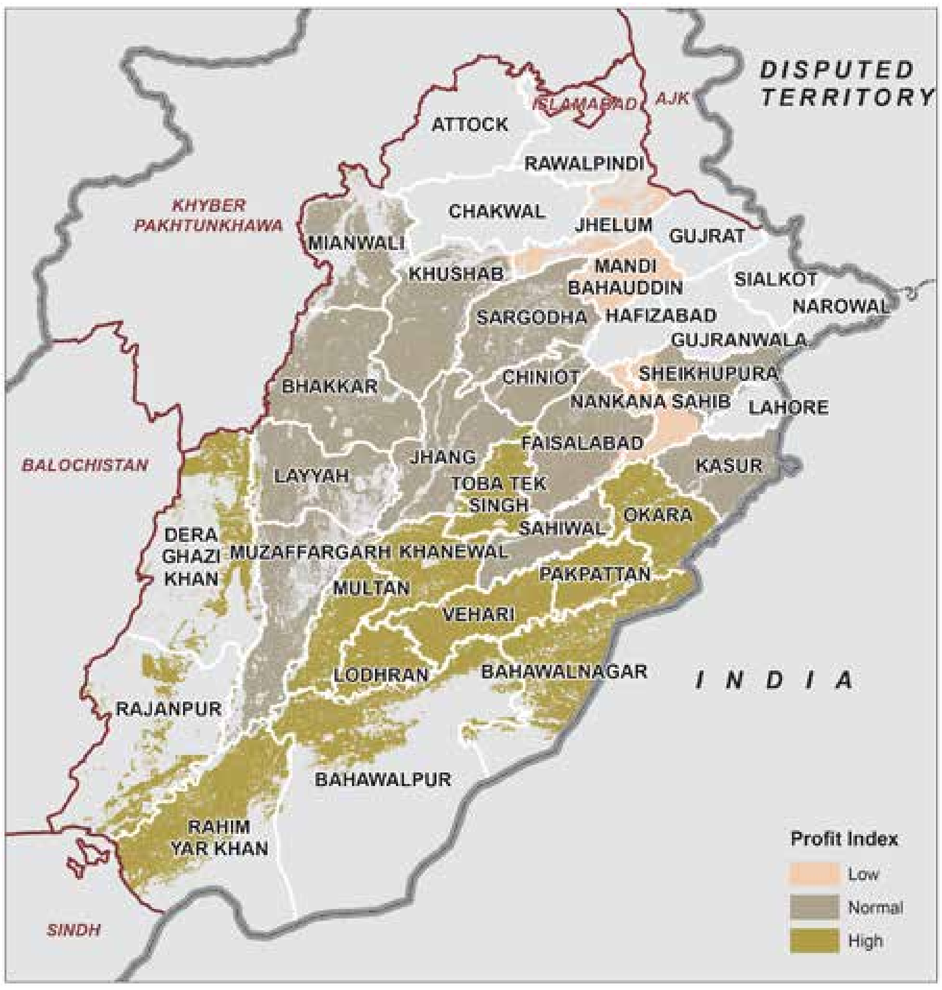
Wheat

ECONOMIC SUITABILITY OF COTTON

Cotton crops are mainly produced in Sahiwal, Multan, D.G. Khan and Bahawalpur divisions of Punjab province. Based on economic suitability, Rajan Pur is highly suitable for cotton production with a net return of Rs. 13 487 per hectare, followed by Rahim Yar Khan and Bahawalpur with net returns of Rs. 13 089 and Rs. 12 905 per hectare, respectively.

The economic suitability map reveals that major parts of zones I-VII are highly suitable for cotton production based on their net returns per hectare in these zones.





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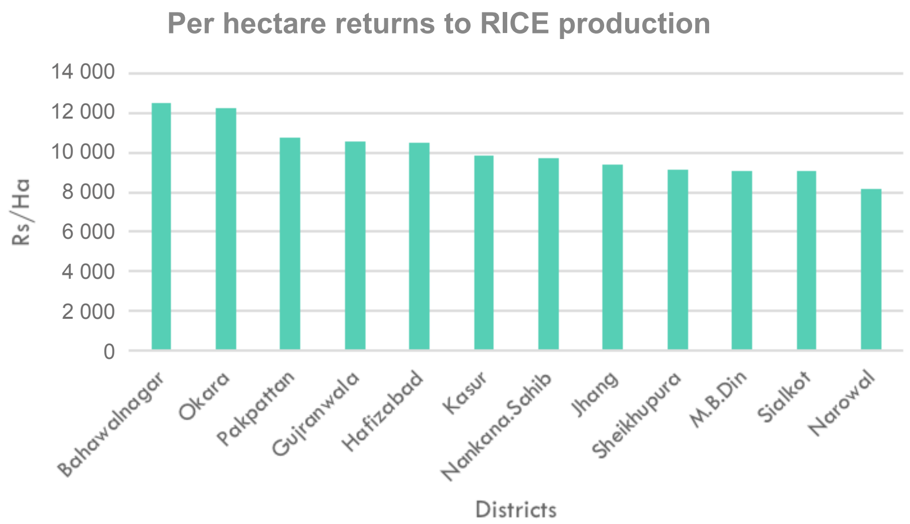
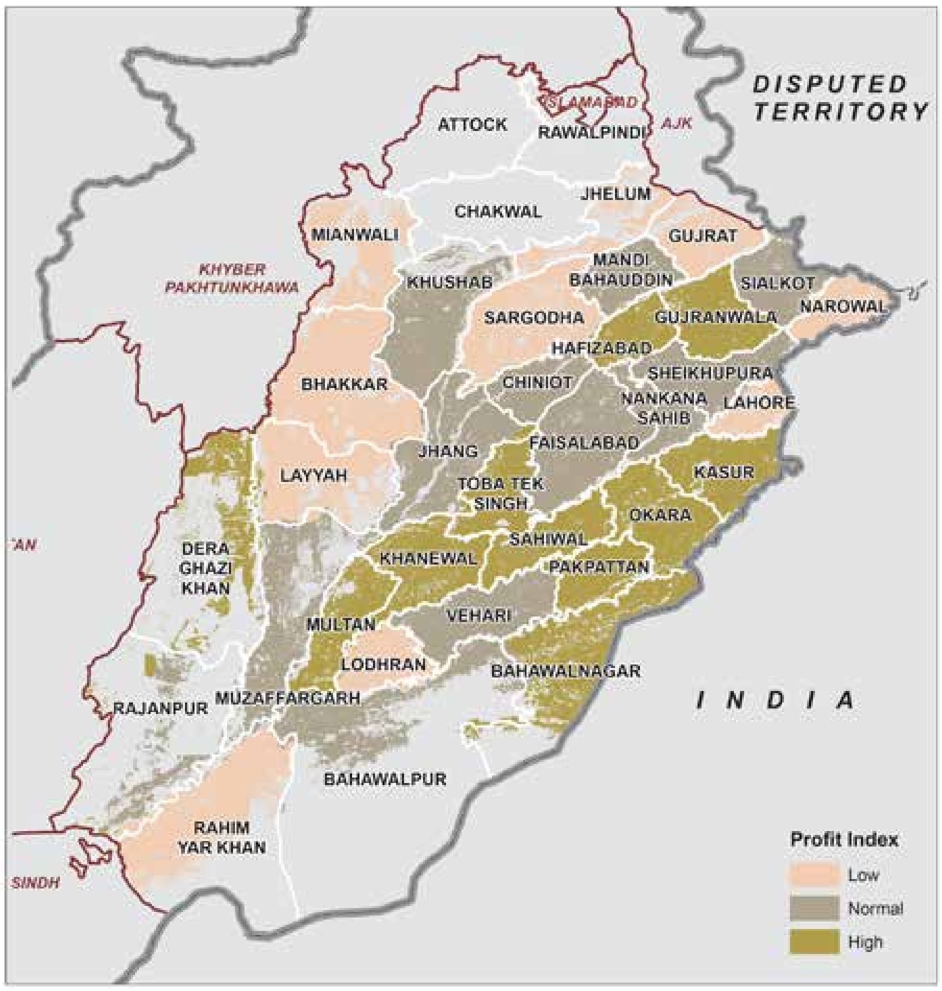
Cotton

ECONOMIC SUITABILITY OF RICE

Rice is cultivated in the majority of the districts of Punjab province. However, economic data suggests that Bahawalnagar, Okara, Pakpattan, Gujranwala, and Hafizabad are some of the most suitable districts for rice cultivation, as they promise higher net returns for rice crops

The economic suitability map shows highly suitable areas for rice cultivation lie in zones VII, VIII, X, and XII. Parts of zone XII (Narowal district) fall in moderate returns compared to high return districts.





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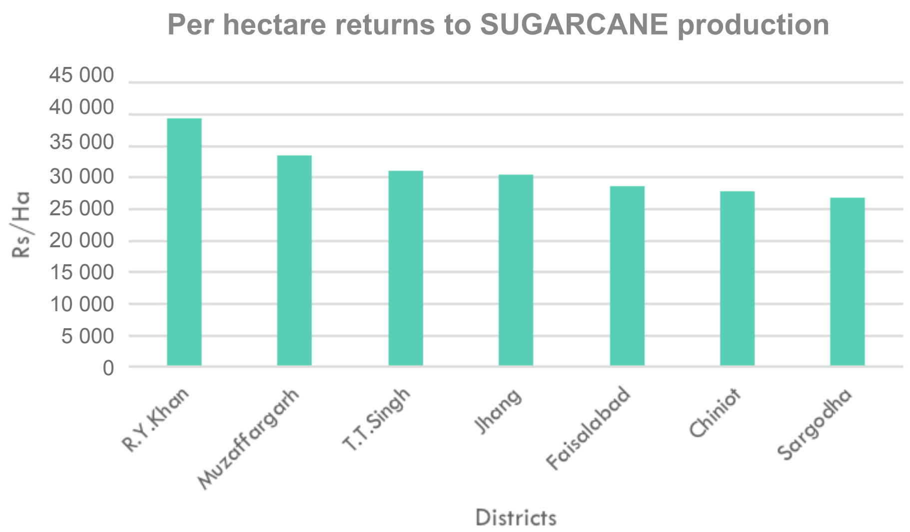
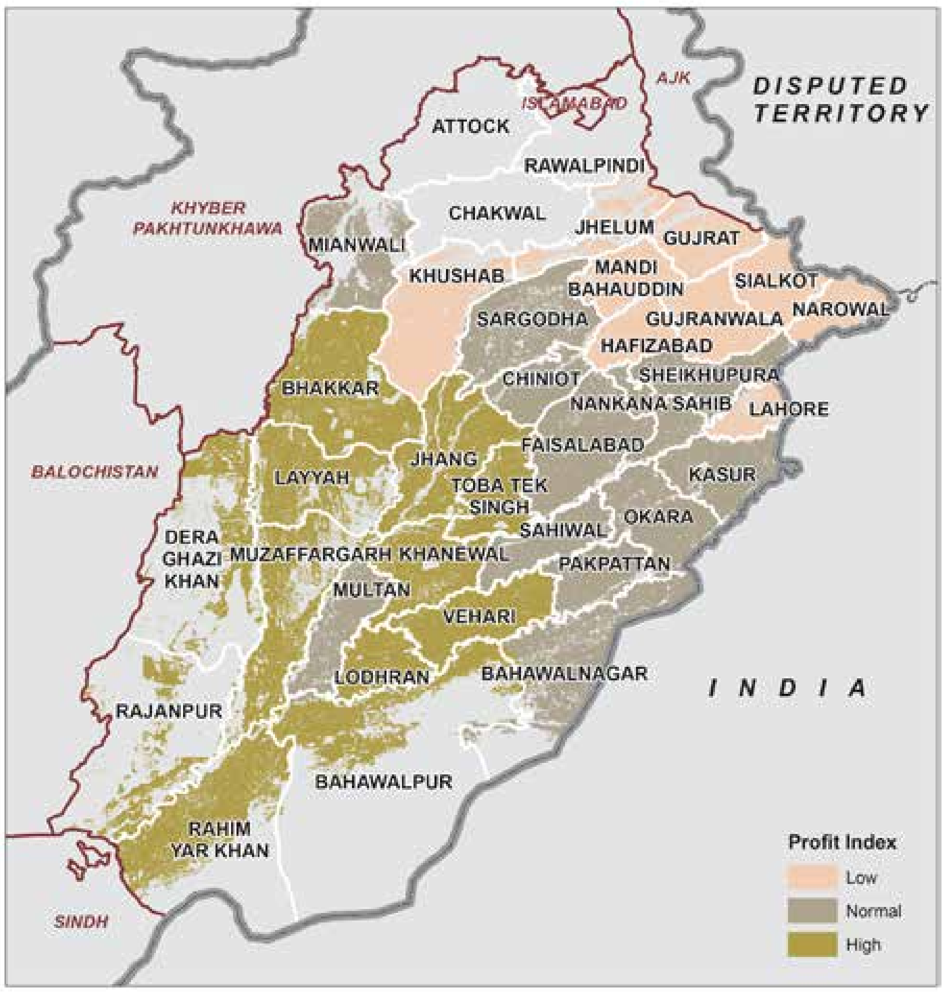
Rice

ECONOMIC SUITABILITY OF SUGARCANE

Sugarcane crops are also cultivated throughout the province, excluding Rawalpindi division. However, based on the net returns, district R. Y. Khan is most suitable, followed by Muzaffargarh and T.T Singh.

The economic suitability map shows that highly suitable zones for sugarcane cultivation in Punjab province lie in zones II, VI, VIII, and X.





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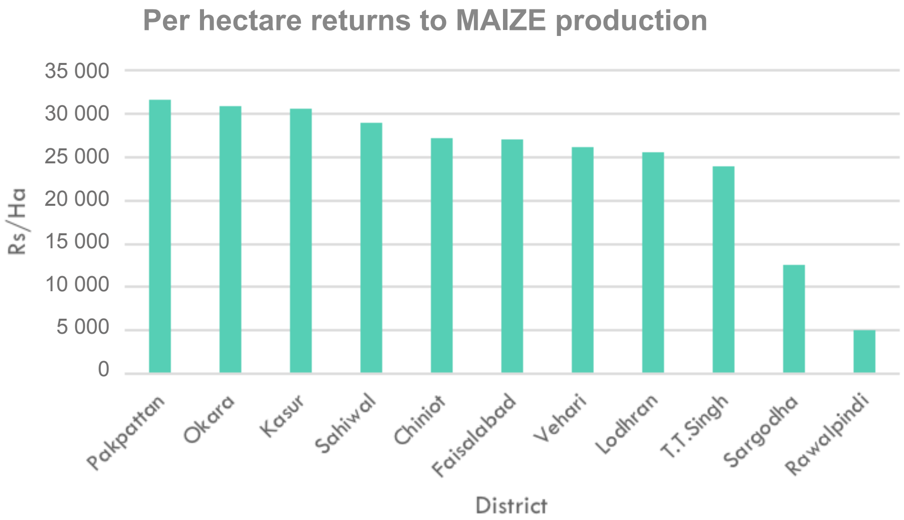
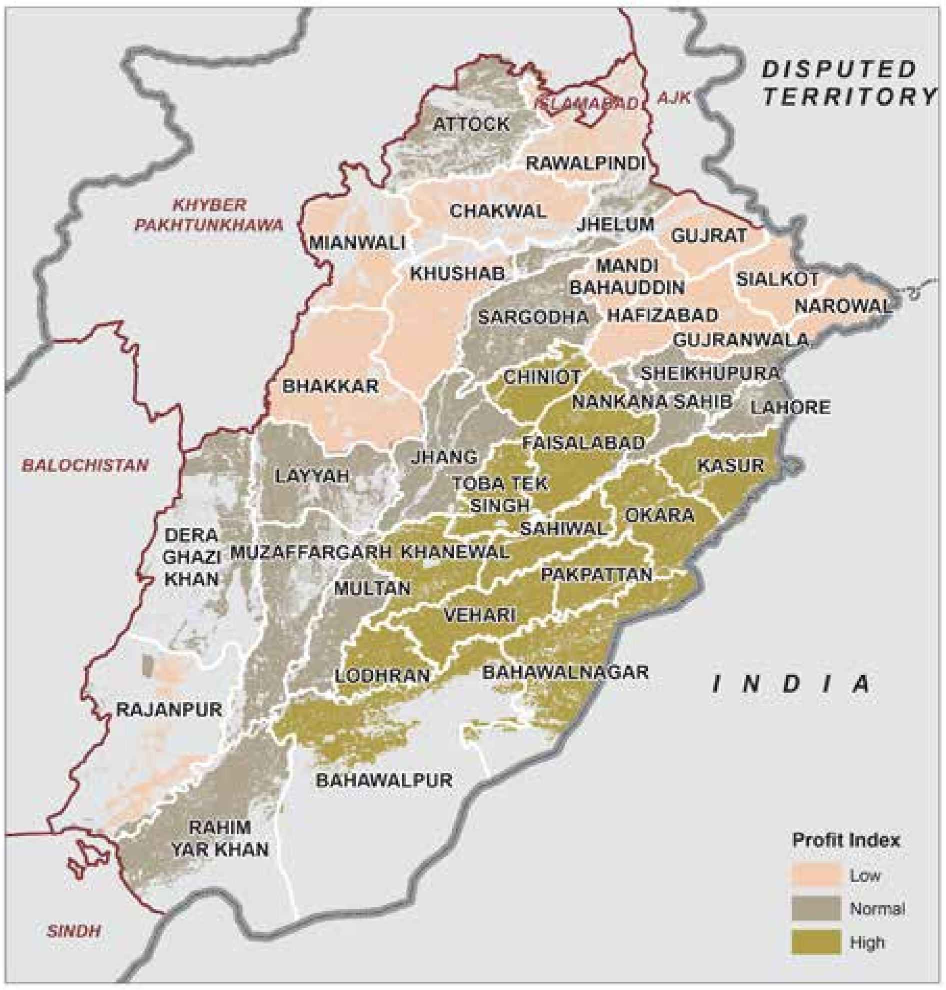
Sugarcane

ECONOMIC SUITABILITY OF MAIZE

Maize crops are cultivated in almost all districts of the province. However, based on the economic data of maize crops, district Pakpattan is highly suitable for the crop with net returns per hectare of Rs. 31 623, followed by Okara and Kasur, with per hectare net returns of Rs. 30 901 and Rs. 30 636, respectively.

Based on the economic gains from maize production per hectare, a major portion of zones V, VII and VIII are highly suitable for maize cultivation in the province, whereas, sugarcane areas in zones XI and XIV have low economic suitability.





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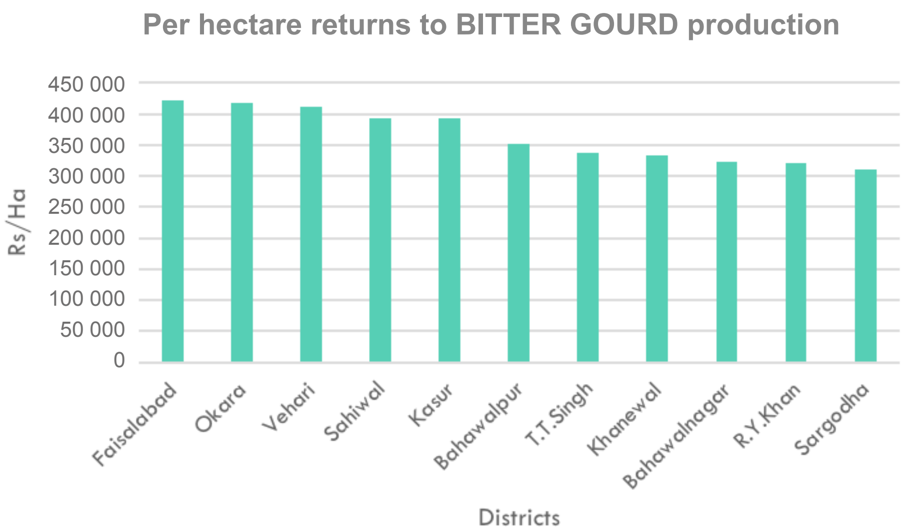
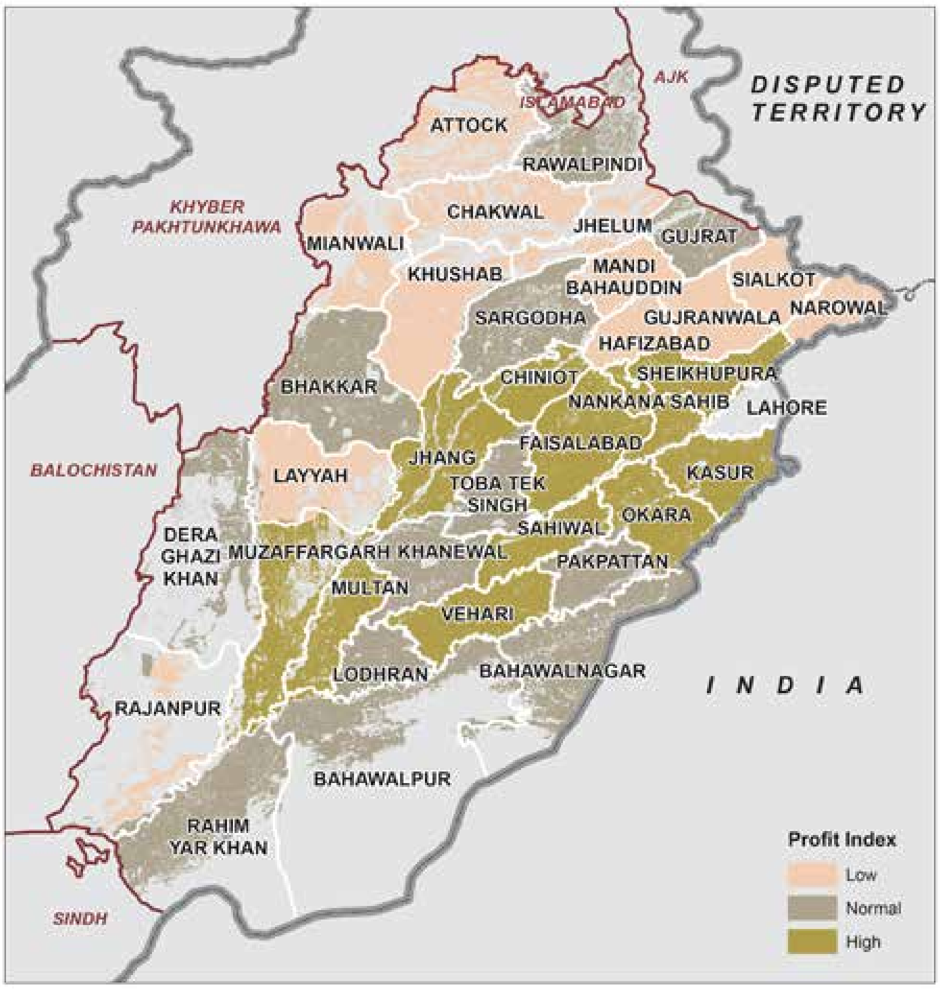
Maize

ECONOMIC SUITABILITY OF BITTER GOURD

Bitter gourd is cultivated in most parts of the province. However, net returns suggest bitter gourd is most suitable in Faisalabad, Okara and Vehari districts. Districts Sahiwal and Kasur are also among the most suitable for bitter gourd cultivation. The economic suitability map shows that bitter gourd is highly suitable in most districts of zones I, II, VII and VIII.





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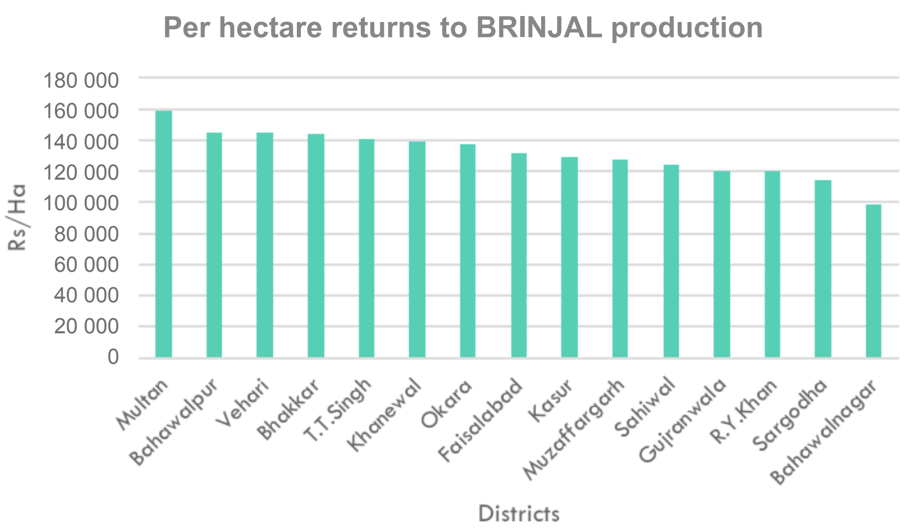
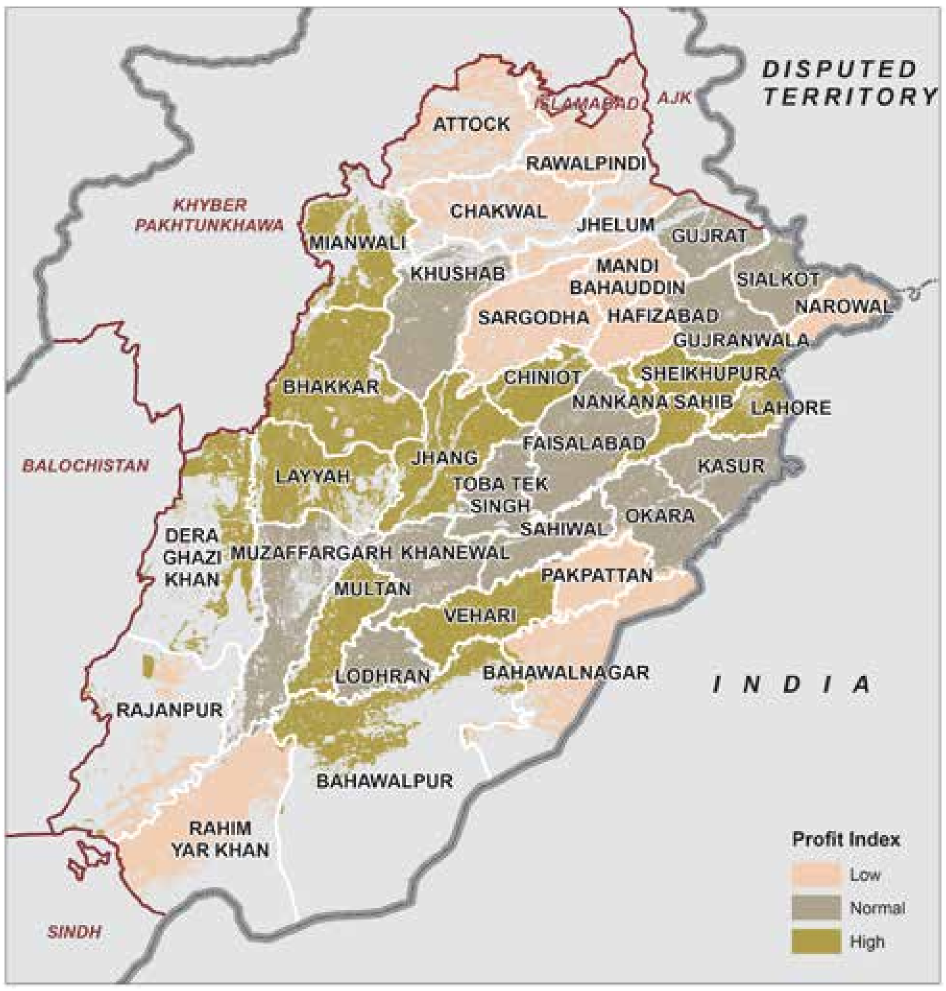
Bitter gourd

ECONOMIC SUITABILITY OF BRINJAL

Based on the profits generated per hectare from brinjal cultivation, Multan, Bahawalpur and Vehari are the top three districts in terms of net returns for its cultivation. Brinjal has higher economic suitability in different parts of zones I, II, VII, VIII, IX, and XI. Parts of zone V are of medium suitability for its cultivation.





Map created by: IM Unit, FAO Pakistan. Data sources: FAO, Government of Punjab, GAUL

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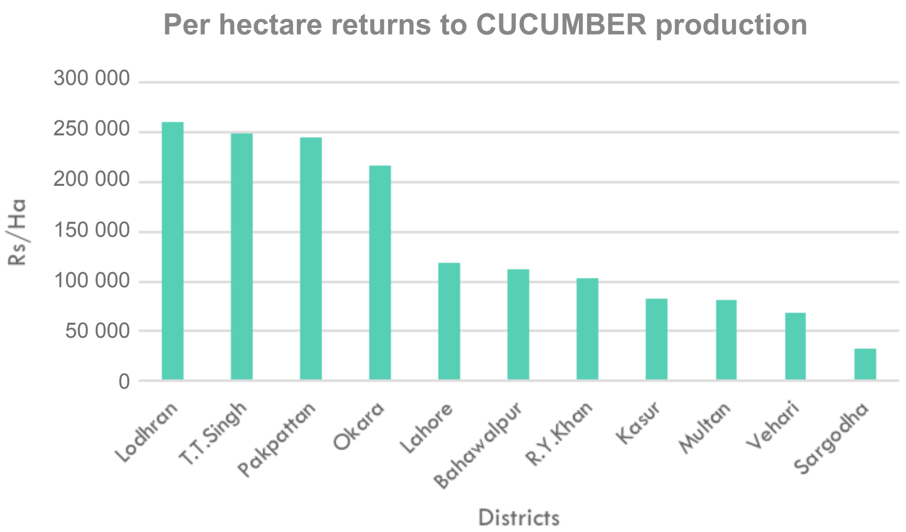
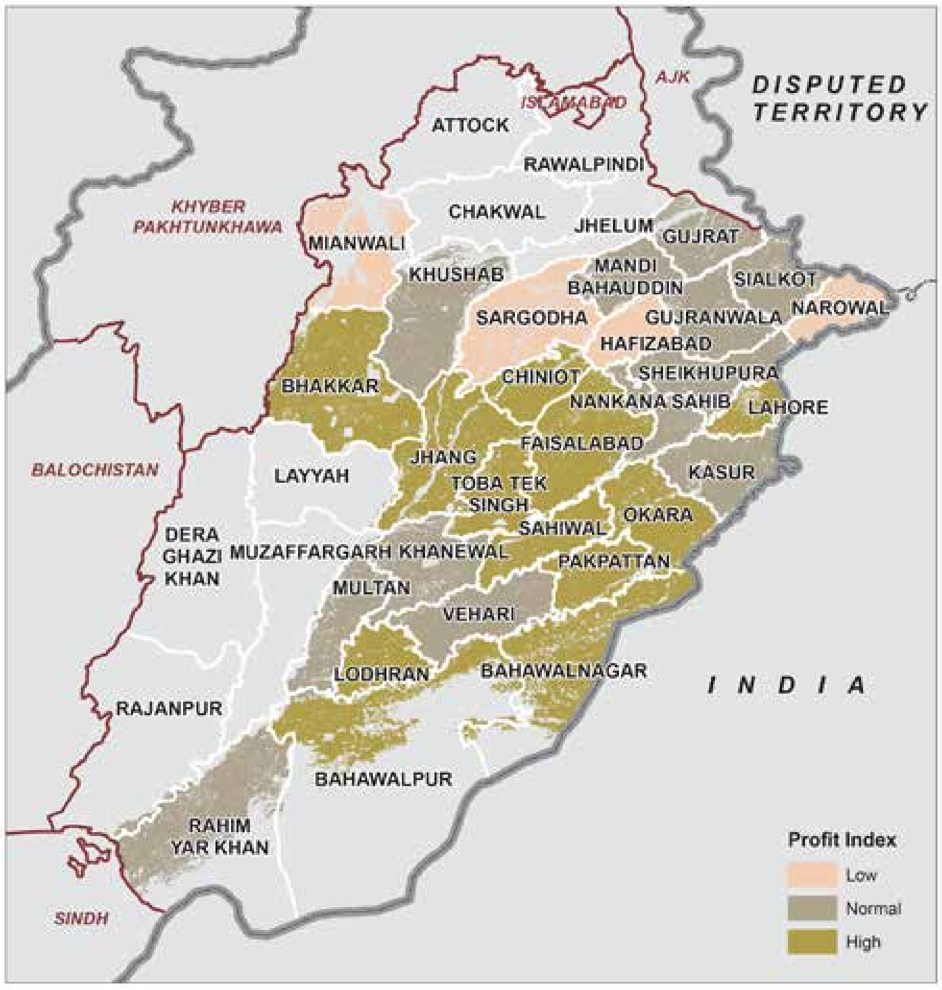
Brinjal

ECONOMIC SUITABILITY OF CUCUMBER

Cucumber is more profitable and economically suitable in Lodhran, followed by T.T. Singh and Pakpattan districts.

The most economically suitable areas lie in a narrow tract of zones V, VII and VIII while some areas in zone I and II are moderately suitable. The low suitability category includes zone V (Multan), X (Kasur) and XI (Sargodha).





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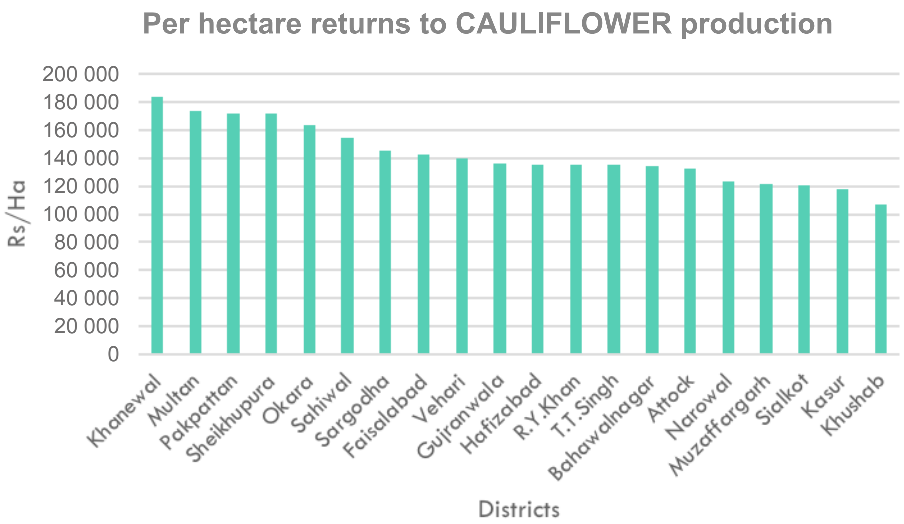
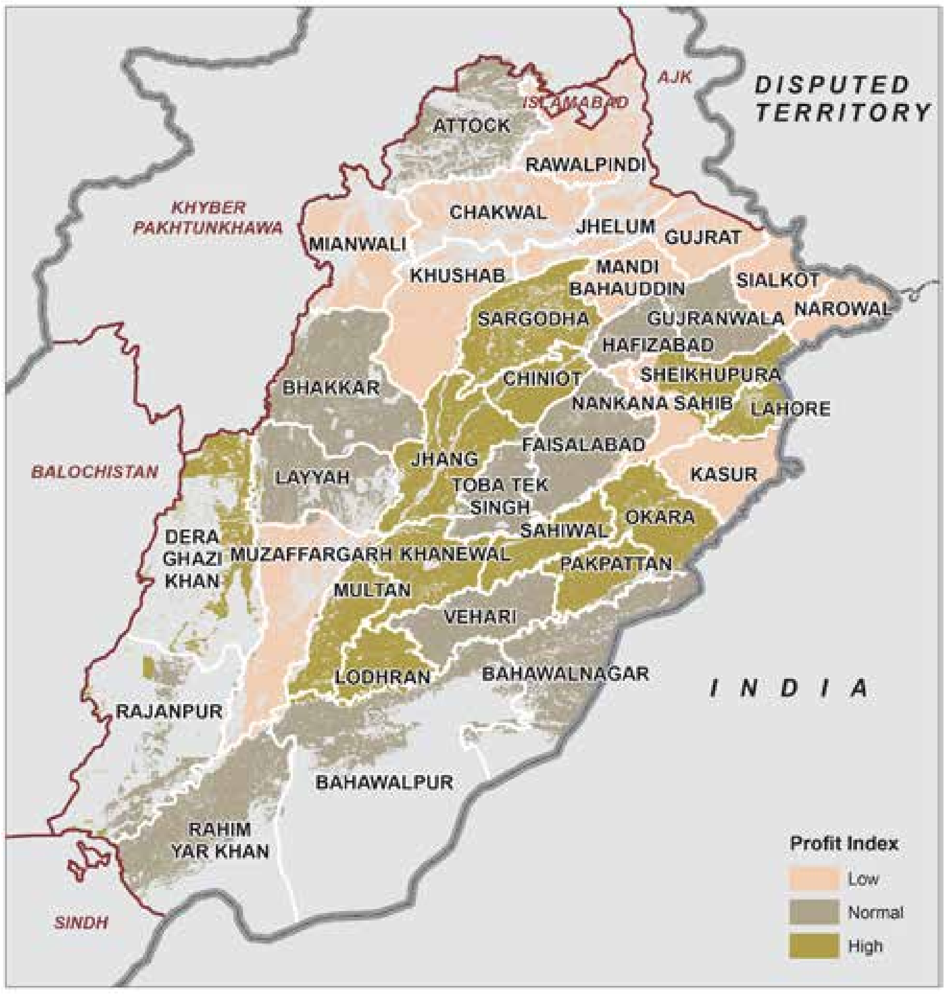
Cucumber

ECONOMIC SUITABILITY OF CAULIFLOWER

Cauliflower is grown throughout the province and generates significant revenues for producers. Districts Khanewal, Multan, Pakpattan, and Sheikhupura have the highest net returns for cauliflower with Rs. 183 585, Rs.173 952, Rs.172 220 and Rs. 171 872, respectively.

The most profitable districts lie in zones II, VI, VII, VIII, X, and XI. Some districts in zones X (Kasur), XI (Khushab) and XII (Sialkot) lie in the medium suitability category.





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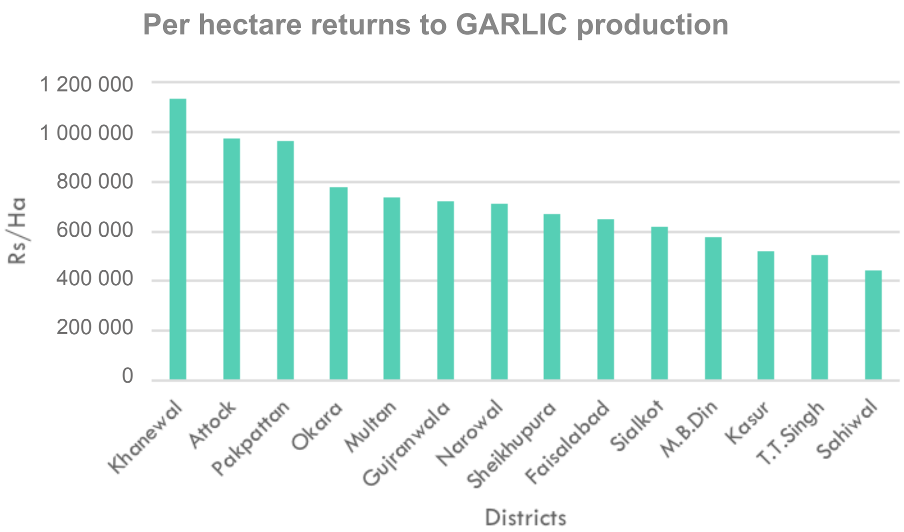
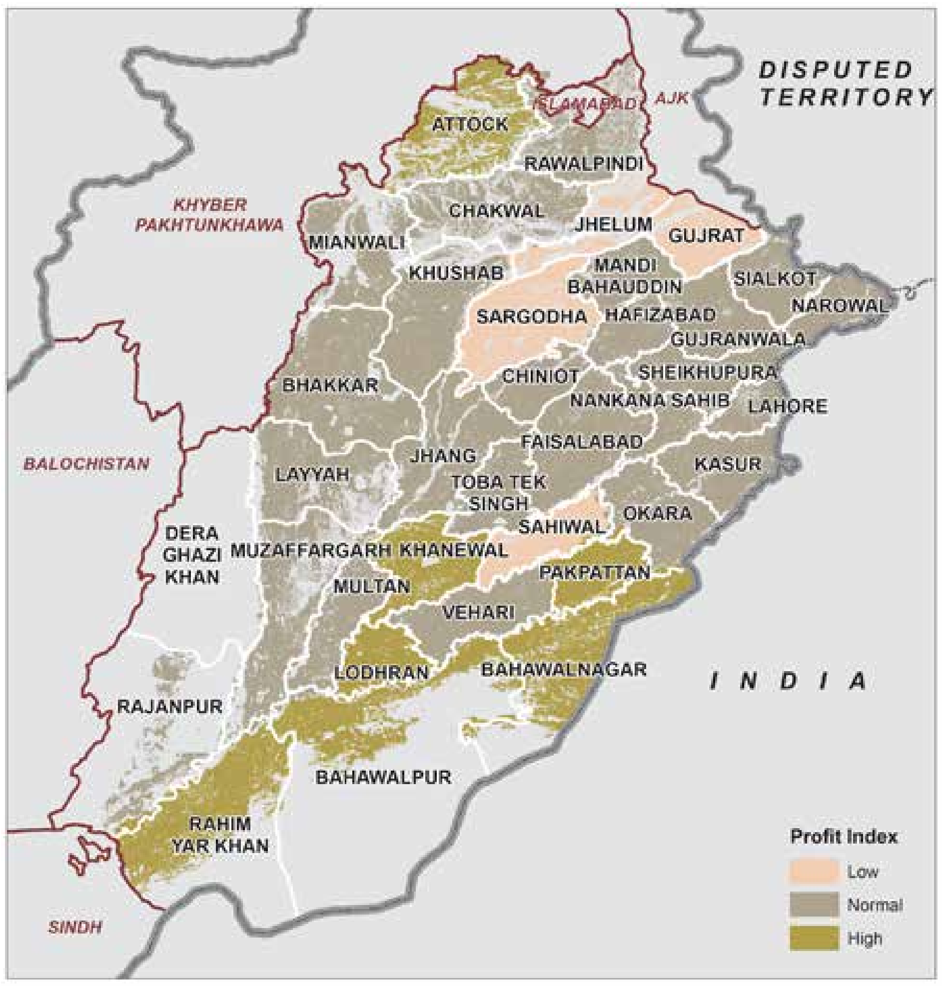
Cauliflower

ECONOMIC SUITABILITY OF GARLIC

Garlic is also produced in most of the districts in the province. However, Khanewal, Attock, and Pakpattan have high economic suitability based on net returns generated from garlic production per hectare; followed by Okara, Multan, and Gujranwala.

The economic suitability map shows that few districts in zones VII, VIII and XIII are highly suitable, while garlic growing districts in zones VI, X, and XII fetch medium returns.





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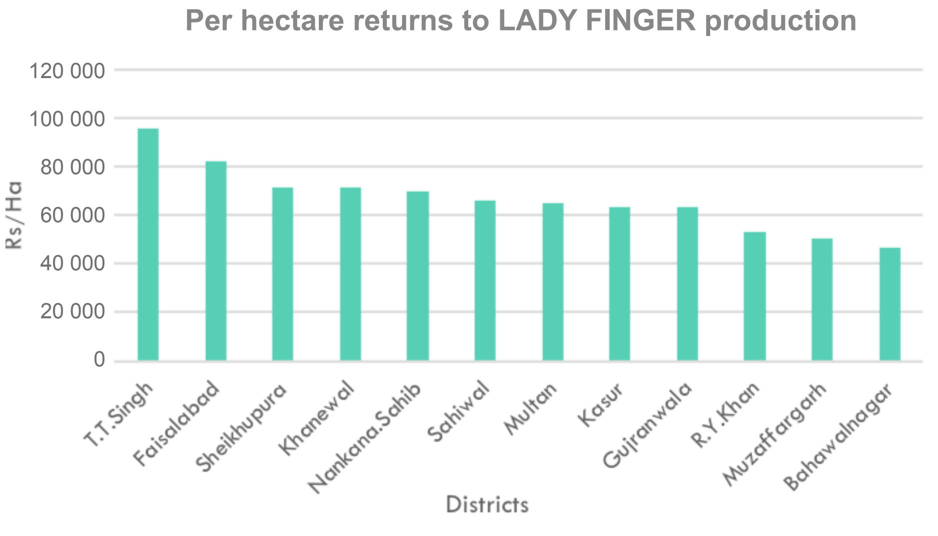
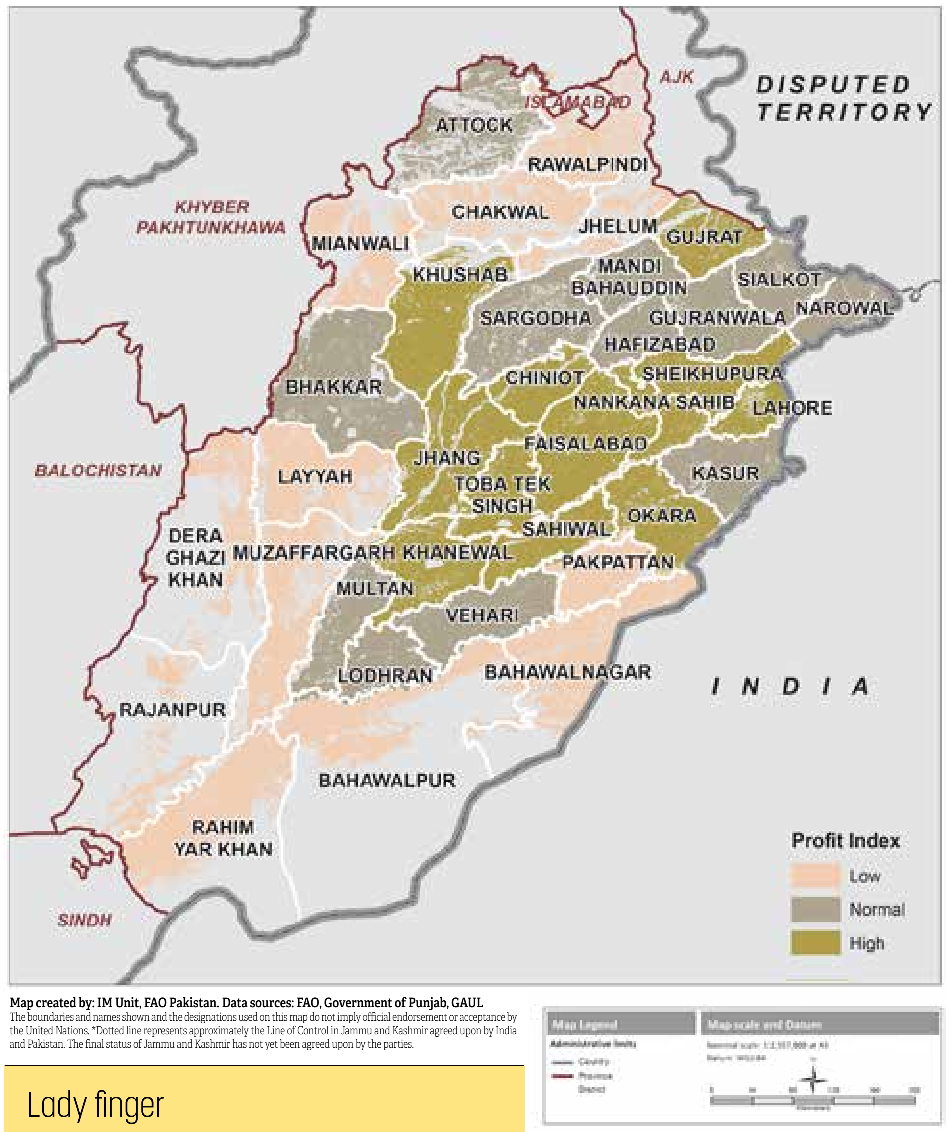
Garlic

ECONOMIC SUITABILITY OF LADY FINGER

The economic data highlights districts T. T. Singh, Faisalabad and Sheikhupura as highly suitable for Lady finger cultivation, as these districts generate the highest net returns per hectare compared to other districts.

The economic suitability map reveals that a narrow strip of districts passing through zones V, VII, VIII and X are highly profitable for lady finger cultivation. However, some areas in zones II, V, and VII comprising districts R. Y. Khan, Bahawalpur, Muzaffargarh, and Bahawalnagar lie in a medium suitability class.





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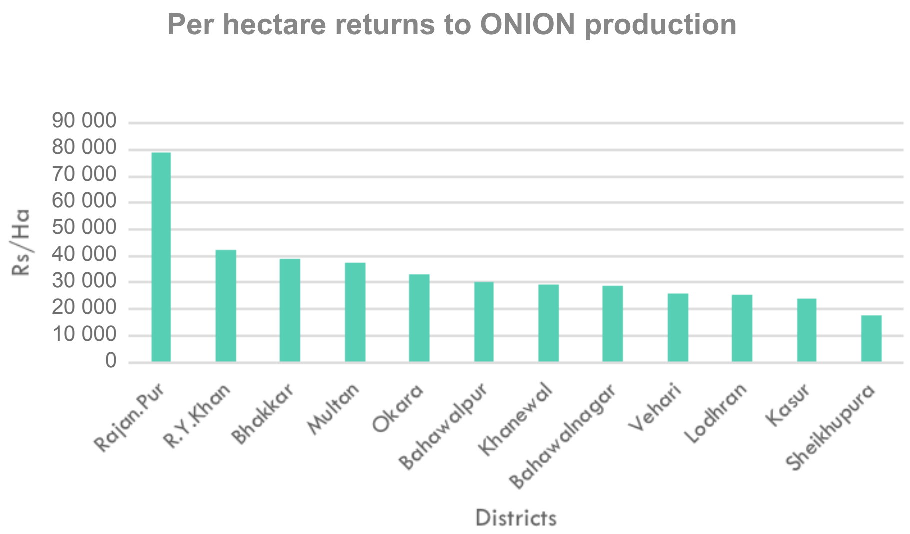
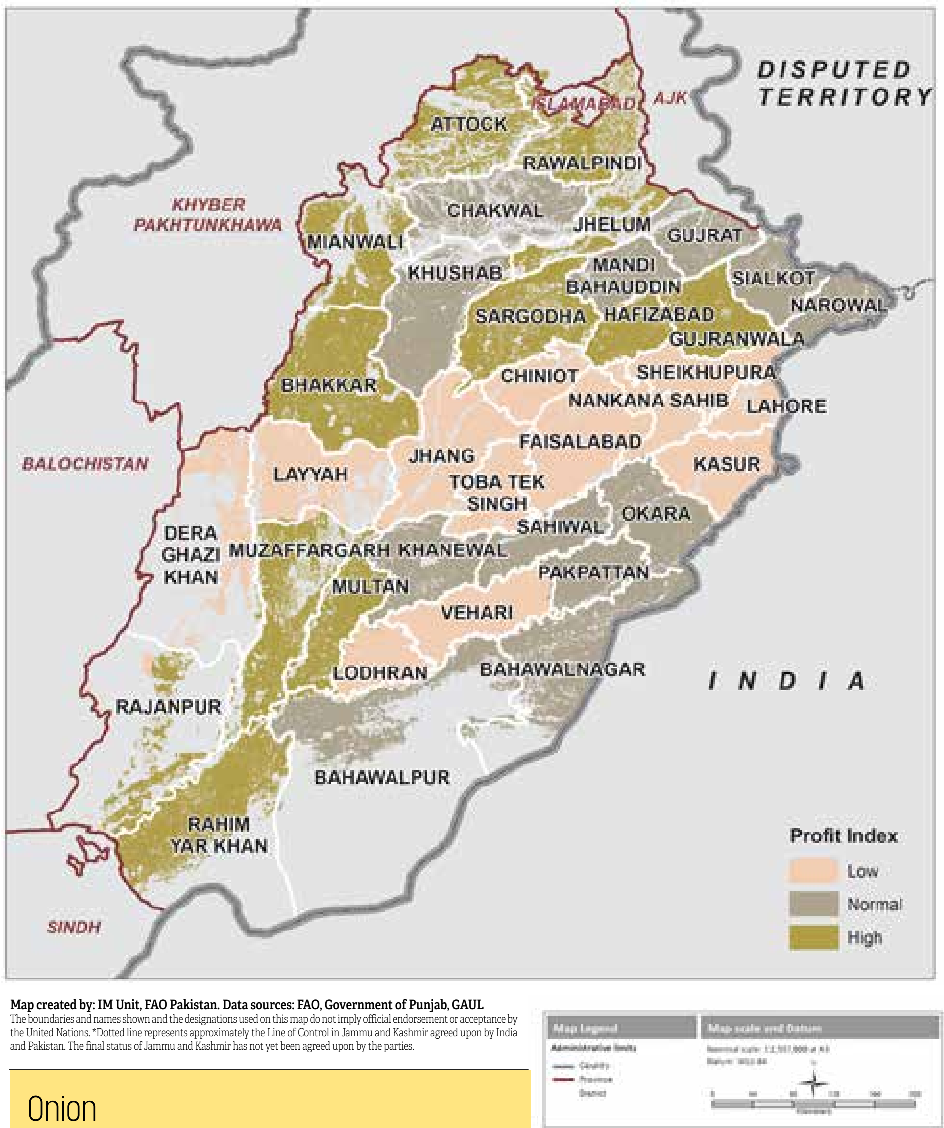
Lady finger

ECONOMIC SUITABILITY OF ONION

Based on the per hectare profits generated for onion production, Rajan Pur district is the most economically suitable district for onion production with per hectare net returns of Rs. 78 873, followed by Rahim Yar Khan (Rs 42 461.39 per hectare).

The economic suitability map shows that major parts of zone II (Rajanpur District) are highly suitable for onion production based on their net returns per hectare. Onion-growing districts in other zones largely fall into the category of medium suitability.





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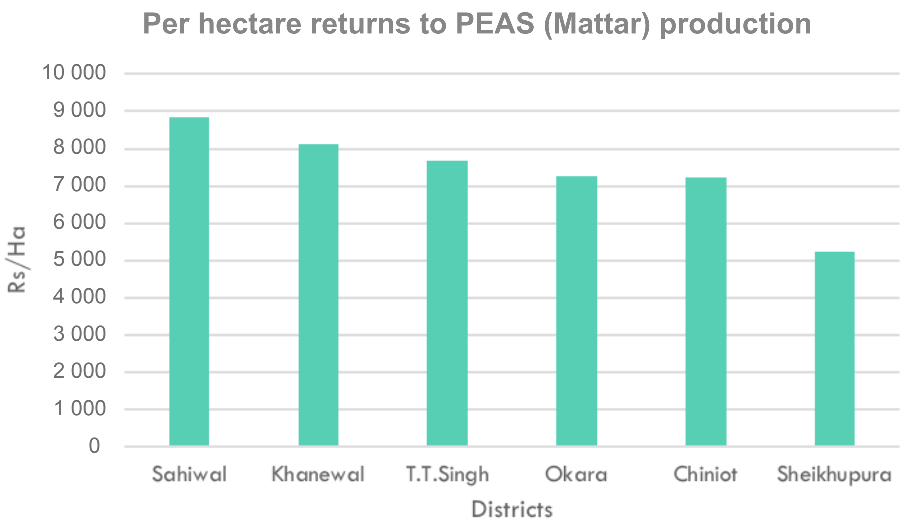
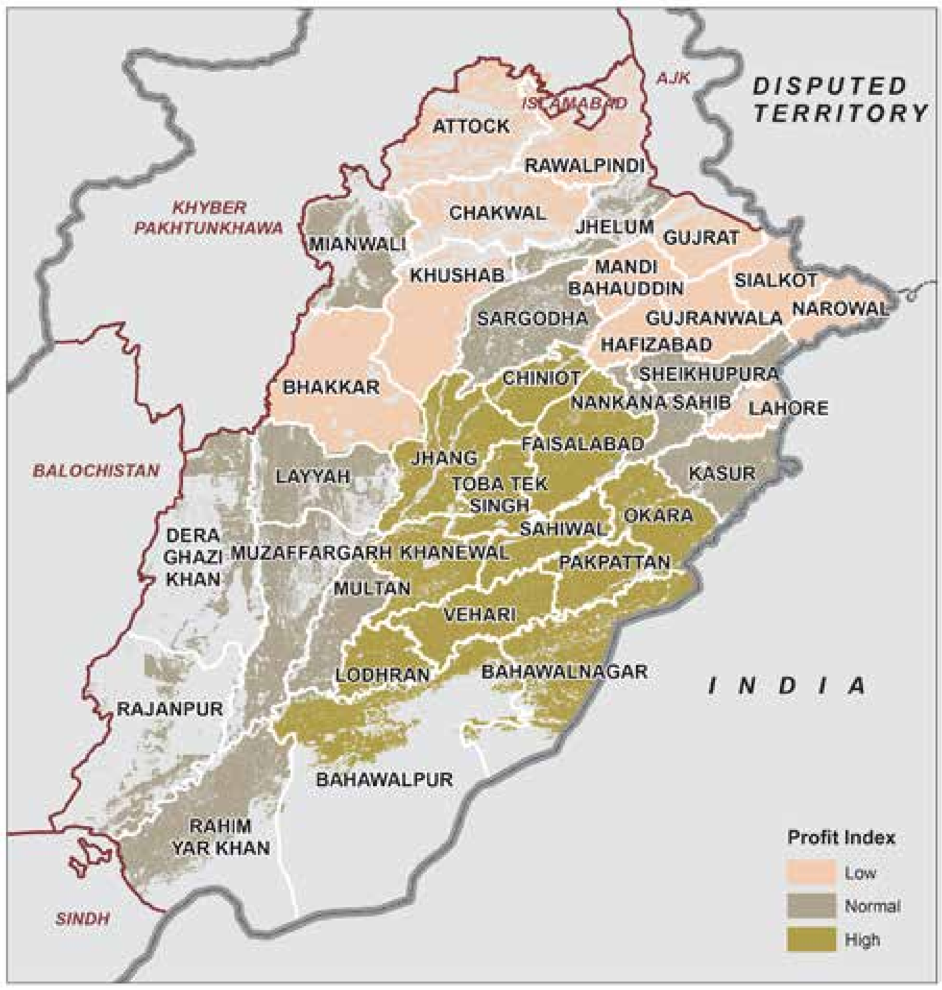
Onion

ECONOMIC SUITABILITY OF PEAS

Sahiwal is the most suitable district for pea cultivation as it generates the highest net returns for pea production in the province, followed by Khanewal and Toba Tek Singh.

The economic suitability map shows that the high return districts lie in zones VII, VIII, and X, while district Sheikhupura (zone X) lies in medium suitability in terms of net returns.





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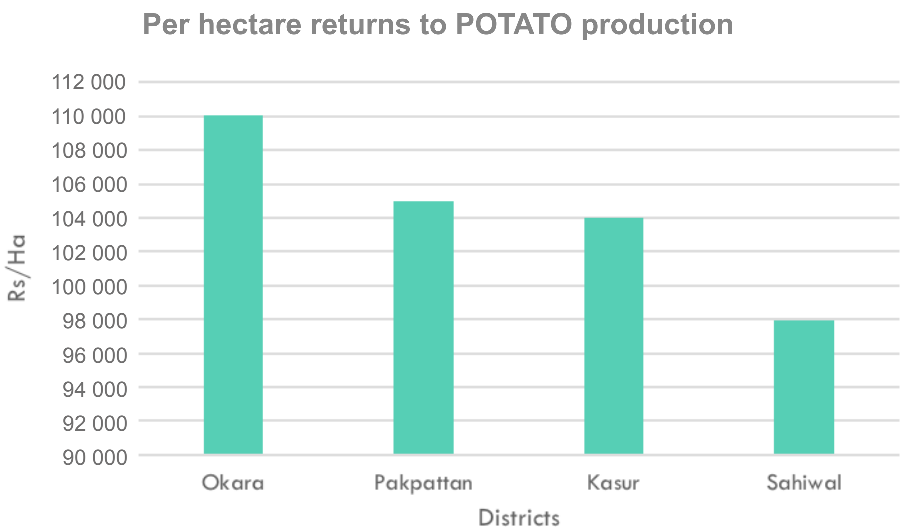
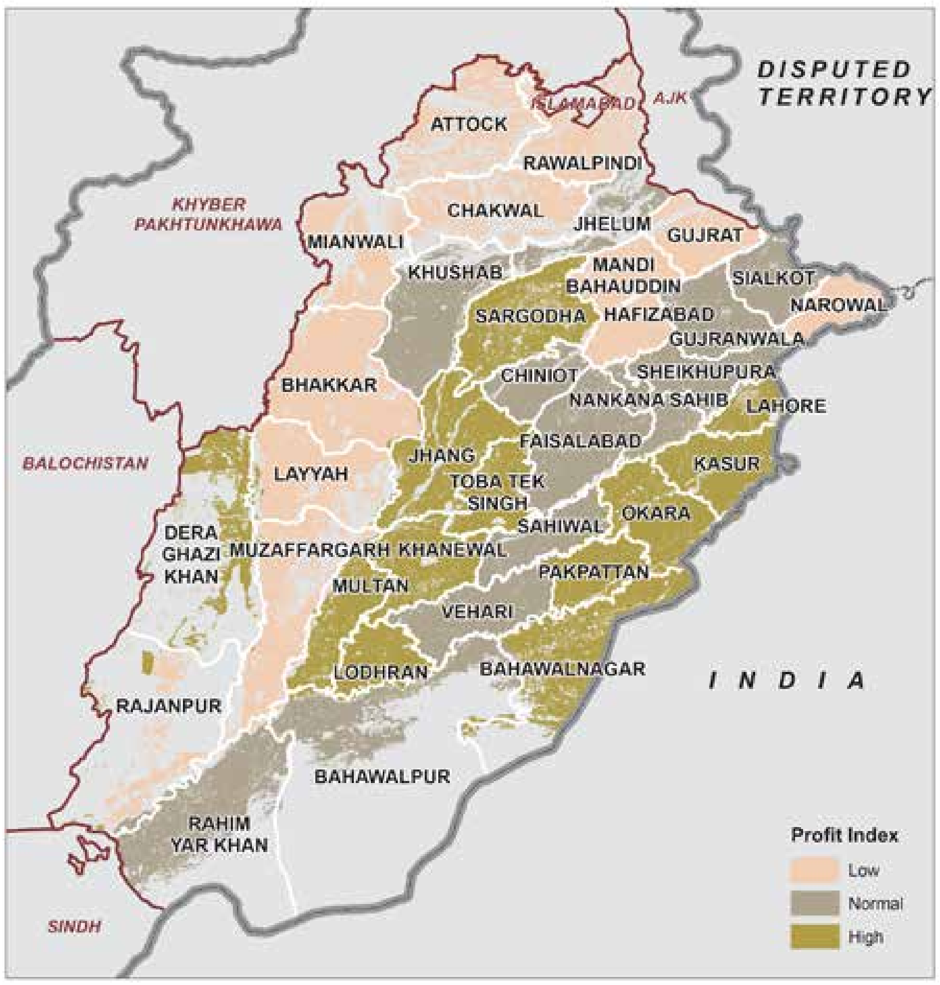
Peas

ECONOMIC SUITABILITY OF POTATO

Data shows that potato cultivation is concentrated in Okara, Pakpattan, Kasur and Sahiwal districts. Of these, Okara gives the highest returns, followed by Pakpattan, Kasur and Sahiwal districts (zones VIII & X).





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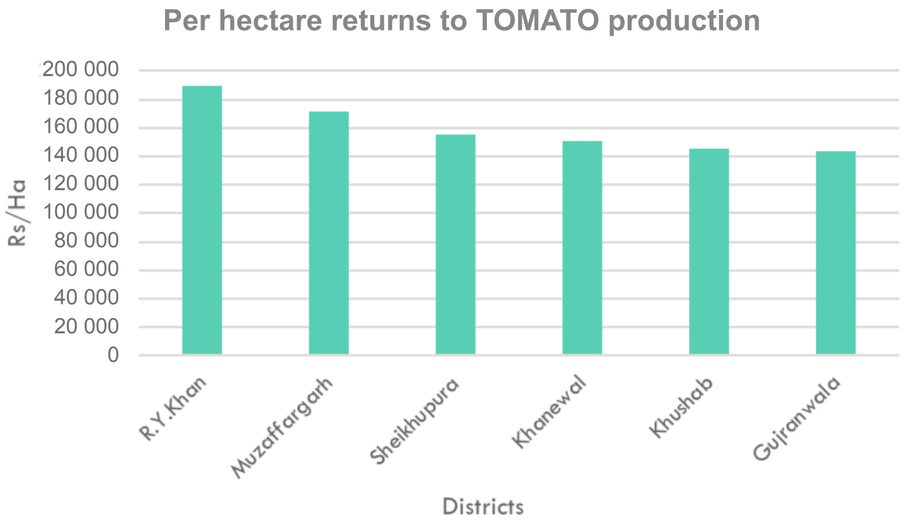
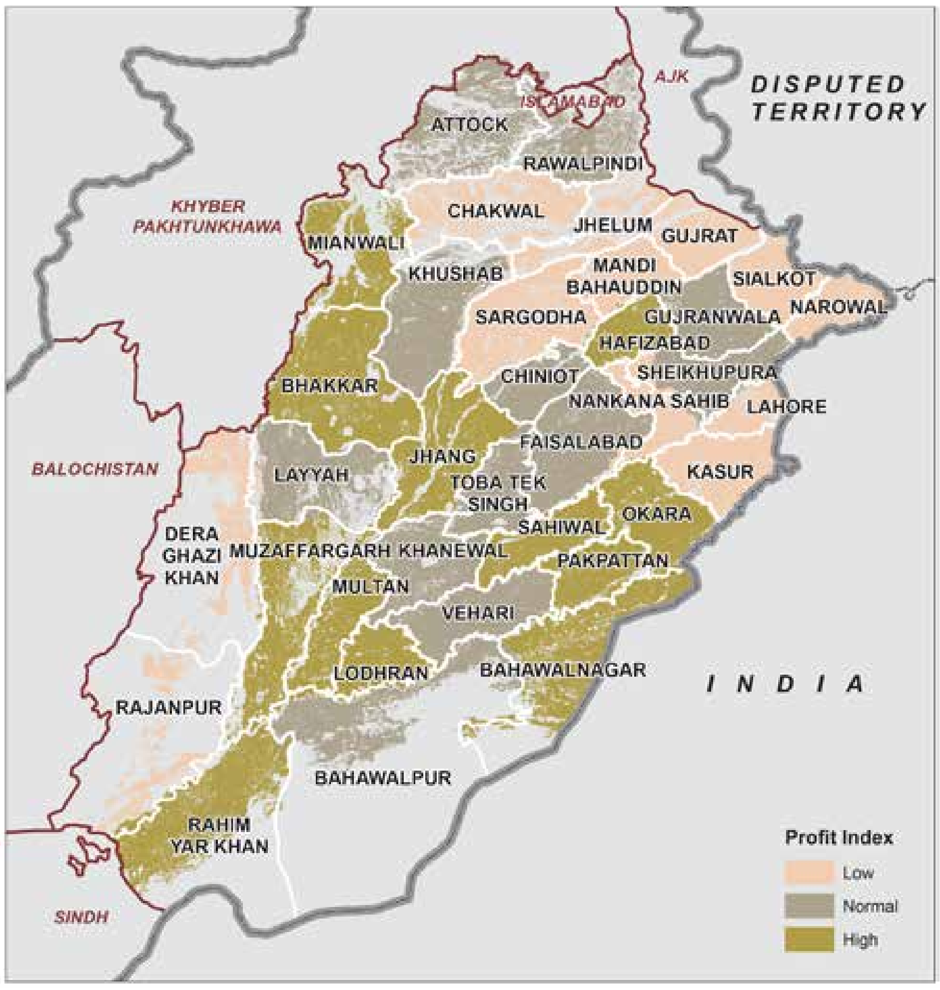
Potato

ECONOMIC SUITABILITY OF TOMATO

Tomato is an important crop for the province and grown in the entire province as it produces significant net revenues for cultivators. Based on the per hectare net returns of tomato cultivation, Rahim Yar Khan generates the highest returns per hectare, followed by Muzaffargarh and Sheikhupura districts.

Based on the economic returns of tomato production, zone II and parts of zones III, VI, and IX, are categorized as highly suitable for tomato production.





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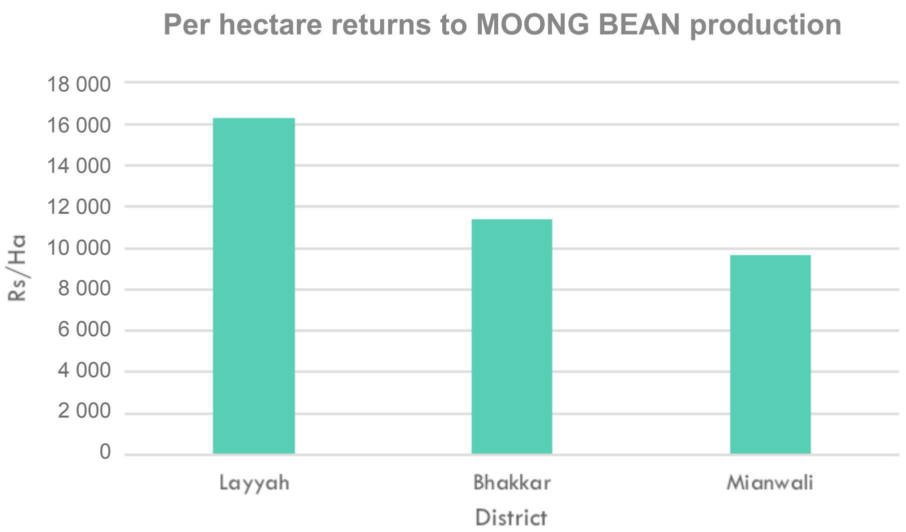
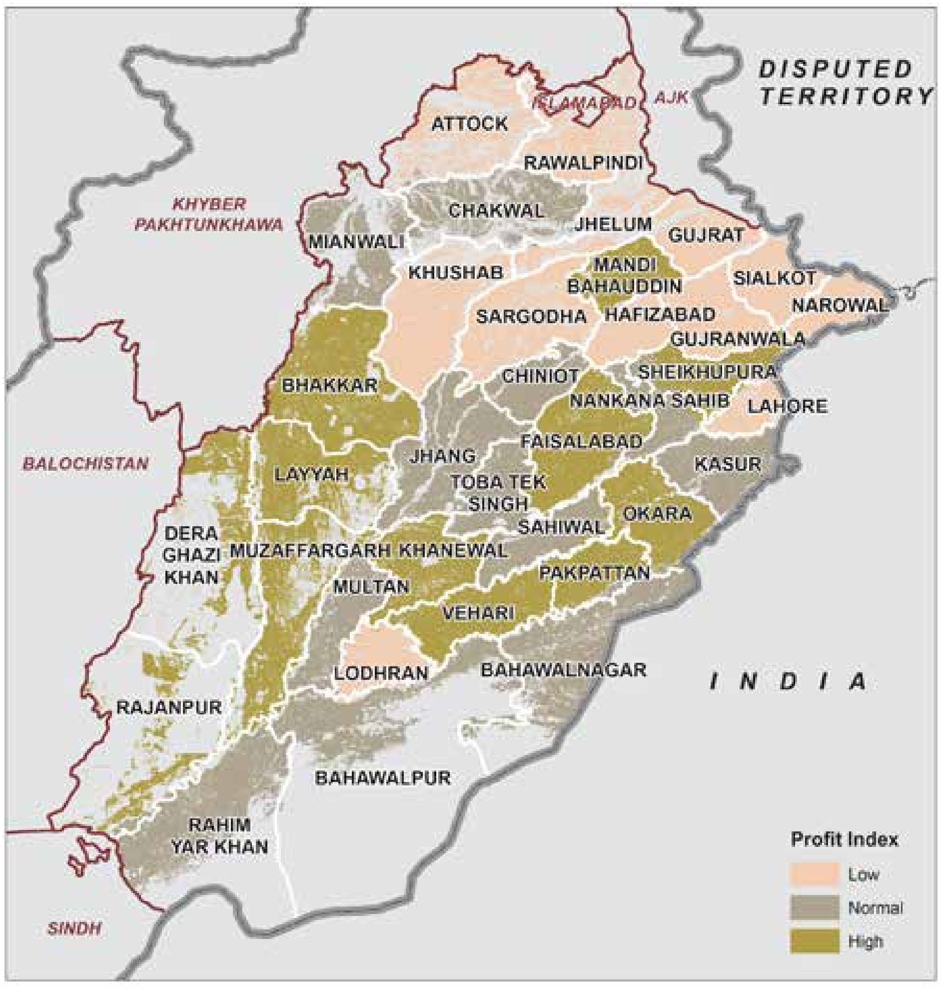
Tomato

ECONOMIC SUITABILITY OF MOONG BEAN

District-wide per hectare, net returns for moong production suggest that district Layyah gives the highest returns, followed by Bhakkar and Mianwali, falling in zones VI, IX, and X, respectively.





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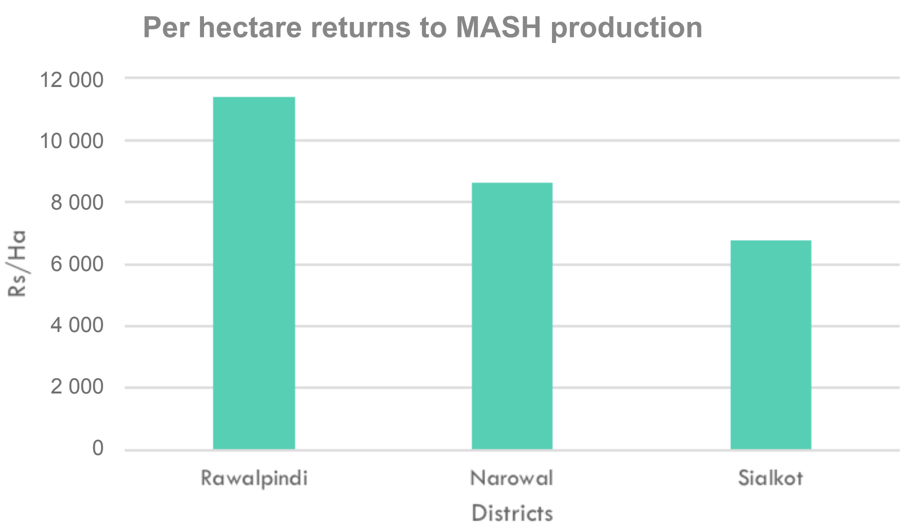
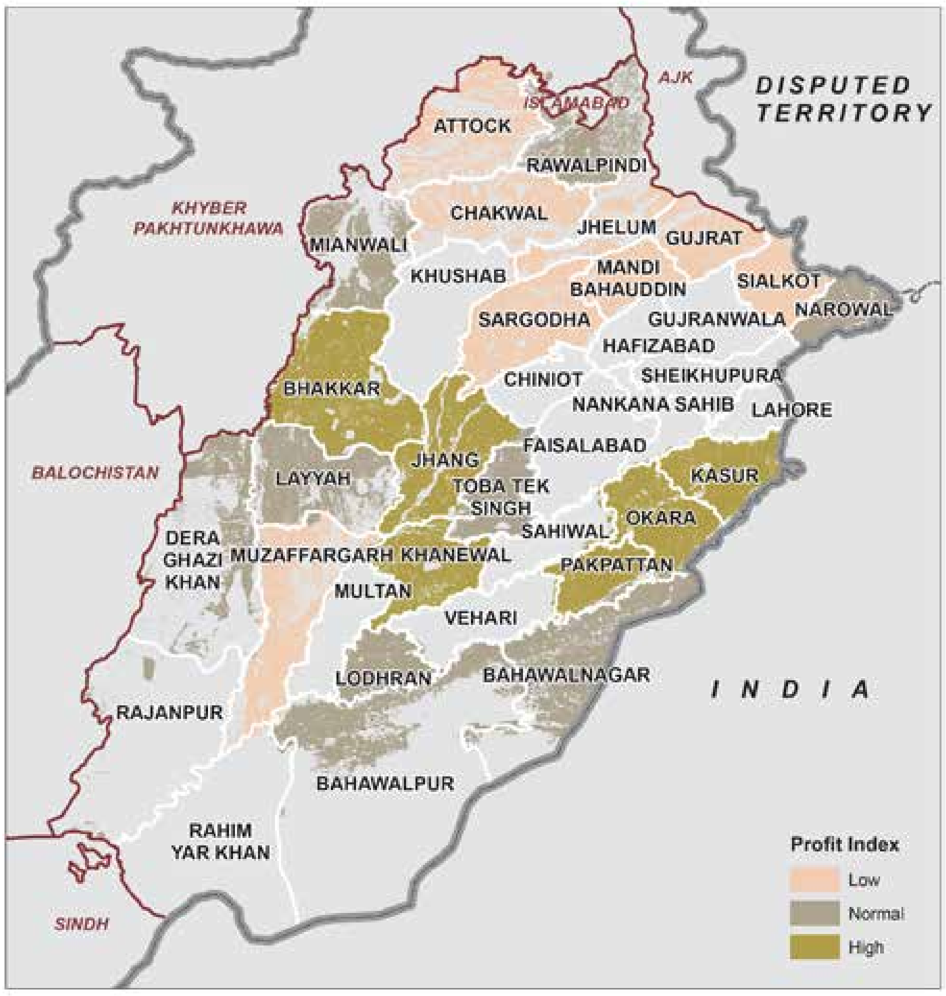
Moong bean

ECONOMIC SUITABILITY OF MASH

Major areas in terms of acreage under mash include Rawalpindi, Narowal and Sialkot districts. Rawalpindi and Narowal fall into high returns, and Sialkot in medium returns for mash cultivation.





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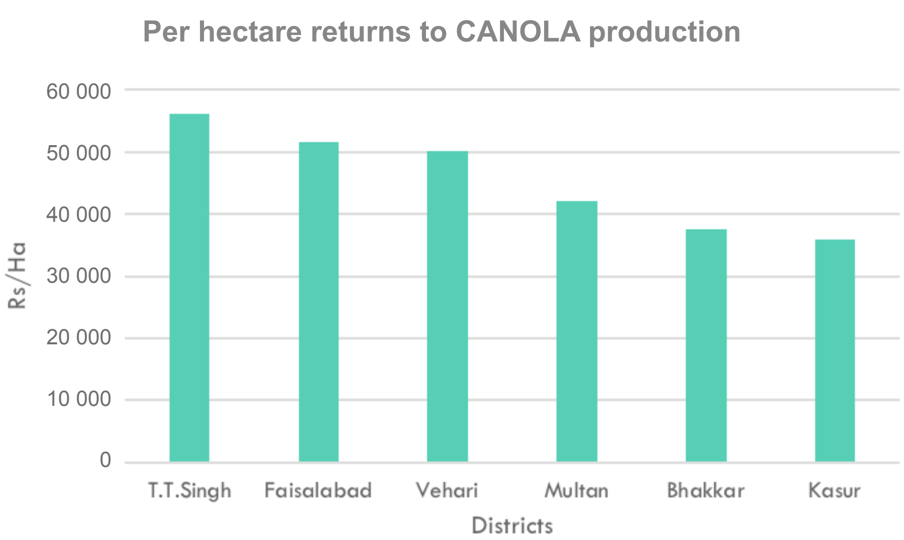
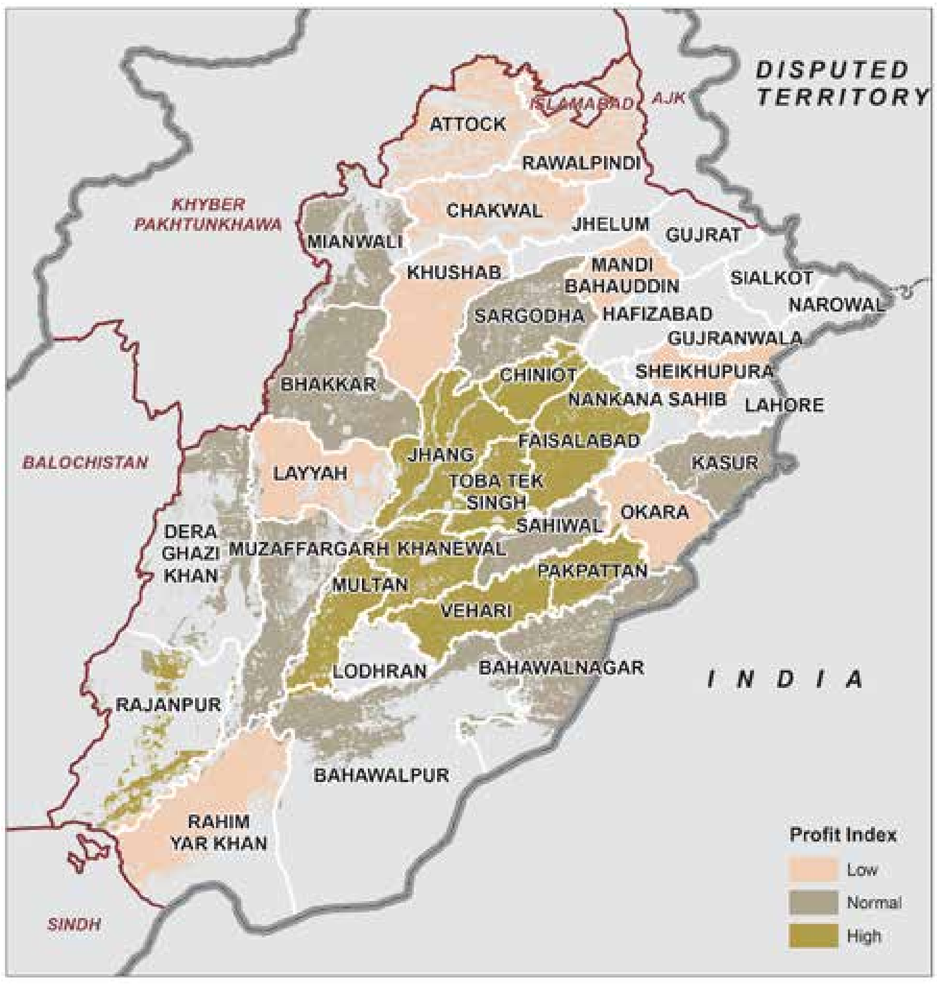
Mash

ECONOMIC SUITABILITY OF CANOLA

Canola cultivation is an important economic activity among the farming communities in the province. Based on economic data, district Toba Tek Singh is the most suitable district for canola production, with net returns per hectare of Rs. 56 156, followed by Faisalabad and Vehari. The canola growing districts with high returns lie in zones V, VII, VIII, and IX. Kasur district (zone X) provides medium returns for cultivation.





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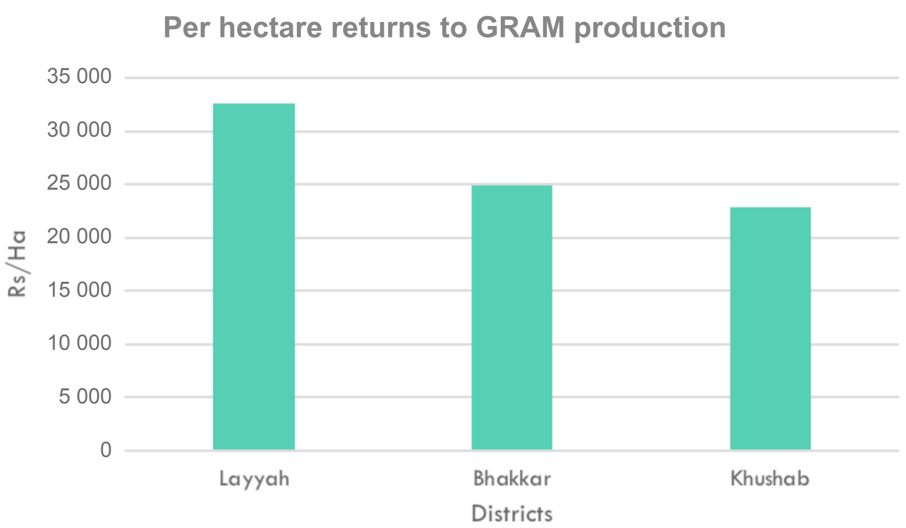
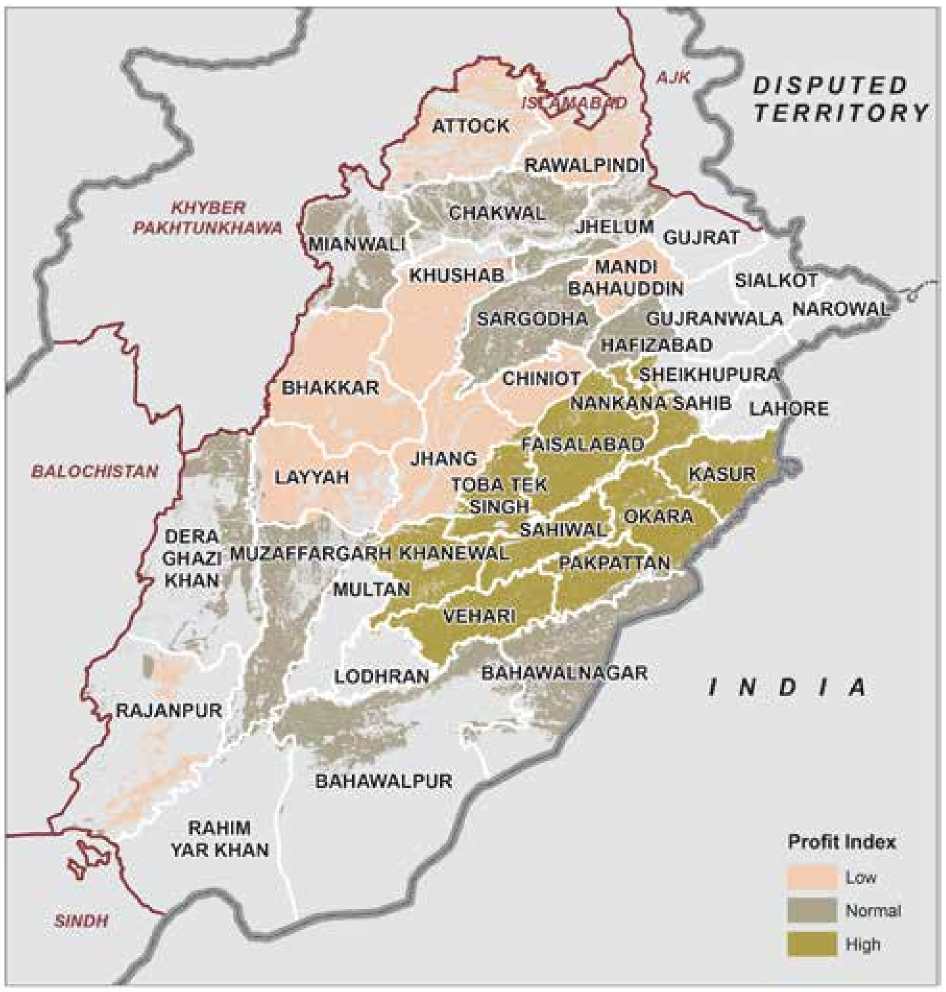
Canola

ECONOMIC SUITABILITY OF GRAM

Gram (chickpea) cultivation is concentrated in Layyah, Bhakkar and Khushab districts. Layyah provides the highest returns for gram cultivation, followed by Bhakkar and Khushab.

The most suitable districts for gram cultivation lie in zones IX and XI..





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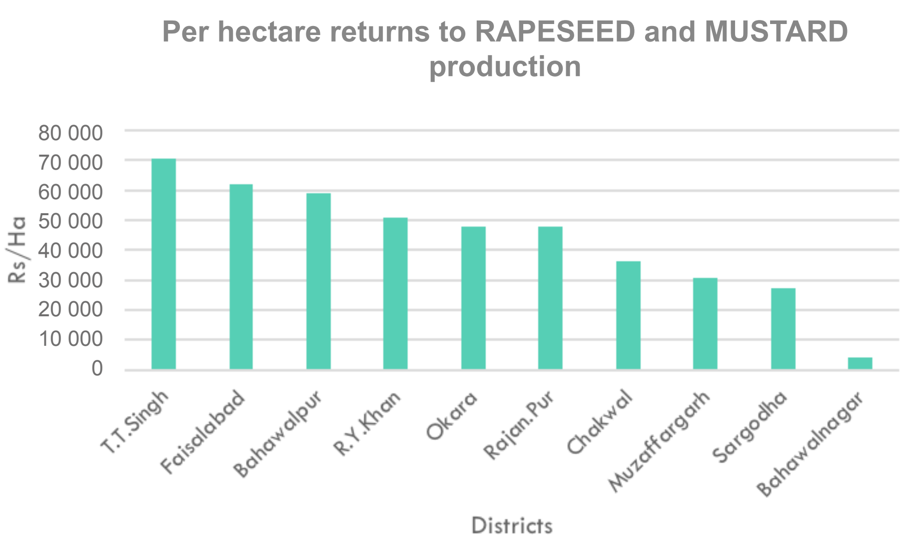
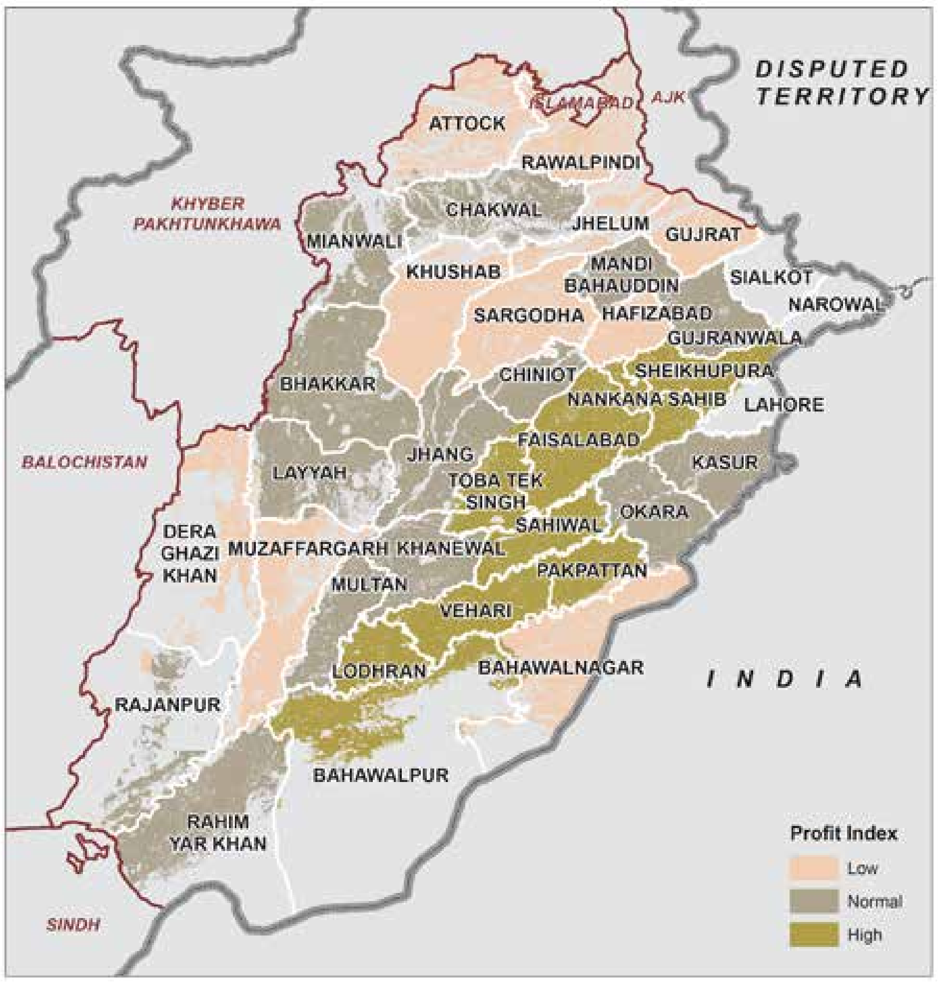
Gram

ECONOMIC SUITABILITY OF RAPESEED AND MUSTARD

The economic data in the above graph shows that the most economically suitable district for rapeseed and mustard production is the province is Toba Tek Singh, with net returns of Rs. 70 653, followed by Faisalabad (Rs. 62 158 per hectare).

The figures reveal that most of the districts in zones I, II, III, V, and VIII are highly suitable for rapeseed and mustard crop cultivation. Some districts in zones VI, XI and XIII are of moderate suitability in terms of economic returns. Bahawalnagar district in zone VII gives low returns per hectare for rapeseed and mustard cultivation.





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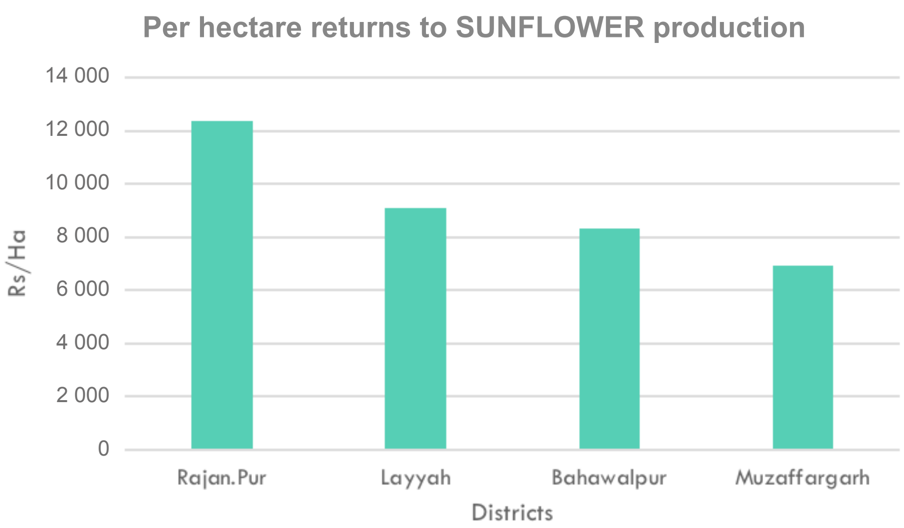
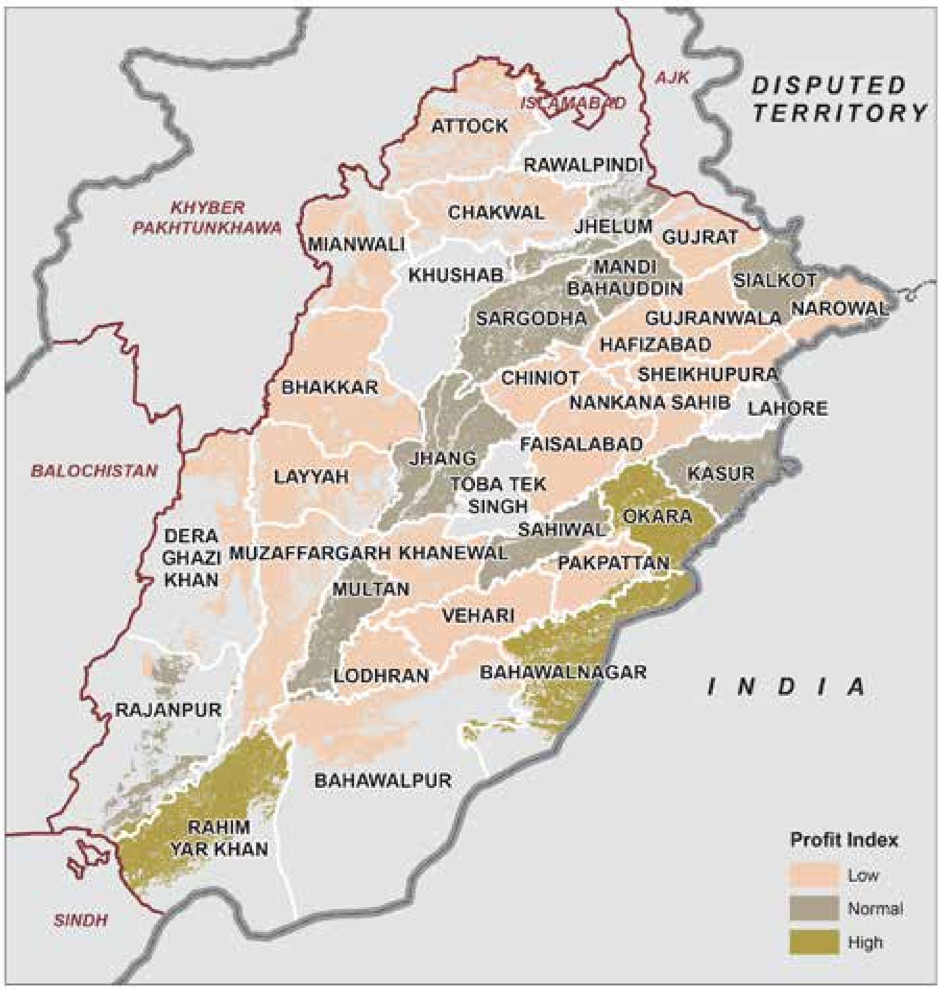
Rapeseed and mustard

ECONOMIC SUITABILITY OF SUNFLOWER

According to the economic data, net returns per hectare for sunflower production are the highest in Rajan Pur district, followed by Layyah and Bahawalpur. Per hectare net returns in these three districts are Rs. 35 506, Rs. 30 684 and Rs. 28 725, respectively.

The suitability map shows that sunflower is economically suitable in zone II, while most parts of zone I and V are also in the high economic suitability category. District Muzaffargarh in zone VI lies in the medium suitability category.





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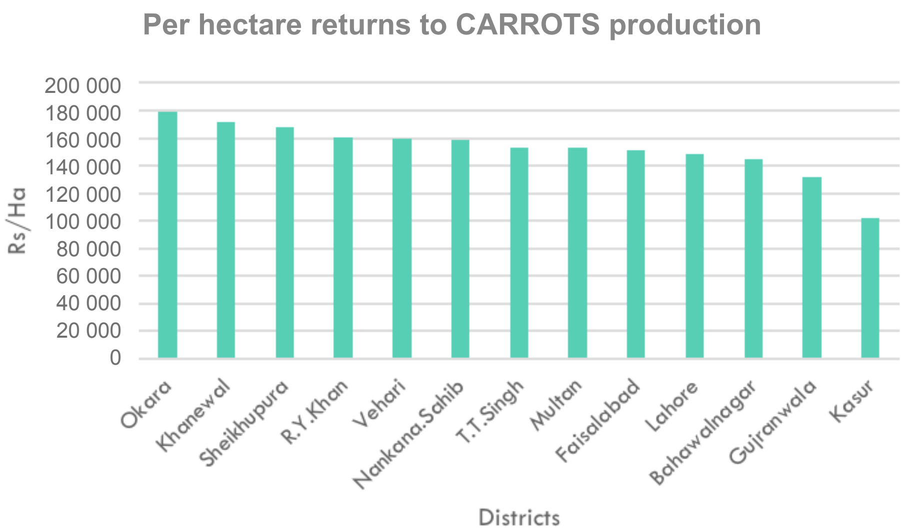
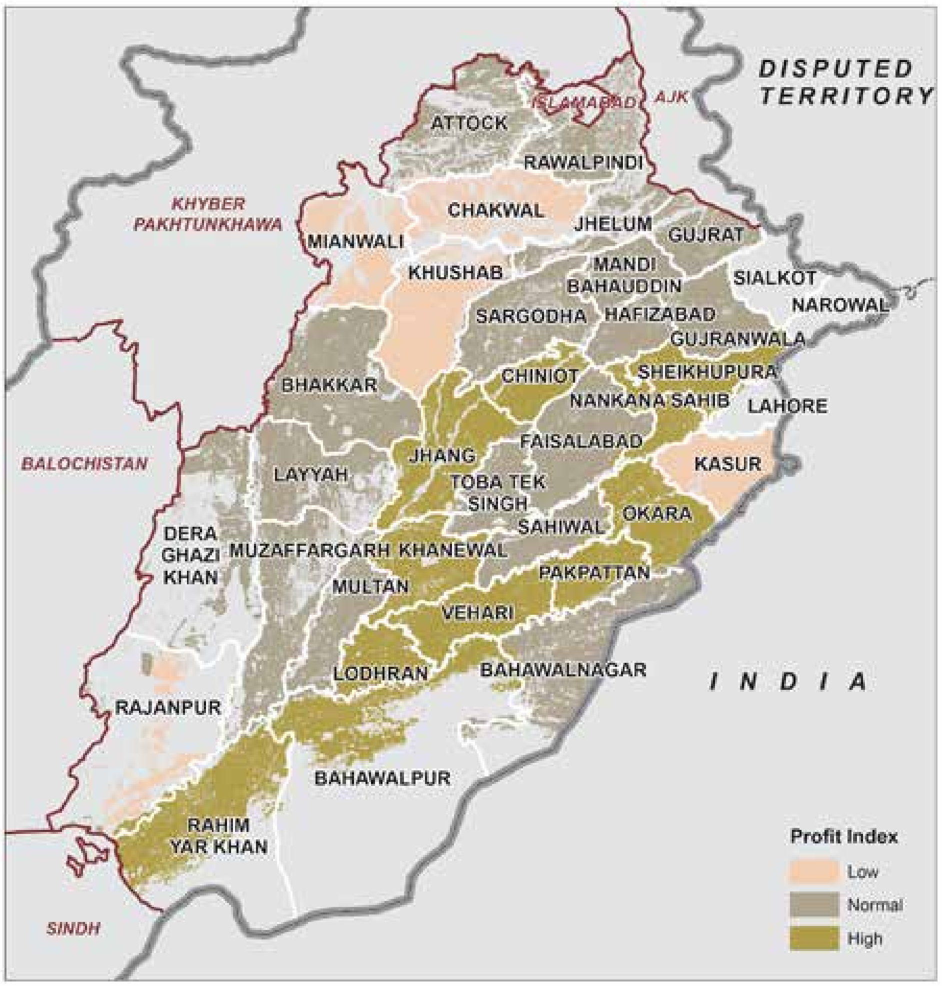
Sunflower

ECONOMIC SUITABILITY OF CARROTS

Carrots are grown throughout the province. However, the most economically suitable district for carrot production is Okara, with Rs. 179 067 per hectare net returns.

Based on the economic data, zone II is reported to be most suitable for carrot cultivation, while most parts of zones V, VII, and VIII and X (excluding Kasur District) are also highly suitable for carrot cultivation.





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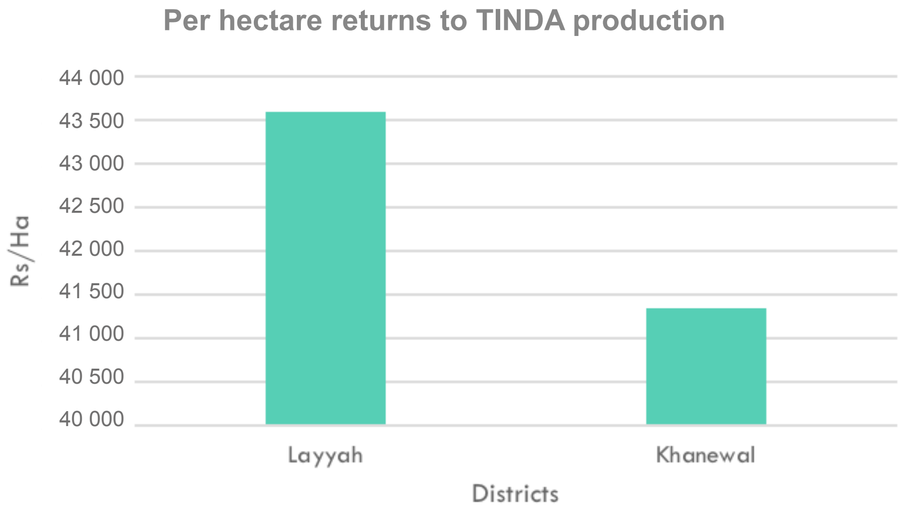
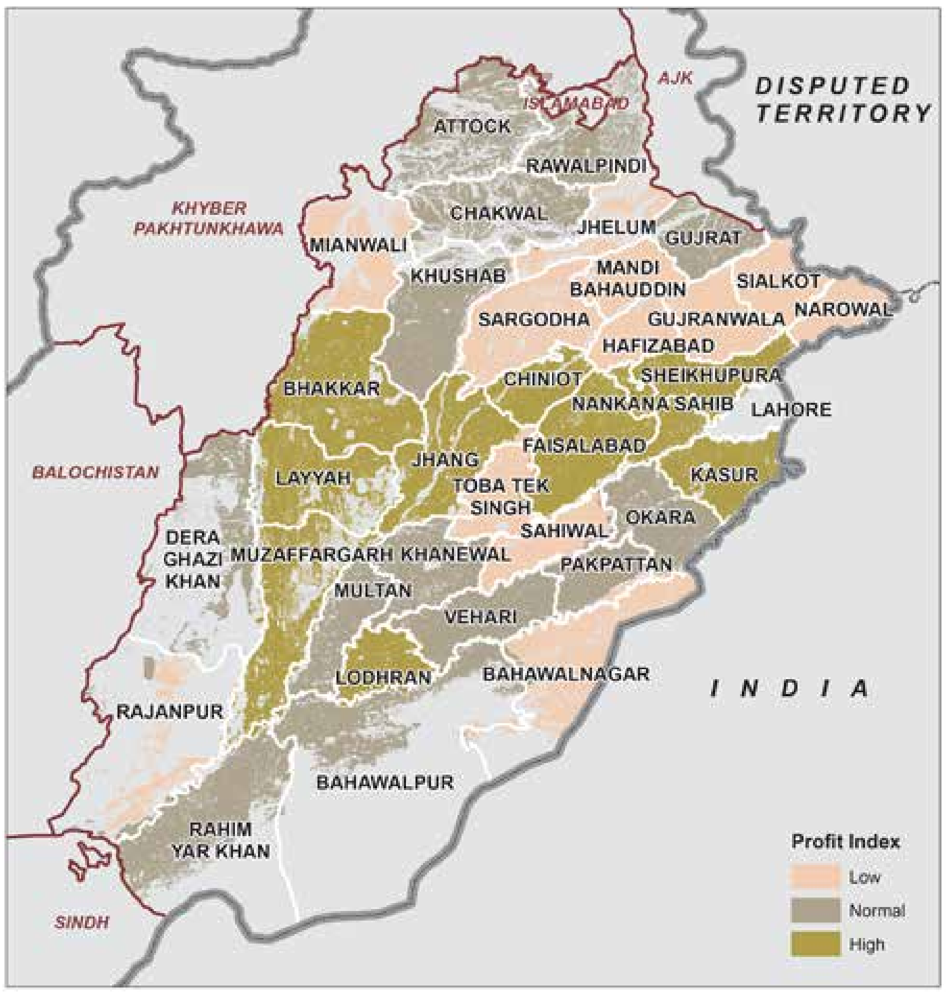
Carrot

ECONOMIC SUITABILITY OF TINDA

According to net returns, Layyah district is the most suitable district for tinda production, followed by Khanewal. It is grown in other districts, but the acreage compared to these districts is too low and does not meet the criteria for the methodology for district consideration i.e. 20 percent area of the maximum cultivated area for a crop in any district. These districts fall in zones VII and IX.





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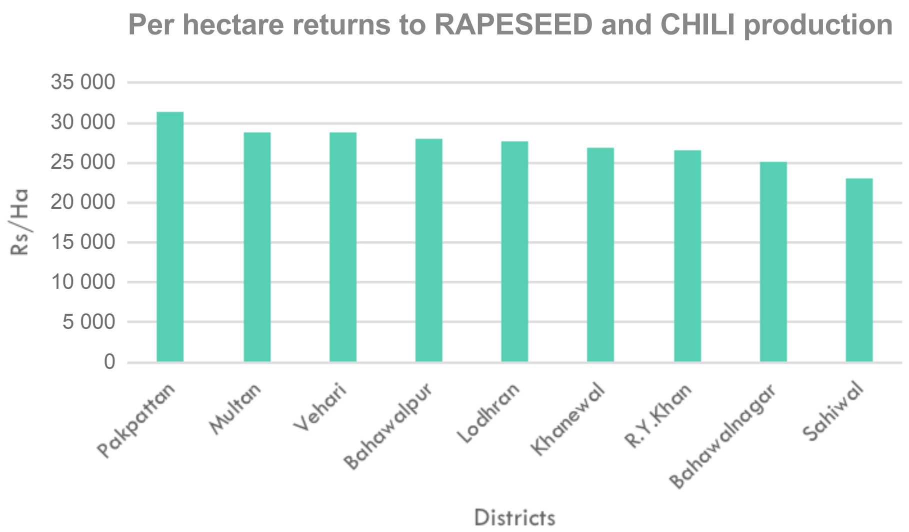
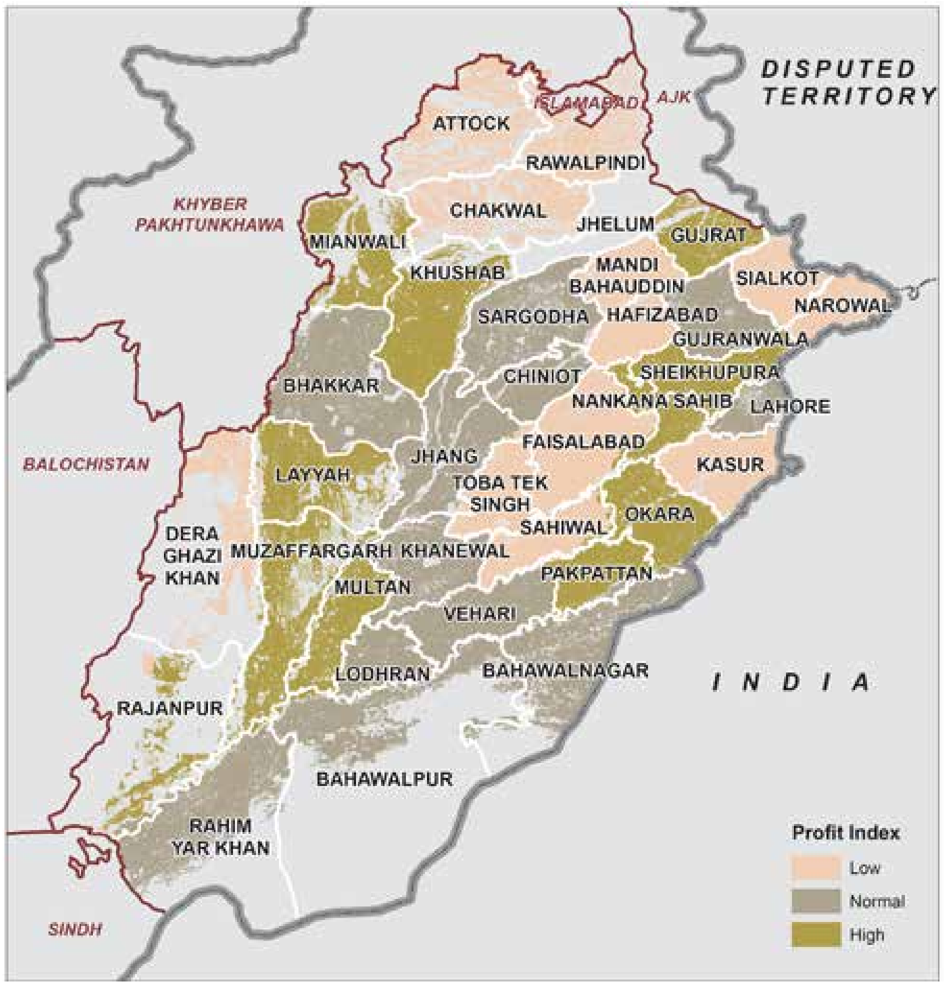
Tinda

ECONOMIC SUITABILITY OF RAPESEED AND CHILI

For chilies, the most economically suitable district in the province is Pakpattan, followed by Multan and Vehari. The suitability map shows that it is profitable to grow chilies in zones I, II, and VII.





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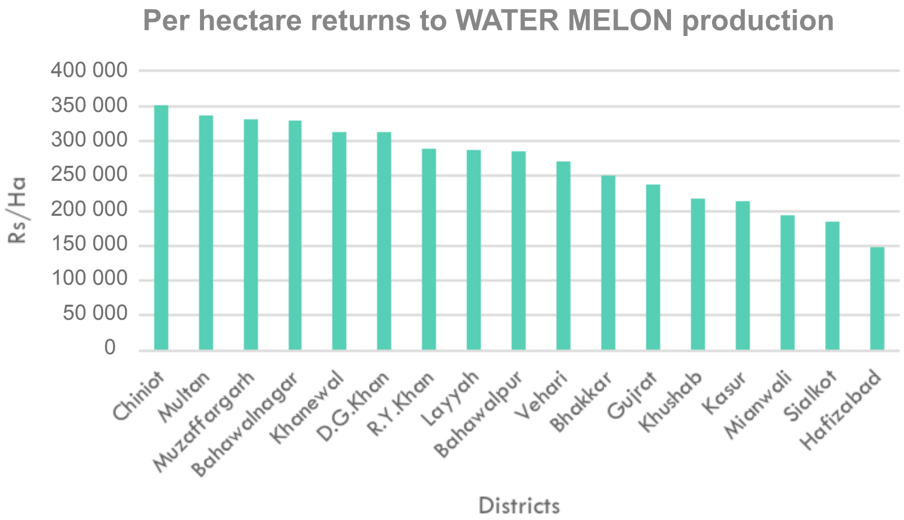
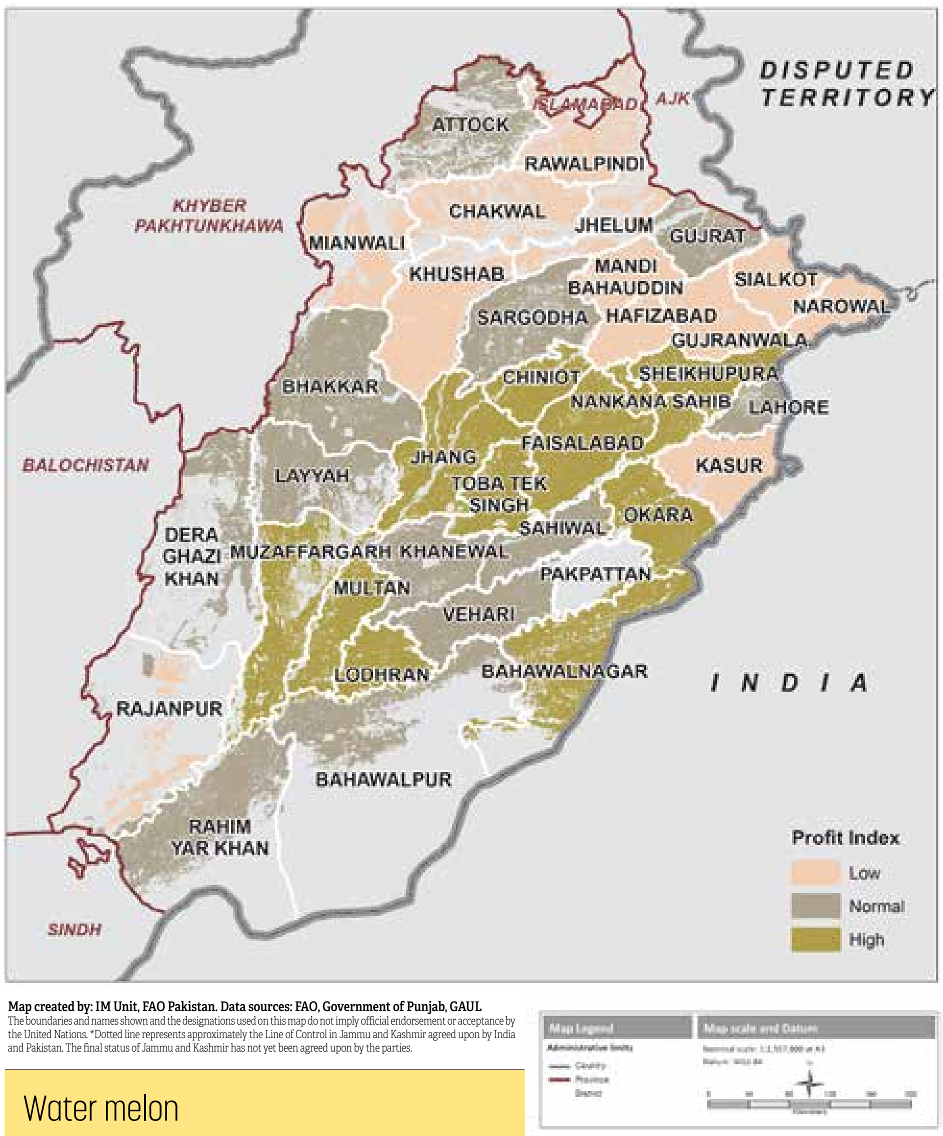
Chili

ECONOMIC SUITABILITY OF WATER MELON

Based on the economic data, the most suitable district for watermelon is Chiniot province with per hectare net returns of Rs. 352 079, followed by Multan.

The economic suitability map shows that watermelon is highly suitable for zones I, II, IV, VI and X, with moderate suitability in some districts of zones X (district Kasur) and XI.





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Water melon

8 Concluding remarks

This report introduced the identification of different agro-ecological zones (AEZs) in Punjab, Pakistan, based on agro-climatic and edaphic variables. AEZs were established using the FAO approach, based on climate, soil characteristics, crop norms, and economic variables. Agro-climatic zones were identified, based on climatic data such as maximum temperature, minimum temperature, wind speed, sunshine hours and humidity, and by calculating ET_0 and the moisture index. Soil-mapping units were constructed at a high resolution of 100 m × 100 m by using soil texture and electrical conductivity (EC). For this purpose, 0.282 million sampling points were used to prepare soil maps. AEZs were developed into homogeneous climatic and edaphic sets by overlaying the agro-climatic and soil maps. Suitability of crops in AEZs was evaluated by developing suitability maps using optimum crop conditions (crop norms).

Suitability maps of agronomic crops showed that wheat is suitable for cultivation in the whole of Punjab, except in a few areas of the province, such as Attock and Rawalpindi. Rice is most suitable in areas of upper Punjab such as Gujranwala, Sialkot, and Gujrat, and in a few areas of Sheikhupura, Sargodha, and Nankana Sahib. Cotton is most suitable in the lower areas of Punjab such as Khanewal, Vehari, Multan, Muzaffargarh, Bahawalpur, and Bahawalnagar.

Suitability maps of fruits also showed that citrus fruits can be grown in different patches across the whole of Punjab, while the core areas include Jhelum, Sargodha, Gujranwala, Layyah, and Rajanpur. Mango is most suited to central Punjab and a few areas of lower Punjab, including Rajanpur, Rahim Yar Khan, etc. Guava is best for cultivation in central Punjab and a few areas of upper Punjab such as Gujrat, Jhelum, and Sialkot. The suitability maps of vegetables showed that garlic is suited to almost all of Punjab except in Attock and Rawalpindi. Cabbage is suitable for cultivation in Gujrat and Narowal, and in a few patches in all of Punjab. The most suitable areas for turnip cultivation are Bhakkar, Layyah, and Mianwali, which are the desert areas of Punjab.

To understand the economic suitability of different crops in different zones, net returns were calculated using available data on crop yield, price and cost of production. The districts with 20 percent of the highest areas cultivated for a crop were considered for comparison to avoid districts with a given crop cultivated in a very small area. This way, the high, medium and low profitability of different districts/zones were determined using 66th, 33rd and below 33rd percentiles, respectively. Based on net returns and comparative profitability levels, economic suitability maps were drawn. Policymakers may promote crop activity in the most suitable zones (on the basis of productivity and profitability) and keep the low-return zones for more suitable crops to attain crop diversification and efficient utilization of resources through public policy instruments.

AEZs should be added as an integral exercise in the agriculture planning process and be expanded to the country level. The use of the latest computing facilities and big data tools should be introduced to generate and handle the vast amounts of data needed for the zoning exercise. The AEZ report should be kept as a living document and should be periodically reviewed and updated. Policymakers should make any agricultural policy-related decisions (credit, subsidies, support price, markets, mechanization, groundwater policy, irrigation pricing, diversification, agriculture import, and export, etc.) based on potentiality and constraints in different zones.

Way forward

Availability and reliability of data are some of the biggest constraints in agriculture. Institutional compartmentalization into federal and provincial data, as well as in many other dimensions, promote inefficiencies, including in generating and sharing quality data. This needs to be resolved through the establishment of a data clearinghouse for agriculture-related information to refine AEZs and promote data-driven solutions.

Groundwater quality and quantity data are tricky. As different estimates suggest, some 45 percent to 55 percent of water in Punjab's agriculture comes from aquifers. Therefore, real-time qualitative and quantitative measurements can help improve agro-ecological zoning (as water is the limiting factor, both in terms of quality and quantity) and farm production decisions.

The report has considered the minimum–maximum temperature in crop suitability norms. A more scientific approach to growing degree days could provide better results. Future research that calculates the growing degree of crops should be promoted.

The current report has used 'crop suitability' without calculating yield estimates across suitable ecological conditions. As a result, vast areas may seem suitable for growing a crop, but the suitability of competing crops is not clear with the current information. There is a need for better yield estimates in different 'suitable' climatic conditions for growing crops, and for more detailed economic studies to evaluate the comparative advantage of different crops in different zones to come up with crop clusters.

Livestock is an integral part of the agricultural system in Pakistan. However, livestock is limited to a few fodder crops in the current study and needs to be studied further, taking animals and rangelands into consideration. In addition, agro-forestry can also be included in future research studies and reports.

The economic data is limited in terms of a number of crops and non-availability of district-wide information on the cost of production. Similarly, the availability and role of market-related factors and population projections determine crop demand and cultivation. The socioeconomic data needs to be modeled using market and population information, along with simple net return calculations.

Considering the importance of, and a different set of issues engaged in, peri-urban agriculture, a different zone may be proposed in a future exercise. In order to predict upcoming changes in AEZs and crop suitability, climate scenarios can be further applied to determine future changes.

Realizing the importance of big data and cloud computing, the Higher Education Commission of Pakistan has taken the initiative to establish a National Center in Big Data and Cloud Computing. The data generated and archived under this initiative, especially through the center's dedicated lab on Precision agriculture and analytics, will help to keep the current report as a living document by feeding it with a constant flow of new data and tools.

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