Final Report
CCAFS Consulting Contract 4500013658

Utilization of *ex situ* collections and climate analogues for enhancing adaptive capacity to climate change

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Farmers continue to cultivate landraces for family consumption; unknowingly contributing for adaptation process

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Front cover photo

The image poignantly represents the bright eyed kids of marginal farmers in Rajasthan state of India, who are going to be affected the most by climatic changes; standing in front of a pearl millet landrace inherited by them and expected to provide definite solutions to fight the effects of climate change on agriculture. Standing together, the two kids also depict need of partnerships.

Photograph by DP Semwal and OP Dhariwal

Acknowledgements

The authors appreciate the guidance and input received from Prof. Pramod Aggarwal (IWMI) and Dr. Prem Mathur (Bioversity International). Proactive support of Prof. Kailash Bansal (NBPGR) at every stage of this project is gratefully acknowledged. Technical contributions of Anuj Singh, Sarika Mittra and Firoz Ahmed are also acknowledged.

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Contents

Prologue

Conservation of genetic variation has been believed to be an insurance against future contingencies. Climate change is one such serious challenge confronting humanity. Agriculture cannot sustain production without adequate measures for climate adaptation. One major input to climate smart agriculture is genetic variability collected and conserved as *ex situ* collections in the genebanks. It is in this context that the CCAFS sponsored programme on "Utilization of ex situ collections and climate analogues for enhancing adaptive capacity to climate change" was a significant pilot study implemented by NBPGR.

This technical report describes how climate analog tools were employed to identify pre-adapted germplasm (value addition to genebank collections) and potentially vulnerable areas (for collection and conservation) in five select crops — wheat, pearl millet, chickpea, pigeon pea and sorghum. The methodology comprised geo-referencing and clustering the accessions, identifying vulnerable areas, designating pre-adapted material, collecting germplasm from predicted sites, and developing database and climate maps. Long term benefits of the project include capacity building and addition of climate attributes layer to existing PGR informatics set up of NBPGR.

The project was envisaged and brought to NBPGR by the farsighted leadership of Prof. Kailash Bansal, Director of NBPGR with the support of Prof. Pramod Aggarwal, Regional Program Leader of CCAFS as well as Dr. Prem Mathur, Regional Director of Bioversity International. Mentoring received from them is acknowledged with gratitude.

17th September 2014

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Executive summary

Climate smart agriculture demands development of new crop varieties involving the use of a wider range of intra-specific diversity so as to increase adaptability and resilience, and improve ecosystem services. As a result varietal development programmes need to be fed by genotypes with excellent adaptation potential. The best way to identify germplasm pre-adapted for changing climate is to group them based on specific traits and then select the most suitable ones. However, germplasm accessions are, at best, characterized for morphological traits, and often physiological attributes (root traits, canopy temperature depression, response to diurnal length, etc.) remain unrecorded. It is therefore essential to make use of passport data especially the coordinate locations of accession collection sites to estimate adaptive capacity of each accession.

Why this study?

"Utilization of *ex situ* collections and climate analogues for enhancing adaptive capacity to climate change" was conceptualized and implemented to link specific agronomic descriptors and geographic origins of germplasm accessions with current and future environmental data. By effectively accessing and interpreting such information, one could shortlist prospective germplasm accessions that are pre-adapted to predicted changes in climate. This was expected to improve the resilience and capacity of agricultural systems to adapt to environmental changes in India.

The specific objectives of the study were to employ climate analog tools to identify pre-adapted germplasm (value addition to genebank collections) and vulnerable areas (for collection and conservation) in five select crops — wheat, pearl millet, chickpea, pigeon pea and sorghum. The methodology comprised geo-referencing and clustering the accessions, identifying vulnerable areas, designating pre-adapted material, collecting germplasm from predicted sites, and developing database and climate maps.

Data mining and geo-referencing

Information on 38,126 accessions belonging to five target crops was mined from NBPGR and relevant global databases. In all, 10947 sorghum, 9499 wheat, 8220 pearl millet, 6167 pigeon pea and 3293 chickpea accessions were geo-referenced based on their collection sites and mapped. Considering the cropping areas of India, it was not surprising that the collection sites primarily belonged to semi-arid to sub-humid regions with hot semi-arid topping the list. Taking into account the changing climate towards semi-arid type in India and several other parts of the world, this early observation has profound utility on the robustness of the predictions. In India, wheat and chickpea are grown in *rabi* season (winter sowing supported by irrigation) whereas pearl millet and pigeon pea are cultivated during *kharif* season (dependent on south-west monsoon). Sorghum is grown as both *kharif* and *rabi* crop. Climatic attributes (only temperature for *rabi* crops) and (both temperature and rainfall for *kharif* crops) observed over only the growing season were attached to the locations. Geo-references were classified based on the agro-ecological zones, and were categorized into altitude groups.

Clustering and mapping

The accessions were subsequently clustered based on computing the probability that a climate record belongs to a multivariate normal distribution described by the climates at the collection points of a calibration set of germplasm accessions. This was carried out by using monthly rainfall totals, monthly average temperatures and monthly diurnal average range to identify sub-groups with significantly distinct climatic ranges. Since climatic parameters were used for clustering, variance was used rather than distance metrics or measures of association to cluster the points. Each of sorghum (10947 accessions/1022 unique locations), wheat (9499 accessions/834 unique locations), pigeon pea (6167 accessions/1005 unique locations) and chickpea (3293 accessions/1138 unique locations) were grouped into 20 clusters whereas 8220 accessions of pearl millet (2116 unique locations) were grouped into 27 clusters.

Temperature data were obtained from the Worldclim 2.5 min database for current climate (1950 – 2000) and from CSIRO -Mk3.5 General Circulation Model for near future (2010-2039). Indian agriculture has been predicted to be challenged with elevated temperatures and hence upward change in maximum (*kharif*) and minimum (*rabi*) temperatures has attracted the greater attention. We concentrated on the changes in the mean maximum temperatures confined to cropping season for each of the five crop species. In order to find out areas most vulnerable to changing climate, the information was mapped employing the geospatial processing program ArcMap.

Climate matching and identification of vulnerable areas

Temperature intervals were maintained at 2°C for a better depiction. Upon a quick perusal of the maps, it was very evident that most of the areas under cultivation are predicted to experience a shift to at least next temperature class (i.e. +2°C mean monthly max temp). Vulnerable sites were identified based on following considerations:

- Mean monthly max temp reaching the top bracket (at or beyond higher end of the temperature range of the crop)
- Fewer accessions from such areas collected and conserved by NBPGR
- More likelihood of finding landraces, farmers varieties and other locally adapted material rather than improved varieties and hybrids
- Likelihood of subsistence farming and serious chance of genetic erosion due to climate change

These empirical inferences, were further supported by climate matching (present to future) carried out for each of the clusters generated by FloraMap analyses. The matching was done by employing MaxEnt program.

Top two vulnerable sites for each crop are listed below. Each site is delimited by smallest administrative boundary called *taluk*.

1. Sorghum: Seven taluks of Karnataka-Maharashtra border and twelve taluks in Tamil Nadu
2. Pearl Millet: twenty-one taluks in Tamil Nadu and thirteen taluks in Rajasthan
3. Chickpea: thirty-two taluks Karnataka-Andhra Pradesh border and thirteen taluks of West Bengal
4. Pigeon Pea: eighteen taluks of Bihar and five taluks in Telangana
5. Wheat: twenty-two taluks of Karnataka-Maharashtra border and sixteen taluks in Madhya Pradesh

Climate matching and identification of sites with pre-adapted germplasm

Sites with current climate variables, that make areas vulnerable in the future, were identified for each crop except pigeon pea. Genebank accessions originating from these sites were termed as pre-adapted material having potential to be utilized directly as varieties or as parents in breeding depending upon agronomic performance in the new sites. Seventy-six pearl millet accessions from Rajasthan, forty-five chickpea accessions from Gujarat, twelve sorghum accessions from Maharashtra and four wheat accessions from Maharashtra-Gujarat border in the sub-coastal areas have been provisionally designated based on locations (source and test sites), climate matching, available agronomic performance data and seed availability in the genebank.

It is important to note that analysis and interpretations come with certain limitations. For instance: prediction of the future temperature regime (lack of local temperature data, using temperature alone as an attribute, limitations of the models, etc.), identification of locations (using climate attributes alone, lack of precise soil data, etc.), designation of germplasm accessions as suitable to newer areas (incomplete passport data, inter-regional differences of season, soil, taste, etc.).

Exploration and germplasm collection

A calendar of special exploration and collection missions based on predictions of future climate has been prepared for all five crops. Three were executed as per the standard procedures established in NBPGR. Thirteen pearl millet landraces were collected from twelve villages of Rajasthan using bulk method. None of these landraces was in cultivation. Farmers, particularly female folk, shared their saved seeds from the storage bins. Eighteen sorghum landraces were collected from seventeen villages of Rajasthan. Eleven accessions were sampled from farmer's field by random method and the rest were collected using bulk method as these were shared by farmers, particularly female folk, from the storage bins. As per the planned collection missions based on 2012-13 report, we could not take up trips in Maharashtra during 2013-14 *rabi* to collect chickpea because of crop loss due to severe hail-storm. One of the areas for chickpea is the transitional area of AP and Karnataka (on either banks of river Tungabhadra). With the available preliminary information, a visit of four days was planned keeping Raichur as major point (due to presence of University of Agricultural Sciences, Raichur). An occasion of socio-religious congregations was selected to interact with people. Commercial cultivation under chickpea was noted to be dwindling and replaced by cotton and vegetables. It was inferred that more sites in this region need to be identified.

Capacity building

We organized a 5-day "Regional Training Workshop on GIS and Climate Analogue Tools for PGR Management and Enhanced Use" during 2-6, December 2013 at NBPGR, New Delhi. The aim of the Workshop was to impart contemporary knowledge on GIS, climate data, climate analogues and their applications in PGR management and utilization along with hands-on experience on various software, databases, clustering and analyses. Participants had an opportunity to listen to presentations by experts on select topics (25% of the time) and work hands-on (75% of the time). The participants included eight persons from ICAR institutes, one each from SAU and CSIR, and four from neighboring countries of the South East Asia (Vietnam, Laos and Cambodia) engaged in PGR management and interested in employing climate analogue tools. Indian participants were supported by dedicated funds available in the project whereas foreign participants were fully sponsored by our collaborator in the project, Bioversity International.

Conclusions and future prospects

The project introduced the power and potential of climate analog tools for value addition to the conserved germplasm as well as identification of vulnerable sites. Based on analyses, accessions of all five selected crop species have been listed as climate ready. These need further evaluation for their suitability to the new sites. Tools for predictions and identification of vulnerable sites are becoming more sophisticated and realistic. These tools need to be employed for identification of critical sites for collection and recollections. An analysis of what to collect in terms of CWR and populations, extent of variation in terms of genetic variability, and contribution to adaptive capacity in terms of novel genes and alleles need to be carried out. Such studies will be able to evaluate the process of prediction based on climate models.

Introduction

The genebank at the National Bureau of Plant Genetic Resources (NBPGR) is one of the largest in the world in terms of *ex situ* collections. On-going programmes at NBPGR focus on enhanced utilization of the genetic resources and identification of germplasm suitable for changed climatic conditions. Experts have demonstrated that the impacts of climate change can be estimated. However, no systematic efforts have been made to add value to genebank collections in terms of their climate suitability or climate readiness. Such efforts can help evaluate genebank collections by plant breeders and researchers with a focus on adaptation, thereby prepare for impact of changing climates on agricultural research as well as food and nutritional security. Pre-requisite for such an effort is to develop a database of germplasm accessions associated with corresponding climate information (both current and future) and their mapping using GIS-based approach for the production of germplasm atlas.

An FAO study[1] has called for increased need for consolidating collections of wild species, including crop wild relatives, due to increased likelihood of extinction for narrowly adapted and endemic species. The study has also predicted novel and increased demands on germplasm in genebanks for adapting agricultural practices to climate change, including the need to screening for different characters. It is in this context that the project "Utilization of *ex situ* collections and climate analogues for enhancing adaptive capacity to climate change" was conceptualized and implemented to link specific agronomic descriptors and geographic origins of germplasm accessions with current and future environmental data. By effectively accessing and interpreting such information, one could shortlist prospective germplasm accessions that are pre-adapted to predicted changes in climate. This was expected to improve the resilience and capacity of agricultural systems to adapt to environmental changes in India.

For NBPGR, this was a beginning and in the absence of any previous experience, five crops were selected (i) that were important from the food security point of view in India and (ii) that had adequate number of accessions in the genebank. Five target crops were selected: wheat (*Triticum* spp.), pearl millet (*Pennisetum typhoides*), chickpea (*Cicer arietinum*), pigeon pea (*Cajanus cajan*) and sorghum (*Sorghum bicolor*).

At the end of the first year, progress was reviewed internally and for want of data availability sesame (*Sesamum indicum*) and guar (*Cyamopsis tetragonoloba*) from the original proposal were replaced by pigeon pea and sorghum.

[1] Jarvis et al. 2010. Climate Change and its Effect on Conservation and Use of Plant Genetic Resources for Food and Agriculture and Associated Biodiversity for Food Security. FAO, Rome.

Activities to be undertaken by NBPGR

Year1
- Mine information from NBPGR databases
- Geo-referencing and mapping
- Attach climatic attributes
- Classify based on agro-ecological zones

Year2
- Climate analogues b/w current (1950-2000) and future (2010-2039)
- Identify sites to collect pre-adapted material
- Identify spots vulnerable to climate changes

Year3
- Collect landraces based on predictions; analyse and multiply seeds
- List climate ready accessions from the genebank
- Report preparation and publications

Timeline

2011-12 (I–IV) 2012-13 (V–VIII) 2013-14 (IX–XII)

	Activities and Work Plan (quarterly)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1.	Geo-referencing of target crops	■	■	■	■								
2.	Mapping of crop diversity to agro-climatic zones using GIS based climate modeling/ homologue-Analogue approach				■	■	■	■					
3.	Seed multiplication of selected *ex situ* germplasm			■	■	■	■	■	■	■			
4.	Field evaluation of selected germplasm				■	■	■	■	■	■	■		
5.	Analogue validation for current climate						■	■	■	■	■	■	
6.	Capacity building workshops/training					■				■			
7.	Data gathering and analysis	■	■	■	■	■	■	■	■	■	■	■	
8.	Data compilation and report submission				■			■					■
9.	Publication of germplasm atlas and other publications											■	■

Geo-referencing the genebank accessions

To obtain information on national collections of the target crops conserved at National Genebank, NBPGR, passport data of the five target crops (wheat, pearl millet, chickpea, pigeon pea and sorghum) were accessed through NBPGR databases. Subsequent to the verification of the botanical identity, information on geographical location was rigorously screened for availability and correctness of details on latitude, longitude and altitude of the collection sites. In the absence of village information for a substantial number of accessions, district was used as minimum collection site information for mapping. To obtain information on international collections of the target crops sourced from India and being conserved at locations other than National Genebank, NBPGR, passport data of the five target crops were obtained from documentations of Bioversity International collection missions (IBPGR database) or accessed via either GENESYS portal or ICRISAT database.

The data sets thus obtained were combined and arranged with common data standards; duplicates were identified and removed; rigorously screened for information on geographical location (latitude, longitude and altitude) of the collection sites. Almost all of the international collections had village information. Therefore, actual village location was used for international collections whereas district HQ was used for attributing location in case of NBPGR Genebank collections. In all, 38,126 accessions were short-listed across five target crops for assessing their utilization with the help of customized GIS tools, climate modelling and climate analogues for enhancing adaptive capacity to climate change.

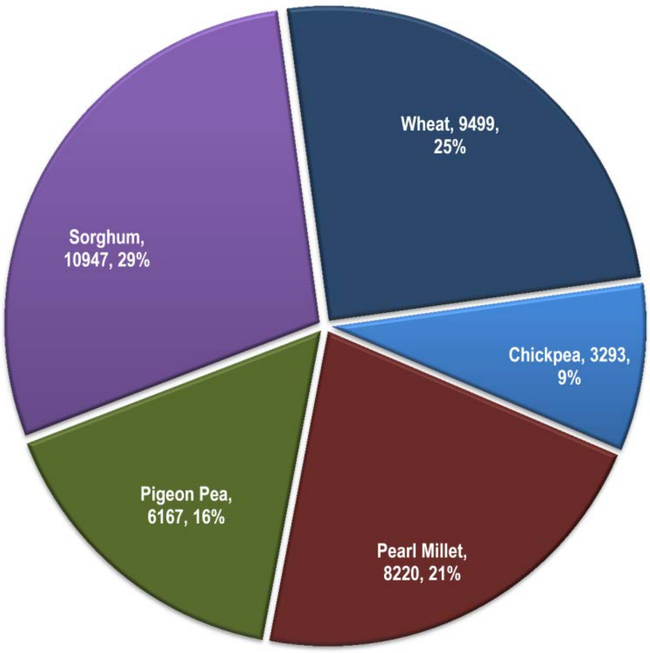


Figure 1. Number of *ex situ* germplasm accessions for which geo-referencing information could be collated in five target crops. Labels indicate name of the crop, number of germplasm accessions which are geo-referenced and representation of each target crop in terms of percentage of 38,126 accessions.

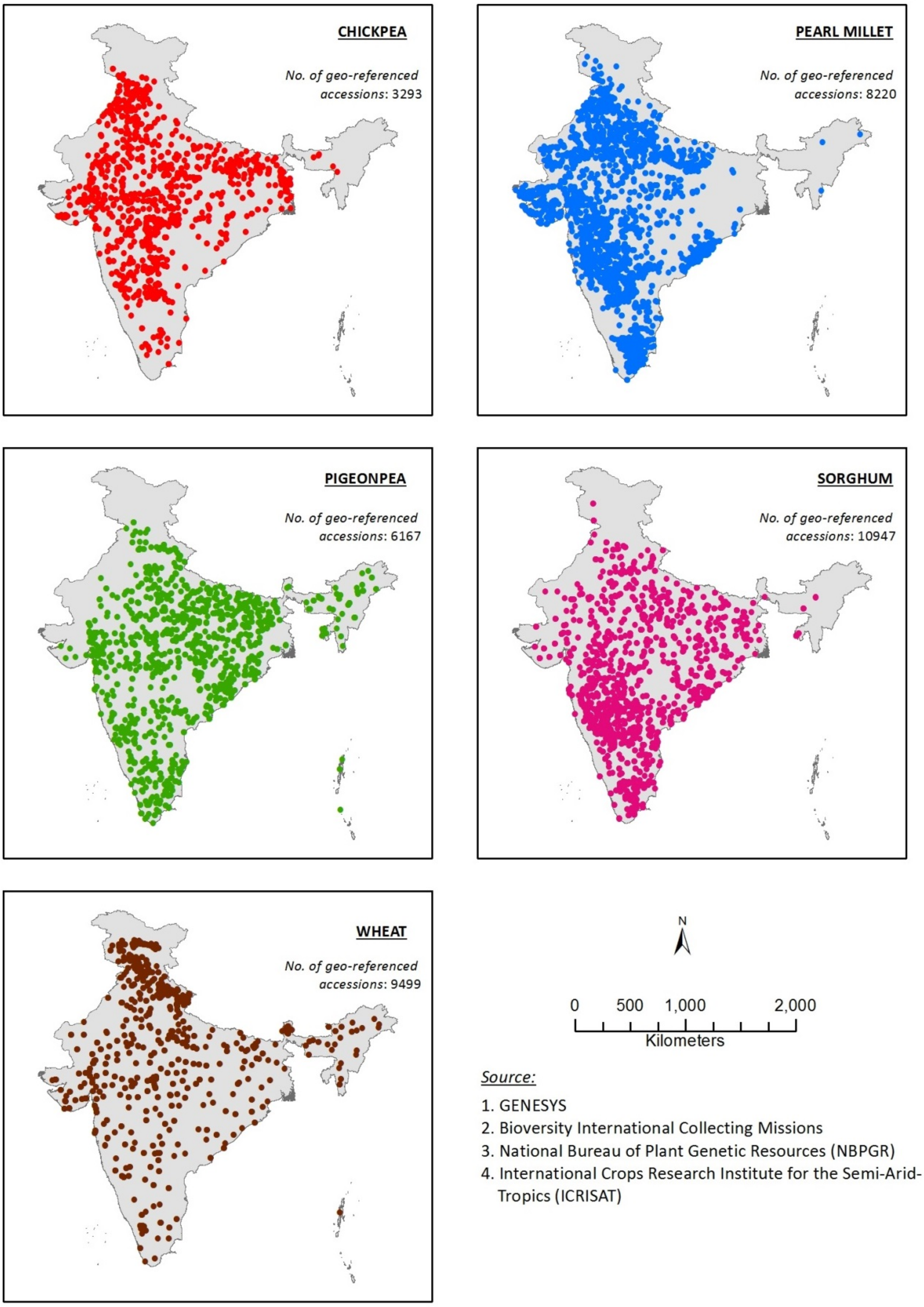


Figure 2. Collection sites of *ex situ* germplasm accessions of five target crops

Evaluation of selected germplasm of target crops as climate ready collections

In order to link the adaptive environment with the genotypes, it was assumed that location information associated with genebank accessions was indeed the primary centre of adaptation and hence the natural selection owing to the local climate has shaped the phenotype and agronomic value of the accessions. To attribute useful traits to the adaptive environment, collections were grouped based on agro-ecological zone. There are various classifications available for Indian sub-continent; we used FAO system of classification as below:

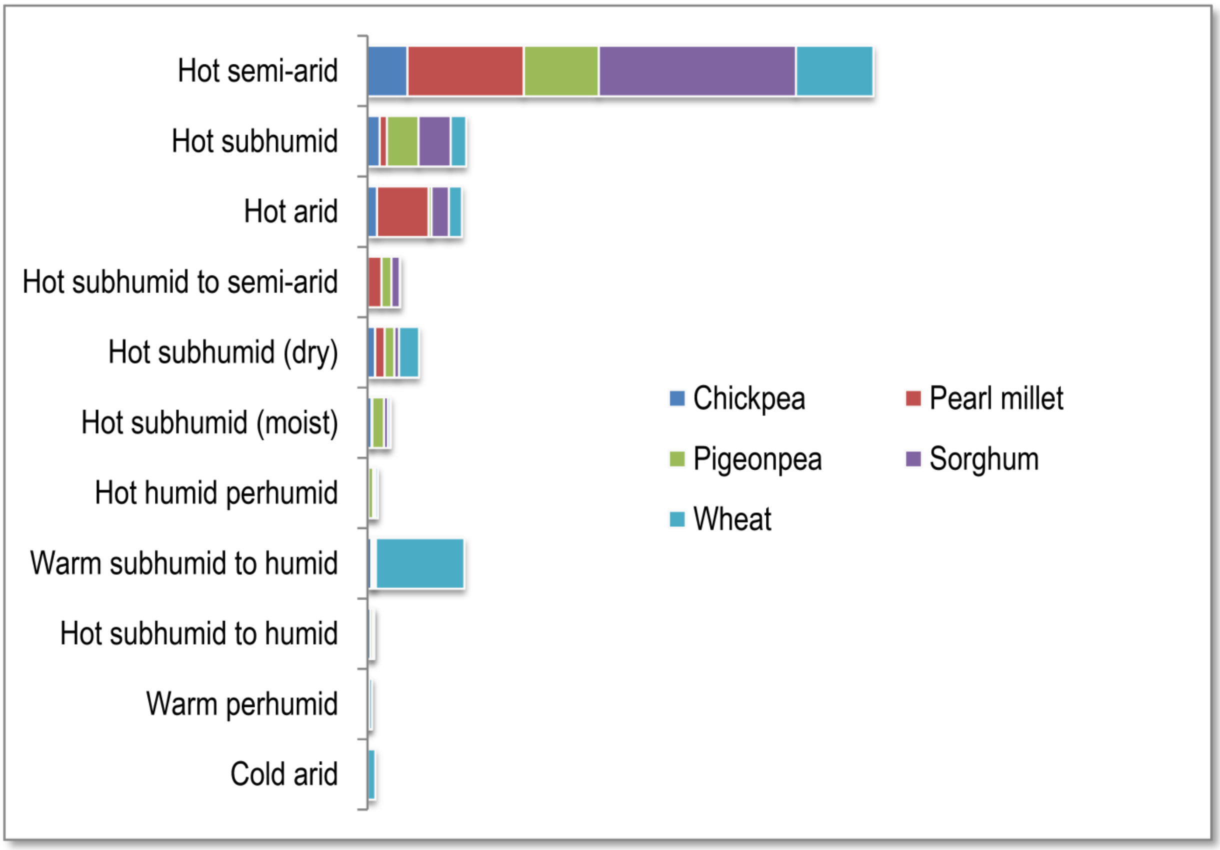


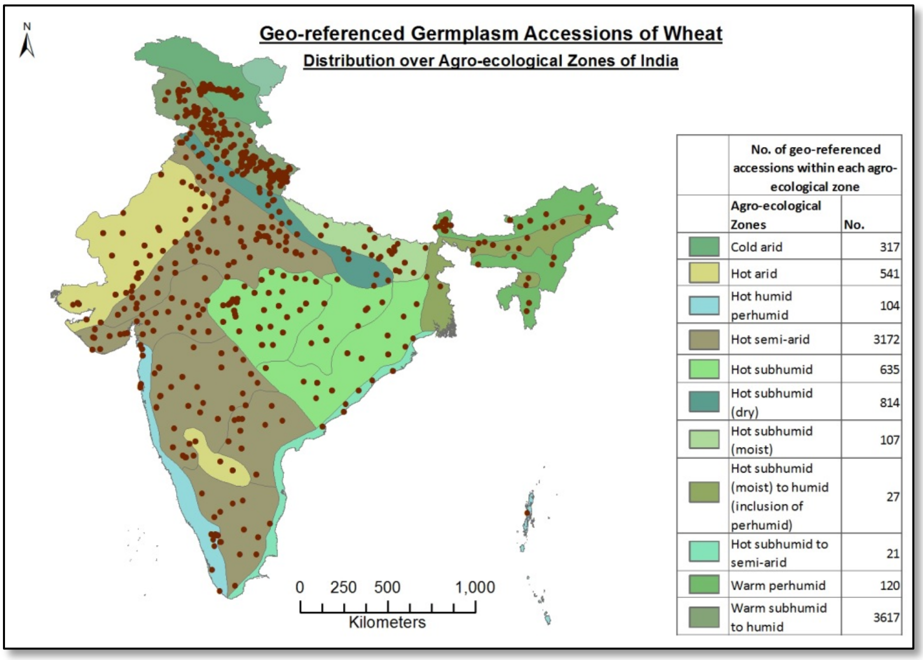
Figure 3. Categorization of germplasm collections of target crops based on the agro-ecological zones (FAO) of the sites that these collections were made

Considering the cropping areas of India, it is not surprising that the collection sites primarily belong to semi-arid to sub-humid regions with hot semi-arid topping the list. Taking into account the changing climate towards semi-arid type in India and several other parts of the world, this early observation has profound utility on the final outcome of the project.

In the following section, crop-wise details are provided on each of the five target crops regarding where exactly the collection sites are located. Identification of a pre-adapted material depends upon accuracy with which the climatic attributes are associated with the short-listed germplasm accessions. This in turn depends upon insightful handling of variables such as agro-ecological zone, elevation of the location, temperature and precipitation regimes of the location, etc.

At this point, it is assumed that rabi crops such as wheat and chickpea face the elevated temperature stress at crucial crop stages and that kharif crops such as pigeon pea, sorghum and pearl millet may be susceptible to both temperature as well as moisture stress. Accordingly, accessions are grouped based on altitude of the location and then compared with the distribution of maximum temperature of the location (Worldclim current climate data 1950 – 2000, monthly averages) and mean annual rainfall taken as average over a given range of elevation.

Wheat



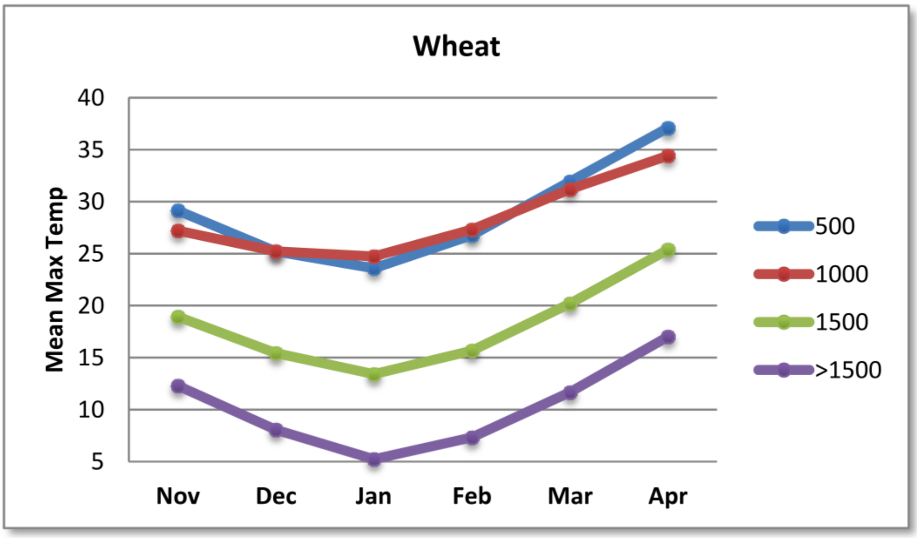
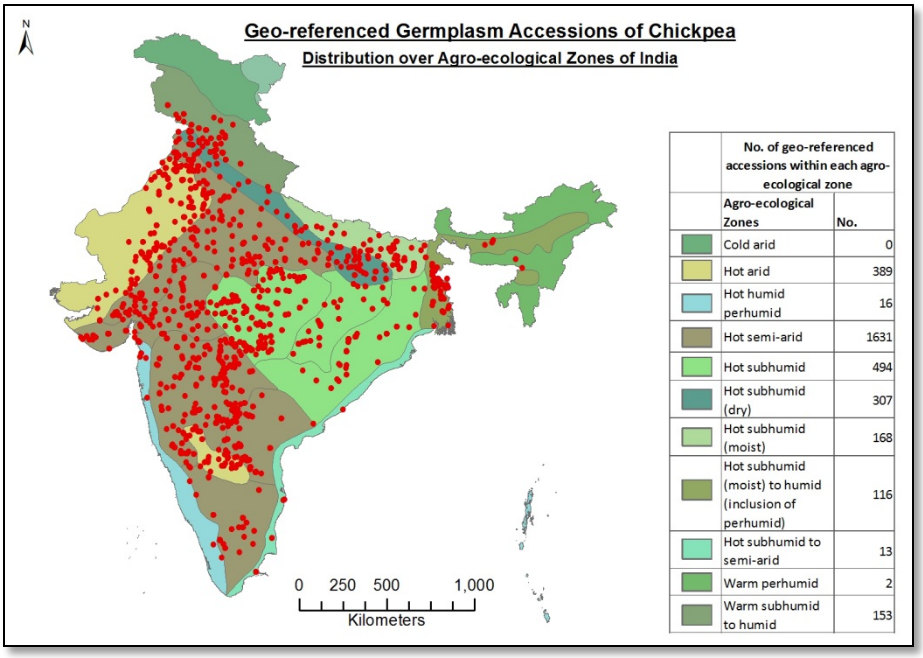


Figure 4. (Top) Distribution of geo-referenced germplasm of wheat over agro-ecological regions of India. Of 9,499 wheat accessions short-listed, nearly equal (34% and 38%) genotypes belonged to hot semi-arid and warm sub-humid to humid regions respectively. Collection sites of wheat accessions were found in almost all agro-ecological zones.

(Bottom) Geo-referenced accessions were grouped based on the altitude of collections sites. Distribution of mean maximum temperatures over locations up to 1000m elevation was nearly identical (blue and red). However, a spike in the temperature at the terminal stages of the crop is pronounced in the locations up to 500m (blue). Wheat collections from altitudes beyond 1000m are less likely to be pre-adapted to terminal heat (green and violet).

Chickpea



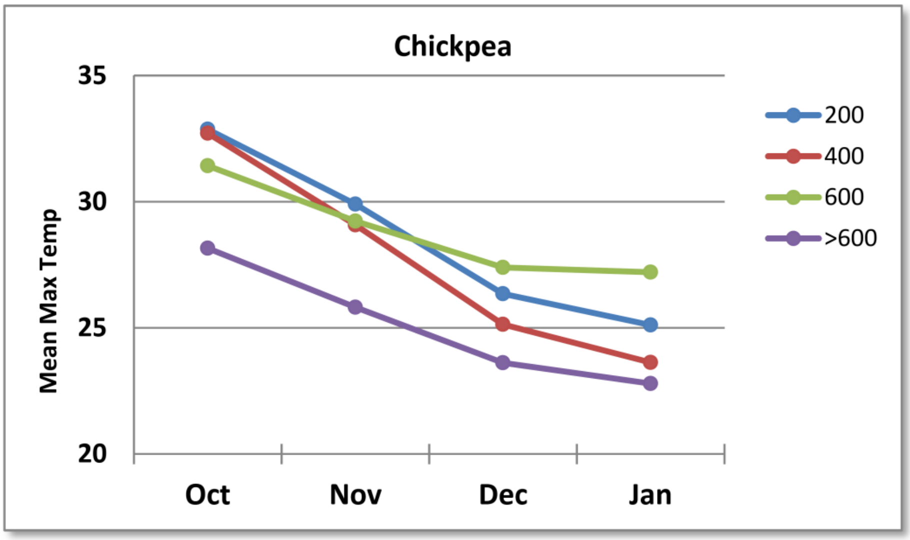
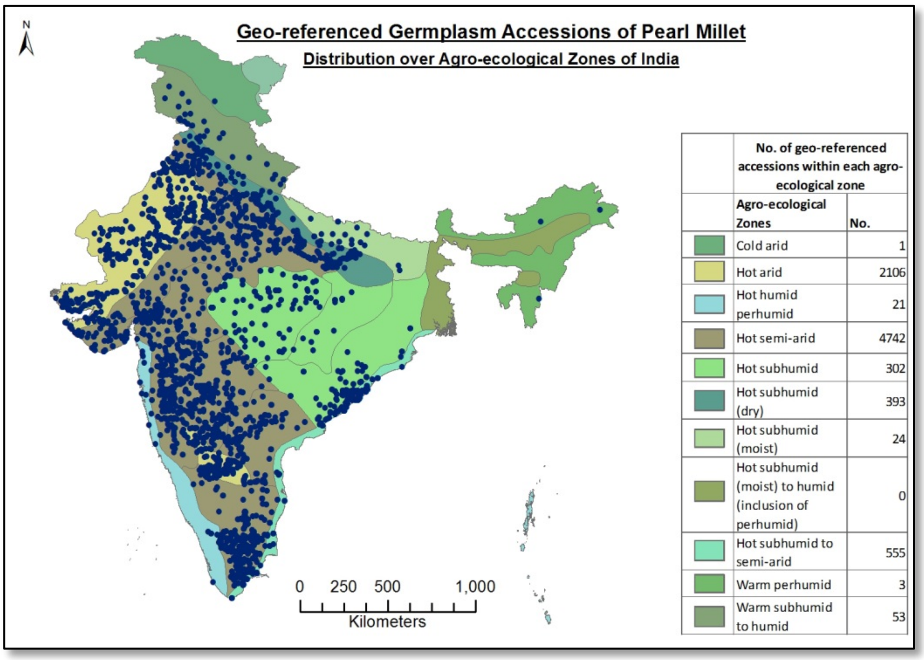


Figure 5. (Top) Out of 3,293 germplasm accessions of chickpea, half were collected from hot semi-arid regions and ~15% and ~12% were collected from hot sub-humid and hot arid regions respectively. State-wise data reveal that hardly any collections were made from north-eastern states.

(Bottom) Geo-referenced accessions of chickpea were grouped based on the altitude of collections sites. Distribution of mean maximum temperatures over locations up to 600m elevation was similar (blue, red and green) in the first half of the crop duration. However, a spike in the temperature in the last 30 days of the crop is pronounced in the locations with altitude 401-600m (green). A closer look at the collections from these locations is more likely to throw up pre-adapted genotypes.

Pearl Millet



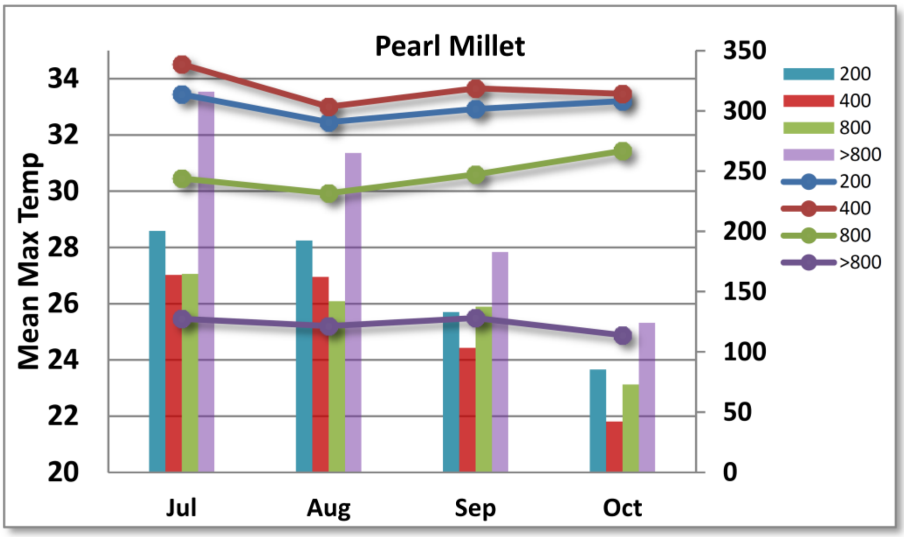
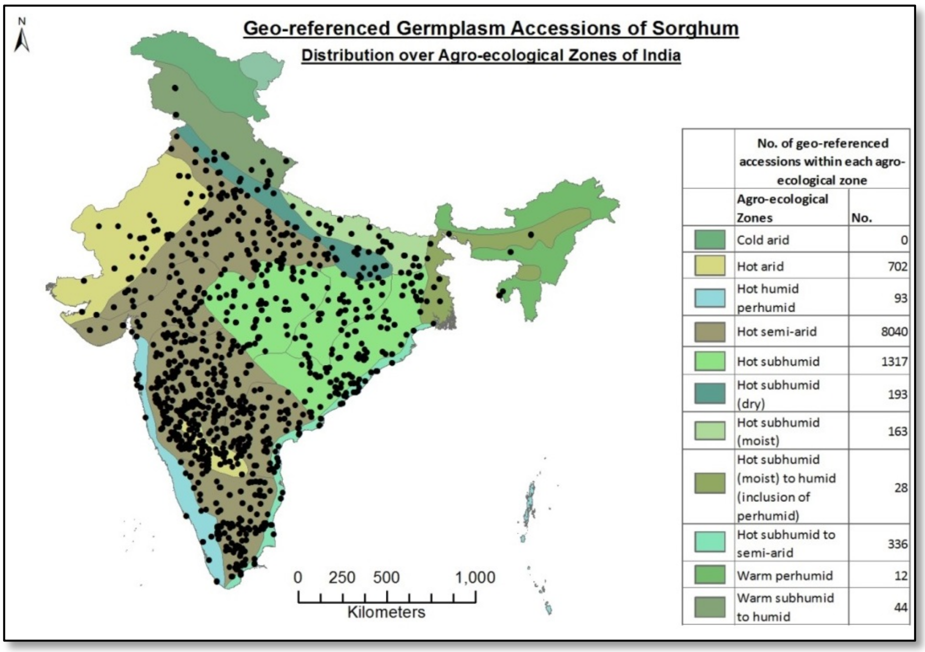


Figure 6. (Top) Out of 8,220 germplasm accessions of pearl millet, more than half (~58%) belonged to hot semi-arid regions about 26% were collected from hot arid regions.

(Bottom) Geo-referenced accessions were grouped based on the altitude of collections sites; distribution of locations based on mean maximum temperatures (lines, primary axis) and average rainfall (vertical bars, secondary axis). Irrespective of the elevation, entire pearl millet cultivation is completed within a 2 °C window. Collections from sites with elevations between 201 to 400m (red) appear to experience exposure to maximum temperature and minimum rainfall. Pearl millet collections from this group are more likely to be pre-adapted to drought conditions. Pearl millet collections from altitudes beyond 800m are less likely to be useful for this trait as these locations receive maximum rainfall in addition to being around 25 °C throughout the cropping period (violet).

Sorghum



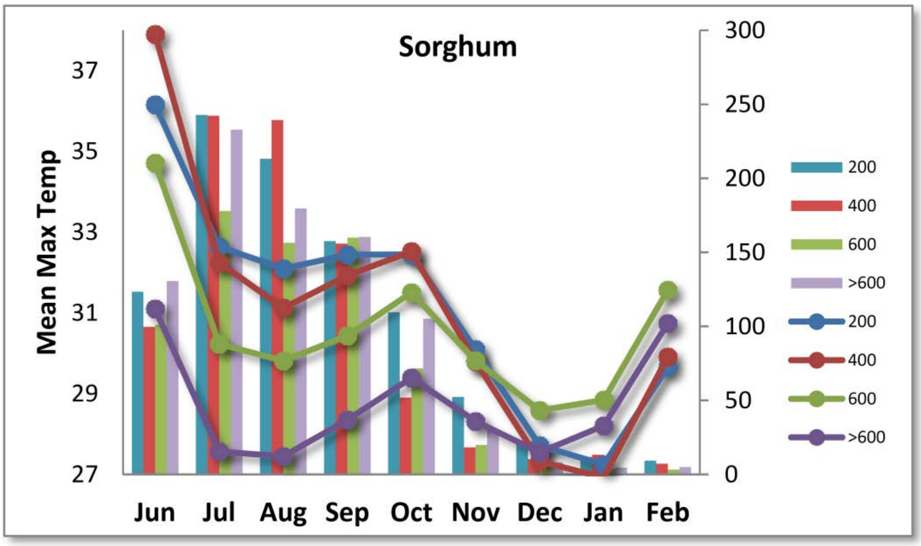
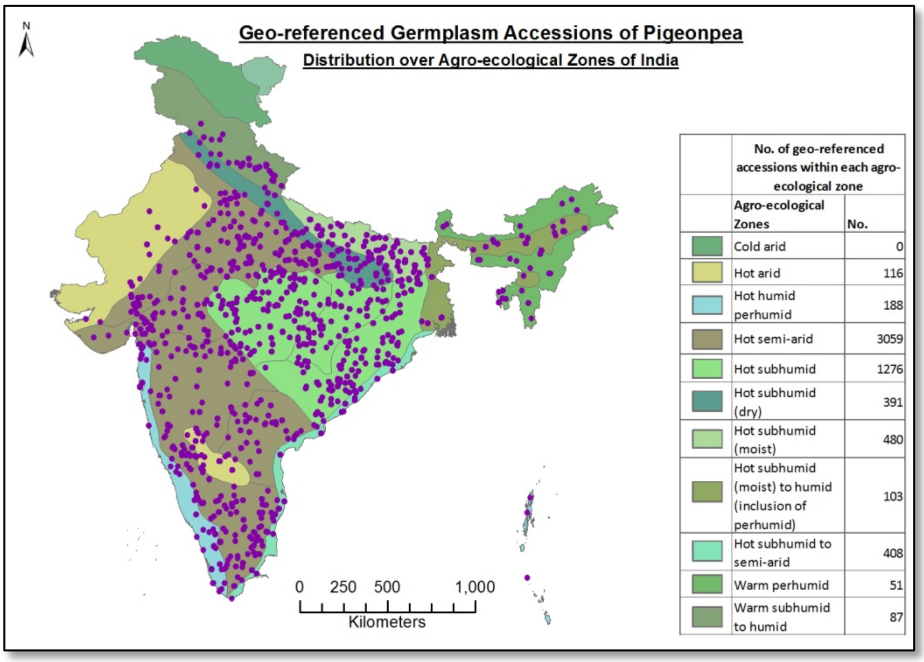


Figure 7. (Top) Out of 10,947 sorghum accessions, nearly 74% were collected from hot semi-arid regions and another 12% from hot sub-humid regions.

(Bottom) Geo-referenced accessions of sorghum were grouped based on the altitude of collections sites; distribution of locations based on mean maximum temperatures (lines, primary axis) and average rainfall (vertical bars, secondary axis). Both *kharif* (Jun to Oct) and *rabi* (Oct to Feb) crops are important in sorghum. Sorghum collections (from sites <600m elevation) experience temperatures upwards of 35 °C in the first month with those from 201m-400m altitude withstand >37 °C. Sorghum being a hardy crop, identifying best pre-adapted material depends upon the identification of crucial crop period, elevation of the target areas and temperature-precipitation pattern in the future. *Rabi* sorghum may give chance to identify genotypes withstanding moisture stress.

Pigeon Pea



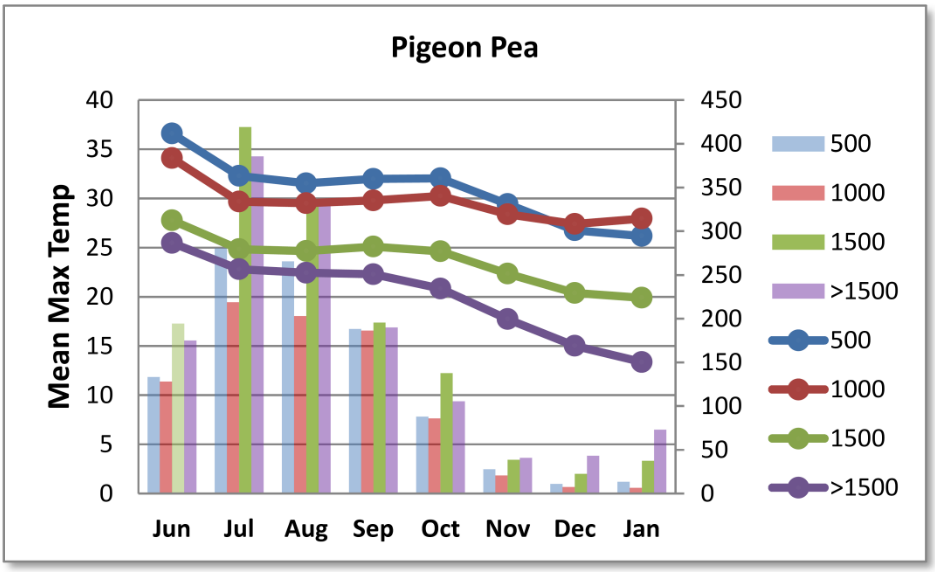


Figure 8. (Top) Out of 6,167 germplasm accessions of pigeon pea, 50% were collected from hot semi-arid regions and 21% of them originated from hot sub-humid regions.

(Bottom) Geo-referenced accessions of pigeon pea were grouped based on the altitude of collections sites; distribution of locations based on mean maximum temperatures (lines, primary axis) and average rainfall (vertical bars, secondary axis). In order to cover genotypes with both short and long durations, temperature and precipitation regimes over eight months are compared. Pigeon pea collections (from sites up to 600m elevation) experience temperatures upwards of 30 °C during most of the crop stand and least average rainfall. Pigeon pea being a hardy crop, identifying best pre-adapted material depends upon the identification of crucial crop period in terms of weeks, elevation of the target areas and temperature-precipitation pattern in the future.

Clustering of geo-referenced accessions on the basis of climatic parameters

The best way to identify germplasm pre-adapted for changing climatic conditions is to group them based on specific traits and then select the most suitable ones. However, germplasm accessions are characterized for agro-morphological characteristics and may not have physiological attributes (root traits, canopy temperature depression, response to diurnal length, etc.) recorded. It is therefore essential to make use of passport data especially the coordinate locations of accession collection sites. In such cases, clustering of accessions requires a different approach. FloraMap[2] is a system for producing the predicted distribution of possible adaptation for germplasm accessions based on computing the probability that a climate record belongs to a multivariate normal distribution described by the climates at the collection points of a calibration set of germplasm accessions. The software uses monthly rainfall totals, monthly average temperatures and monthly diurnal average range to identify sub-groups with significantly distinct climatic ranges.

Since climatic parameters were used for clustering, variance was used rather than distance metrics or measures of association to cluster the points. Therefore, Ward's method was employed which involved agglomerative clustering algorithm. Each of sorghum (10947 accessions/1022 unique locations), wheat (9499 accessions/834 unique locations), pigeon pea (6167 accessions/1005 unique locations) and chickpea (3293 accessions/1138 unique locations) were grouped into 20 clusters whereas 8220 accessions of pearl millet (2116 unique locations) were grouped into 27 clusters.

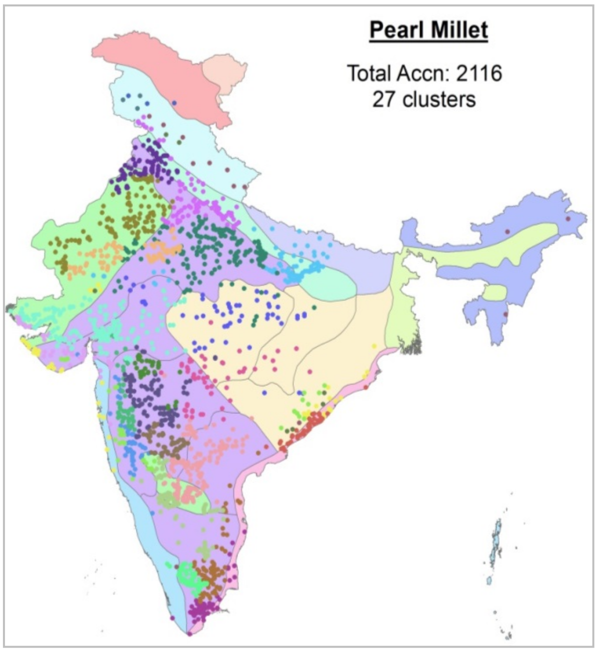
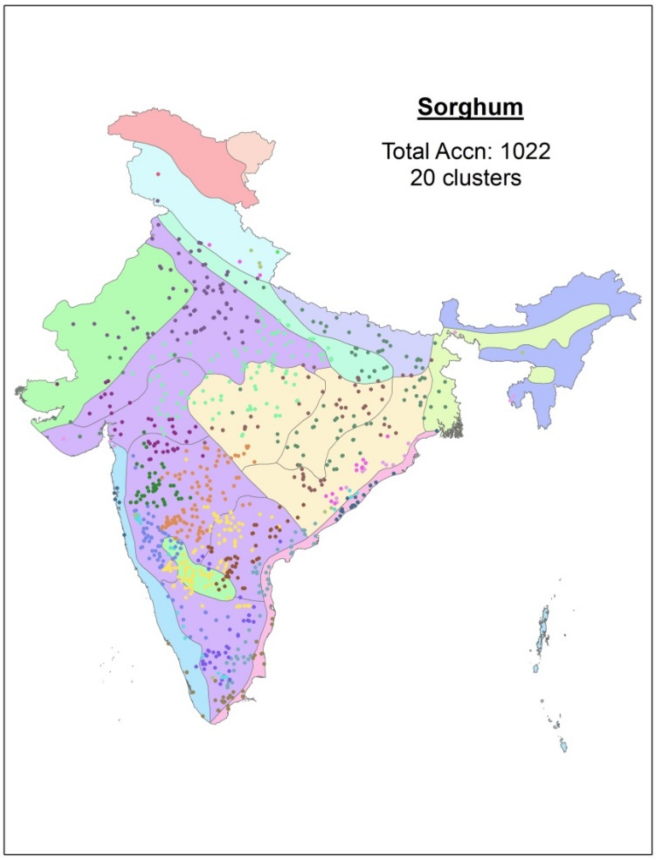
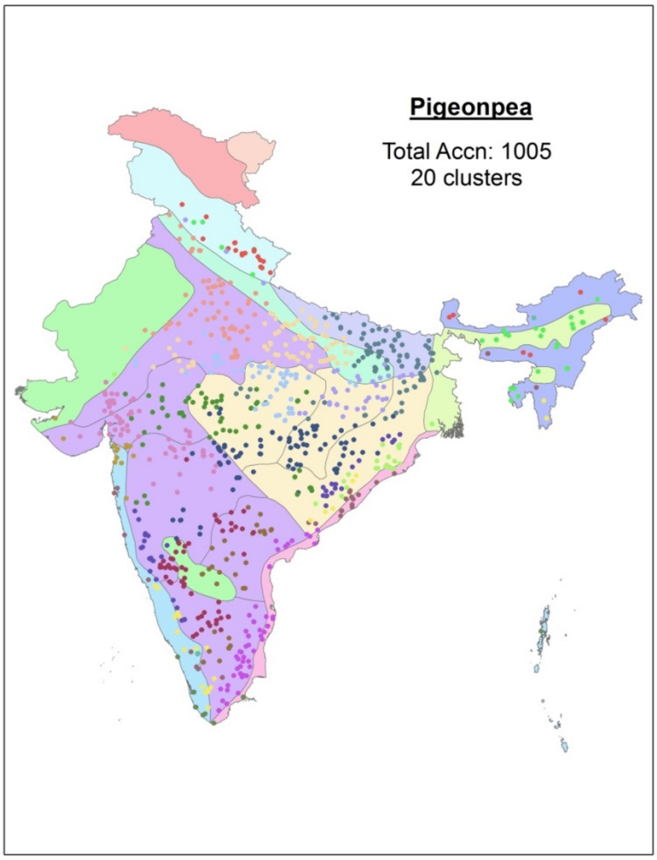
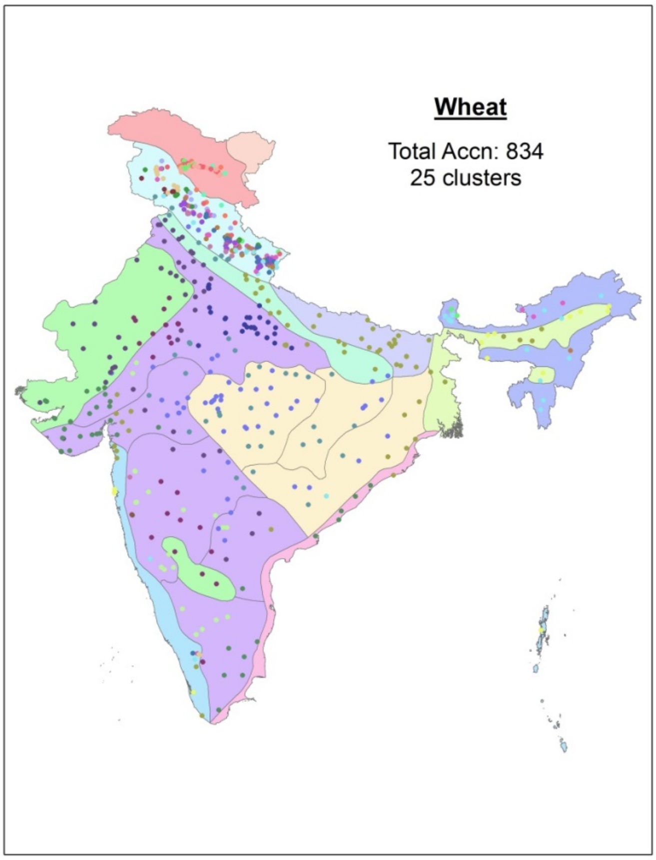


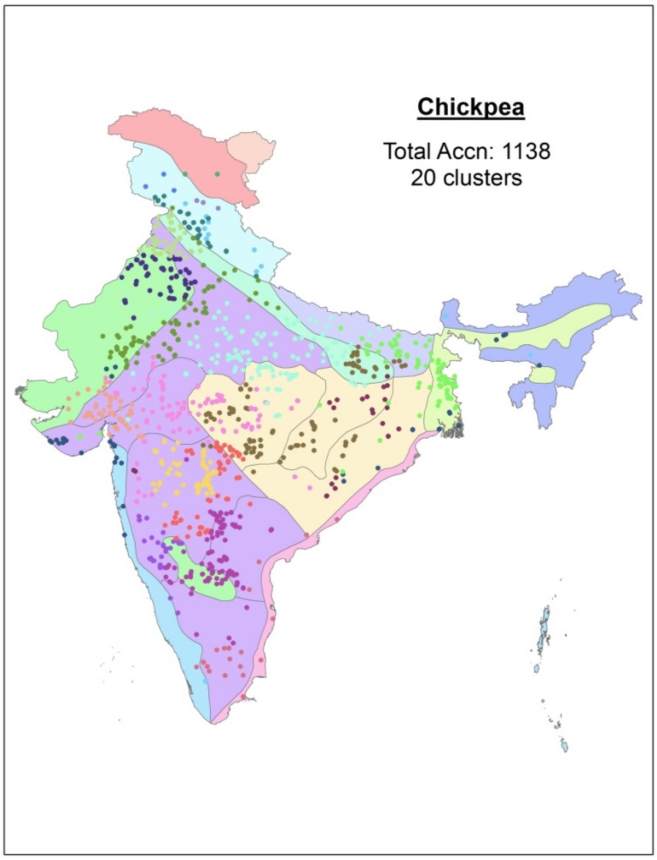
Figure 9. Germplasm accessions clustered based on climatic attributes and mapped on agro-ecological zones; Pearl millet (left) and sorghum, wheat, pigeon pea and chickpea (next page).

[2] Jones PG and Gladkov A 1999. FloraMap: A computer tool for predicting the distribution of plants and other organisms in the wild. CIAT, Colombia.


Sorghum
Total Accn: 1022
20 clusters


Pigeonpea
Total Accn: 1005
20 clusters


Wheat
Total Accn: 834
25 clusters


Chickpea
Total Accn: 1138
20 clusters

Mapping geo-referenced collections on current and future climatic scenario

Temperature data were obtained from the Worldclim 2.5 min database for current climate (1950 – 2000) and from CSIRO -Mk3.5 General Circulation Model (GCM) SRES A1B of the CSIRO Atmospheric Research Group of Australia (2010-2039). It has been established that impacts of climate change may depend more on changes in mean minimum (Tmin) or maximum (Tmax) temperatures than averages. Agronomically, reduced minimum temperatures affect germination. However, Indian agriculture touted to face elevated temperatures; it is the change in maximum temperature that has attracted the greater attention. The present analysis concentrated on the changes in the mean maximum temperatures confined to cropping season for each of the five crop species. In order to find out areas most vulnerable to changing climate, the information was mapped employing the geospatial processing program ArcMap.

For a better understanding and depiction, temperature intervals are maintained at 2°C. It was very evident upon a quick perusal of the maps that most of the areas under cultivation are predicted to experience a shift to at least next temperature class (i.e. +2°C mean monthly max temp). Based on close visual observation areas were identified as vulnerable with following criteria:

1. Mean monthly max temp reaching the top bracket (at or beyond higher end of the temperature range of the crop)
2. Fewer accessions from such putative vulnerable areas collected and conserved by NBPGR
3. More likelihood of finding landraces, farmers varieties and other locally adapted material rather than varieties and hybrids
4. Likelihood of subsistence farming and greater chance of genetic erosion due to climate change

It is important to note that analysis and interpretations come with certain limitations. For instance: prediction of the future temperature regime (lack of local temperature data, using temperature alone as an attribute, limitations of the models, etc.), identification of locations (using climate attributes alone, lack of soil data, etc.), designation of germplasm accessions as suitable to newer areas (incomplete passport data, inter-regional differences of season, soil, taste, etc.).

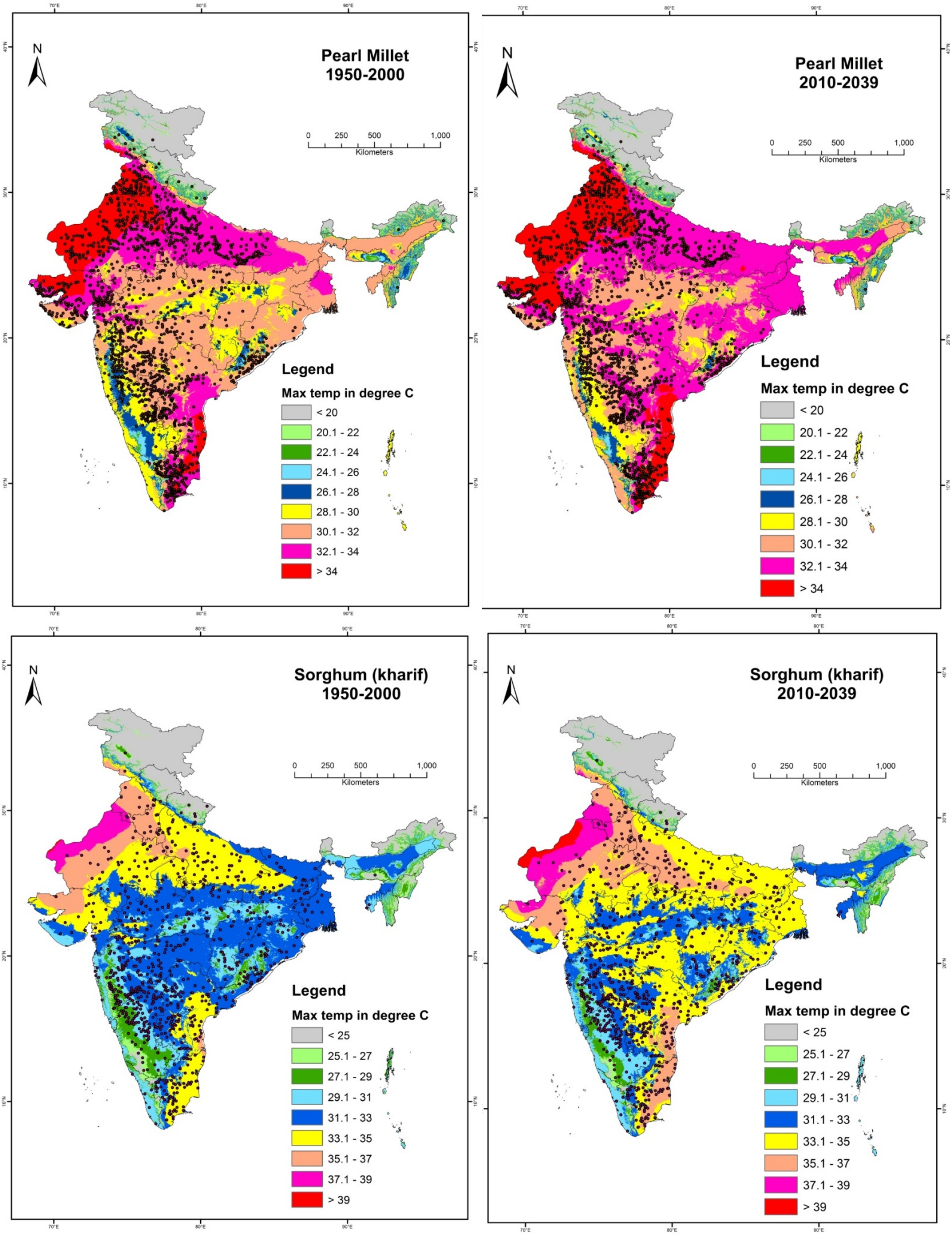


Figure 10. Quantitative changes in the areas under different temperature regimes predicted for 2010-2039 overlaid with sites of collection for pearl millet (top) and sorghum (bottom) to identify vulnerable locations and areas with pre-adapted germplasm

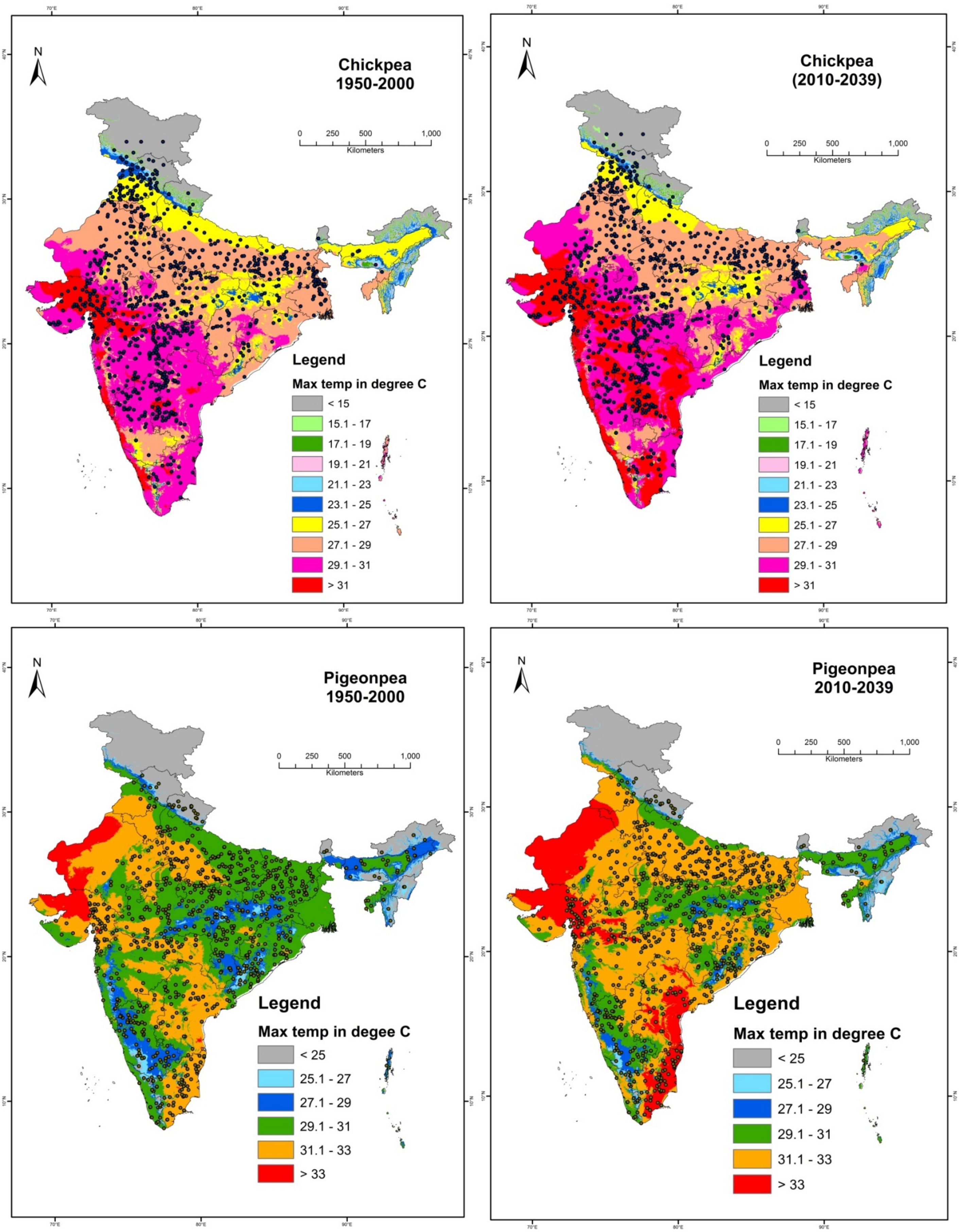


Figure 11. Quantitative changes in the areas under different temperature regimes predicted for 2010-2039 overlaid with sites of collection for chickpea (top) and pigeon pea (bottom) to identify vulnerable locations and areas with pre-adapted germplasm

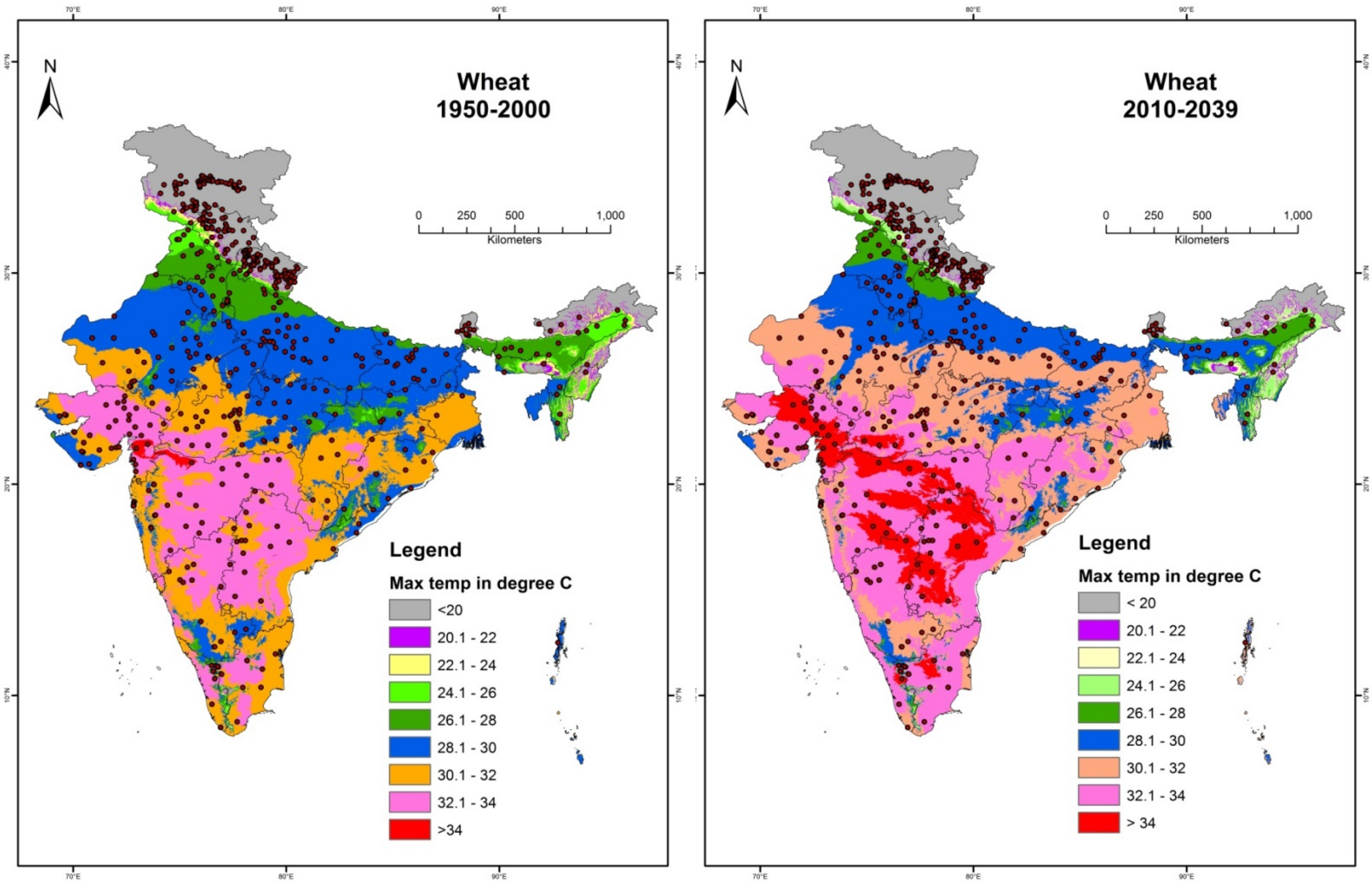


Figure 12. Quantitative changes in the areas under different temperature regimes predicted for 2010-2039 overlaid with sites of collection for wheat to identify vulnerable locations and areas with pre-adapted germplasm

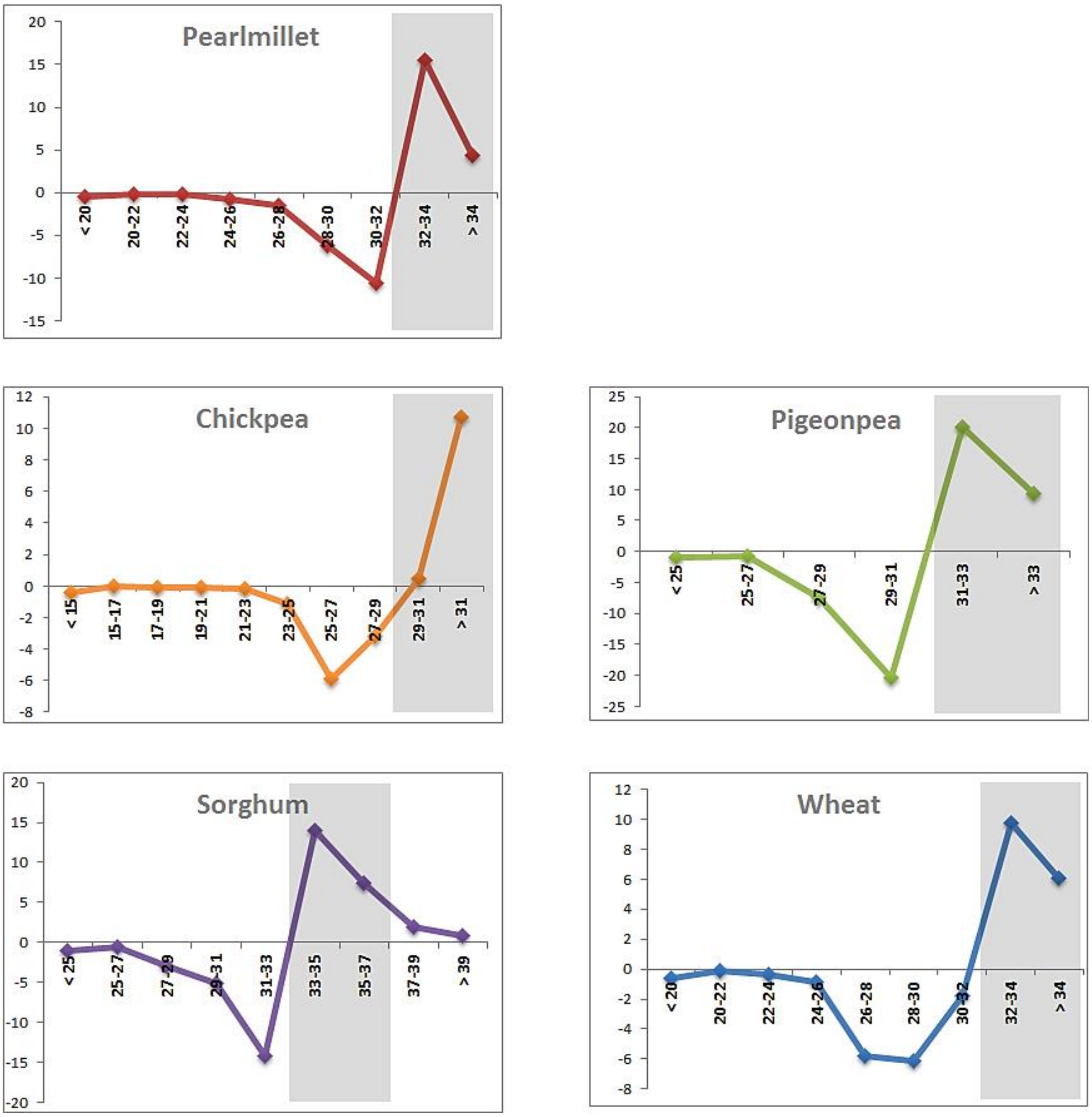
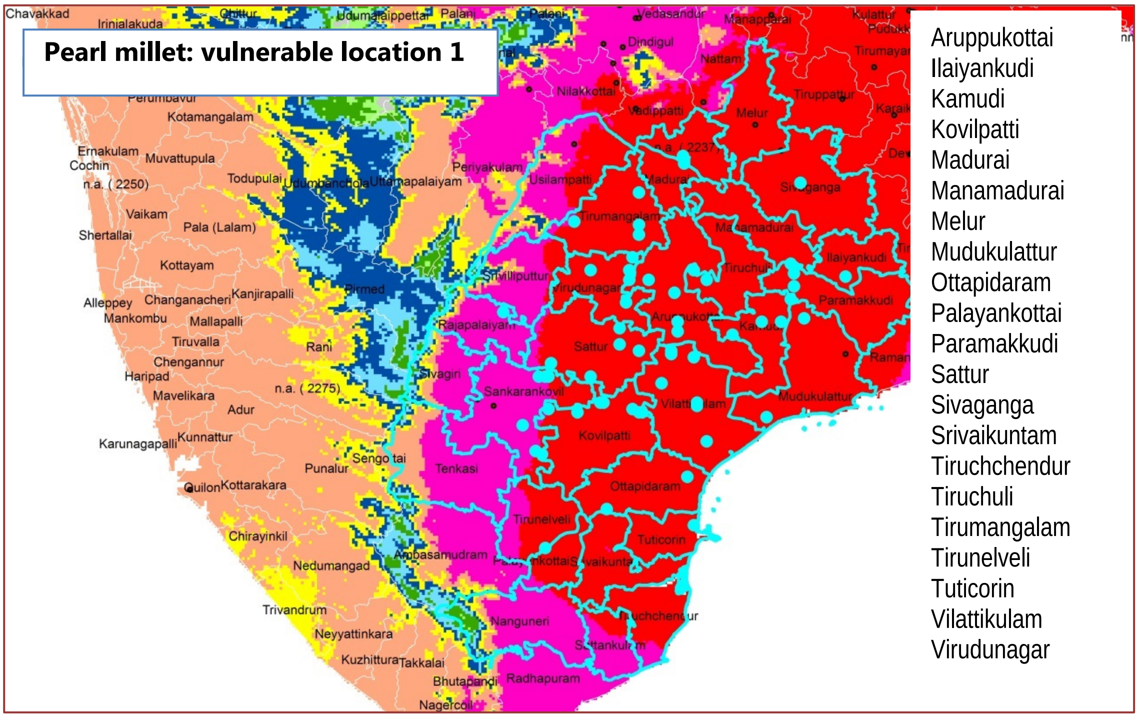


Figure 13. Change in the area under different temperature regimes (reflected by monthly mean maximum temperature) in five crops during corresponding cultivation seasons. Change in area from current climate (1950-2000) to future climate (2010-2039) is expressed in *per cent* (on y-axis) across different temperature classes (on x-axis) specific to a crop. Note that the lost areas often belong to the most optimum temperature regimes.

Identification of vulnerable sites and sources of pre-adapted genotypes

In the following section, such areas that are most likely to go vulnerable if the predictions for 2010-2039 come true are illustrated. For each crop, two sample vulnerable locations are represented. The locations are associated with largest change in the mean monthly maximum temperatures estimated to affect plant growth and development adversely. These empirical inferences, were further supported by climate matching (present to future) carried out for each of the clusters generated by FloraMap analyses. The matching was done by employing MaxEnt program (www.cs.princeton.edu/~schapire/maxent/). Future climate probability matching was done for these clusters using the UKMO-HadCM3 (2020s) GCM SRES A1B of the Hadley Centre for Climate Prediction and Research/ Met Office, U.K.

There are three sets of illustrations. First ones depict vulnerable locations and the list of taluks that need to be visited for exploring and collecting locally adapted diversity that in the times to come may not survive in its entirety. The second type of illustrations generated show the probability of climate matching around selected clusters supporting the conclusions reached based on the first maps. Climate matching areas with greater than 0.60 probability matching were found to be shrinking. Based on the assessment of vulnerability from the outputs of these climate matching analyses, schedule of recollecting missions to collect further samples of diversity already held has been proposed. However, based on 2010-2039 predictions, sufficient evidence was not available to recommend collecting missions from the new climate matching areas where germplasm has not yet been collected. Detailed analyses might throw more light on this. The third set of maps shows best possible locations from where pre-adapted germplasm can be sourced. This is done on the basis of the fact that such areas already experiencing the top bracket of temperatures in the current climate may have experienced selection pressure and genotypes performing better (reflected by farmers' choice) are supposed to be best adapted to the local conditions. Such pre-adapted genetic material may be amenable for testing their suitability to newer areas of similar temperature regime in the future. In pigeon pea however, current set of analyses could not show any such areas.



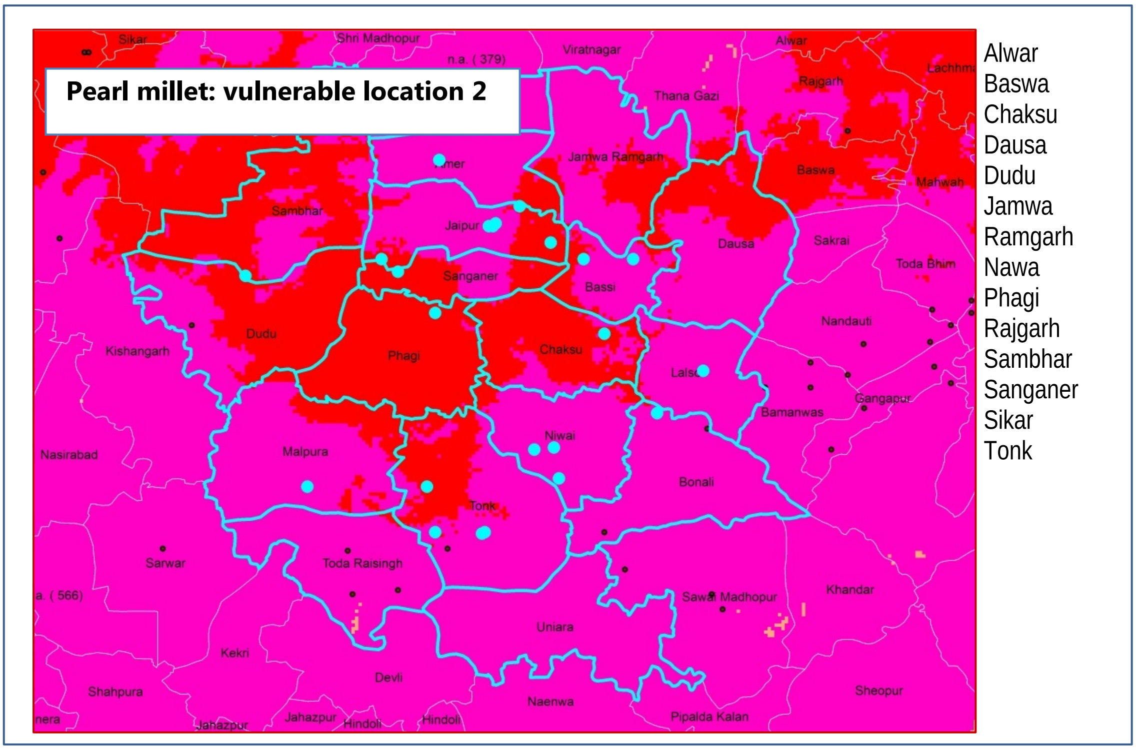


Figure 14. Two of the vulnerable sites identified in pearl millet. Also given are the names of taluks from where collection activities are to be planned.

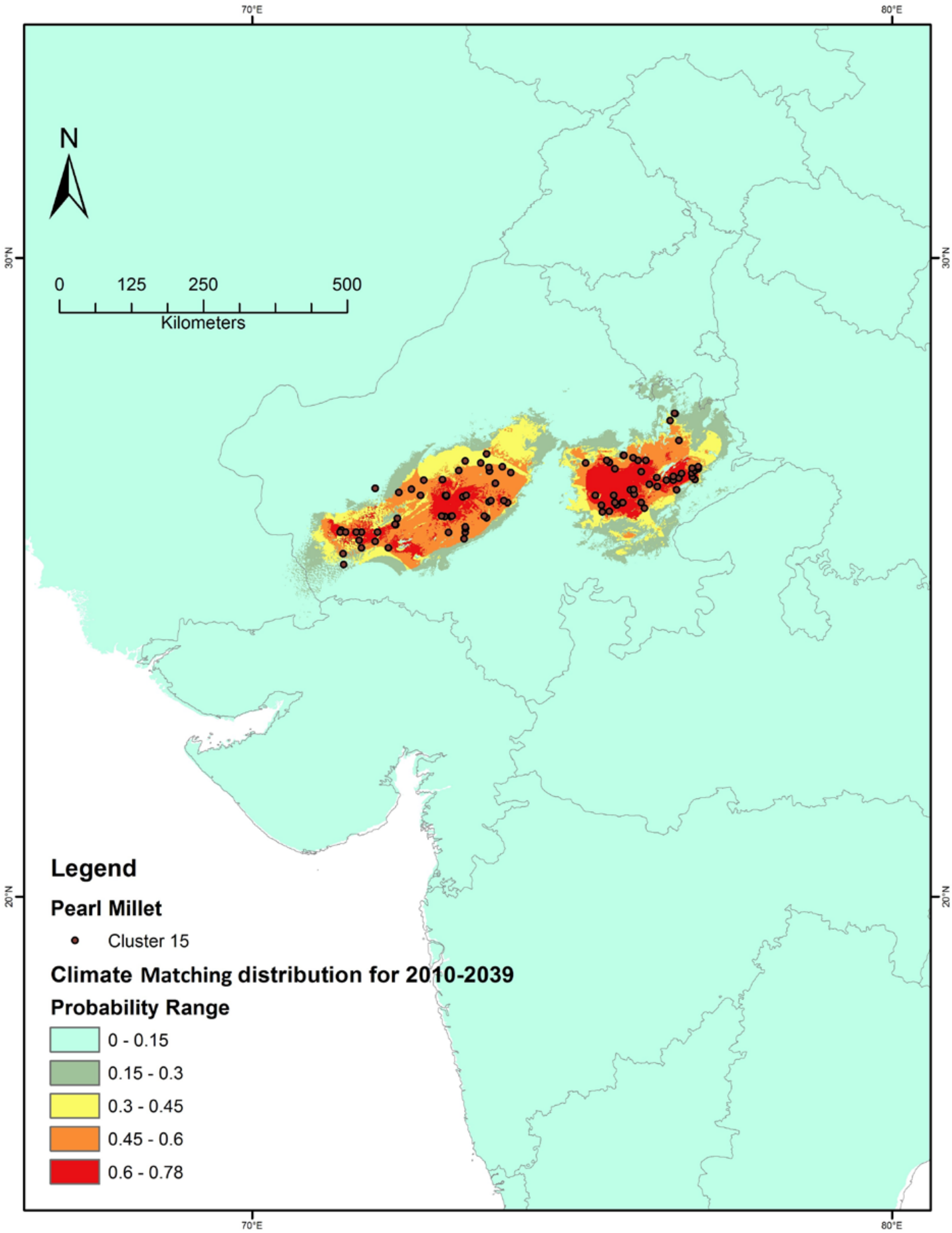


Figure 15. Climate matching distribution for pearl millet cluster 15. The results of climate matching may be seen in the light of results depicted in Fig.14 and Fig.16.

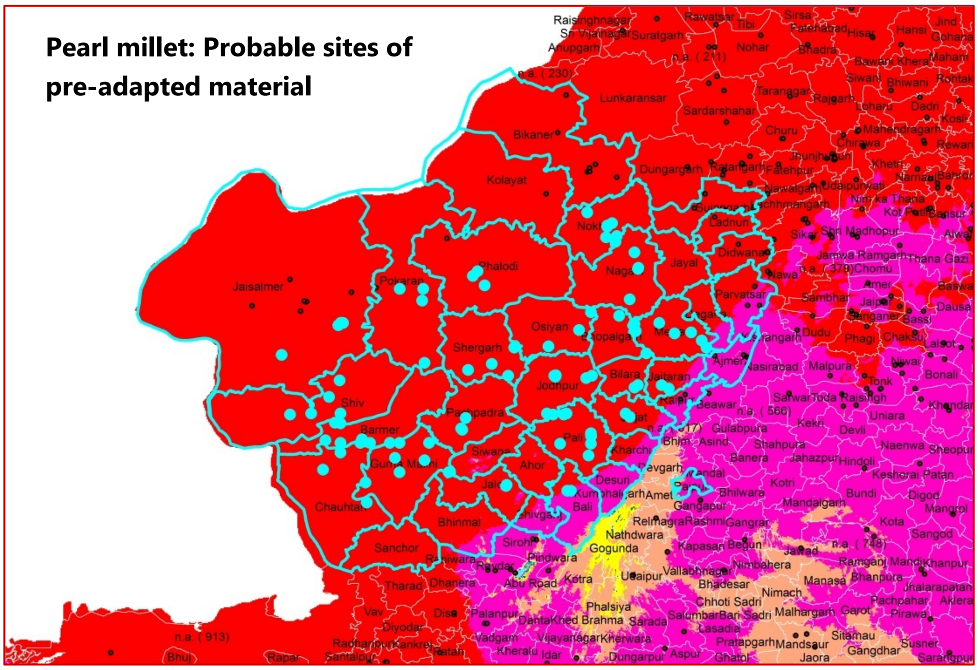
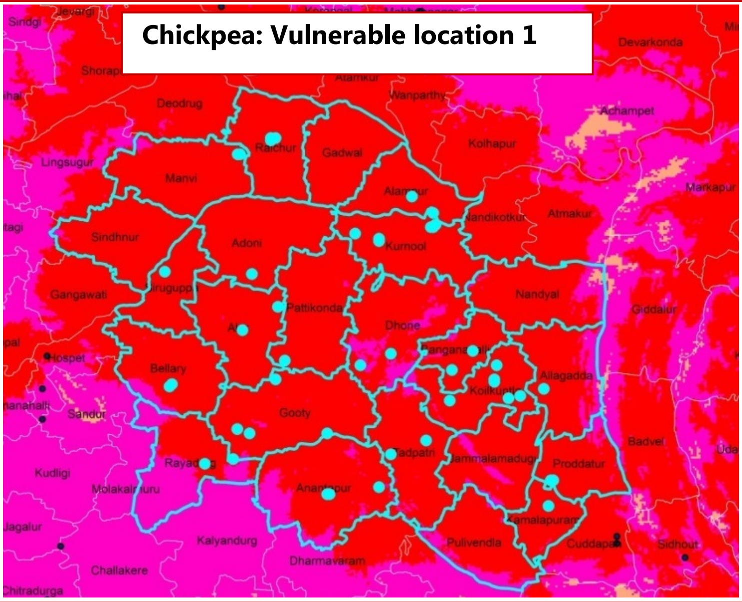
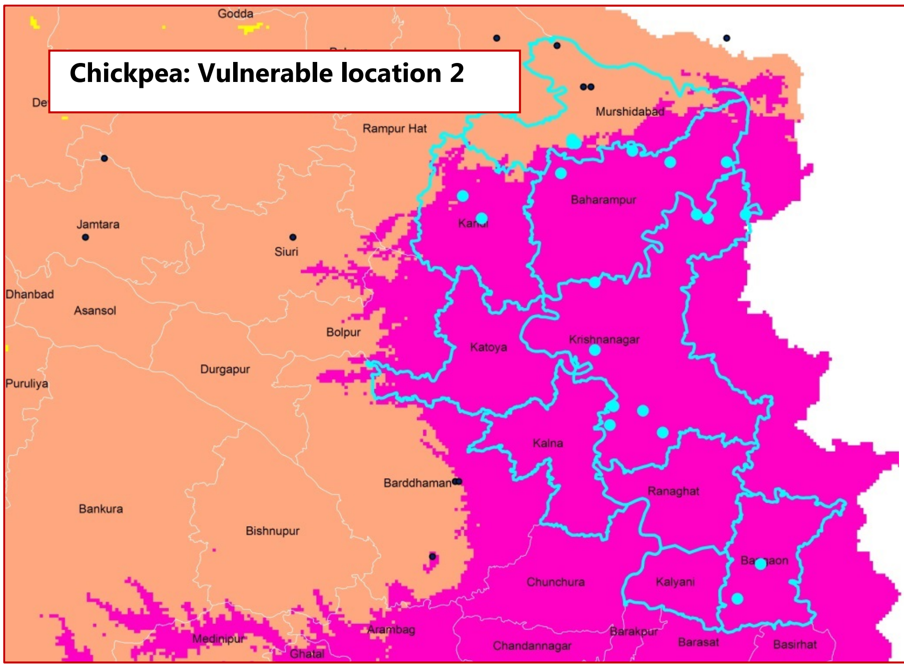


Figure 16. Sites of sourcing pre-adapted pearl millet germplasm. Accessions short-listed are given in the table below.

Accession	Long	Lat	Cluster	Accession	Long	Lat	Cluster	Accession	Long	Lat	Cluster
3221	73.13	25.3	12	3158	73.73	26.2	15	3204	71.08	25.73	16
3220	73.16	25.3	12	3156	73.93	26.2	15	20140	71.16	25.88	16
3216	72.61	25.34	12	3426	73.29	26.26	15	20125	70.78	25.95	16
370718	72.61	25.35	12	3160	73.03	26.27	15	20123	71.11	26.1	16
3422	74.31	26.52	13	3161	72.63	26.28	15	3192	71.2	26.24	16
20085	74.27	26.58	13	3230	73.02	26.28	15	3188	71.19	26.71	16
3425	74.18	26.65	13	20082	73.34	26.28	15	3189	71.21	26.73	16
20150	71.43	25.2	15	80714	73.03	26.28	15	3191	71.23	26.73	16
20151	71.42	25.37	15	20161	72.29	26.33	15	3175	71.9	26.92	16
20130	71.92	25.56	15	3162	72.49	26.38	15	20110	71.71	27.02	16
20131	71.67	25.58	15	20156	71.92	26.39	15	3173	71.91	27.02	16
3224	73.31	25.6	15	1011	73.8	26.47	15	11889	72.43	27.05	16
1034	73.07	25.7	15	3432	73.57	26.79	15	3171	72.33	27.13	16
3225	73.33	25.7	15	3234	73.33	26.82	15	3170	72.37	27.17	16
3207	71.39	25.74	15	3445	73.66	26.93	15	3245	73.73	27.19	16
80036	73.33	25.76	15	20134	71.70	25.45	15	80950	73.73	27.2	16
3226	73.33	25.78	15	3213	72.12	25.45	15	3251	73.7	27.33	16
1512	73.33	25.79	15	20147	71.70	25.70	15	1013	73.54	27.42	16
20136	72.24	25.82	15	20141	71.95	25.70	15	3256	73.55	27.47	16
3212	72.23	25.83	15	80630	71.37	25.70	15	1026	73.47	27.55	16
20137	72.27	25.92	15	3199	71.45	25.70	15	3262	73.47	27.56	16
8306	73.66	25.93	15	1071	71.62	25.70	15	3260	73.51	27.58	16
1035	73.01	25.95	15	3210	72.95	25.95	15	1015	73.3	27.67	16
1036	73.1	25.95	15	20162	73.12	25.95	15	20129	71.21	25.625	16
3154	73.99	26.17	15	1466	73.625	25.95	15				
3157	73.7	26.18	15	3203	71.06	25.48	16				



Adoni
Alampur
Allagadda
Alur
Anantapur
Banganapalli
Bellary
Dhone
Gadwal
Gangavati
Gooty
Gulbarga
Jammalamadugu
Jevargi
kadapa
Kamalapuram
Koilkuntla
koppal
Kurnool
Makhtal
Manvi
Nandyal
Pattikonda
Proddatur
Pulivendla
Raichur
Rayadurg
Shorapur
Sindhnur
Siruguppa
Tadpatri
Yadgir



Baharampur
Bangaon
Barasat
Basirhat
Chandanagar
Chunchura
Kalna
Kalyani
Kandi
Katoya
Krishnanagar
Murshidabad
Ranaghat

Figure 17. Two of the vulnerable sites identified in chickpea. Also given are the names of taluks from where collection activities are to be planned.

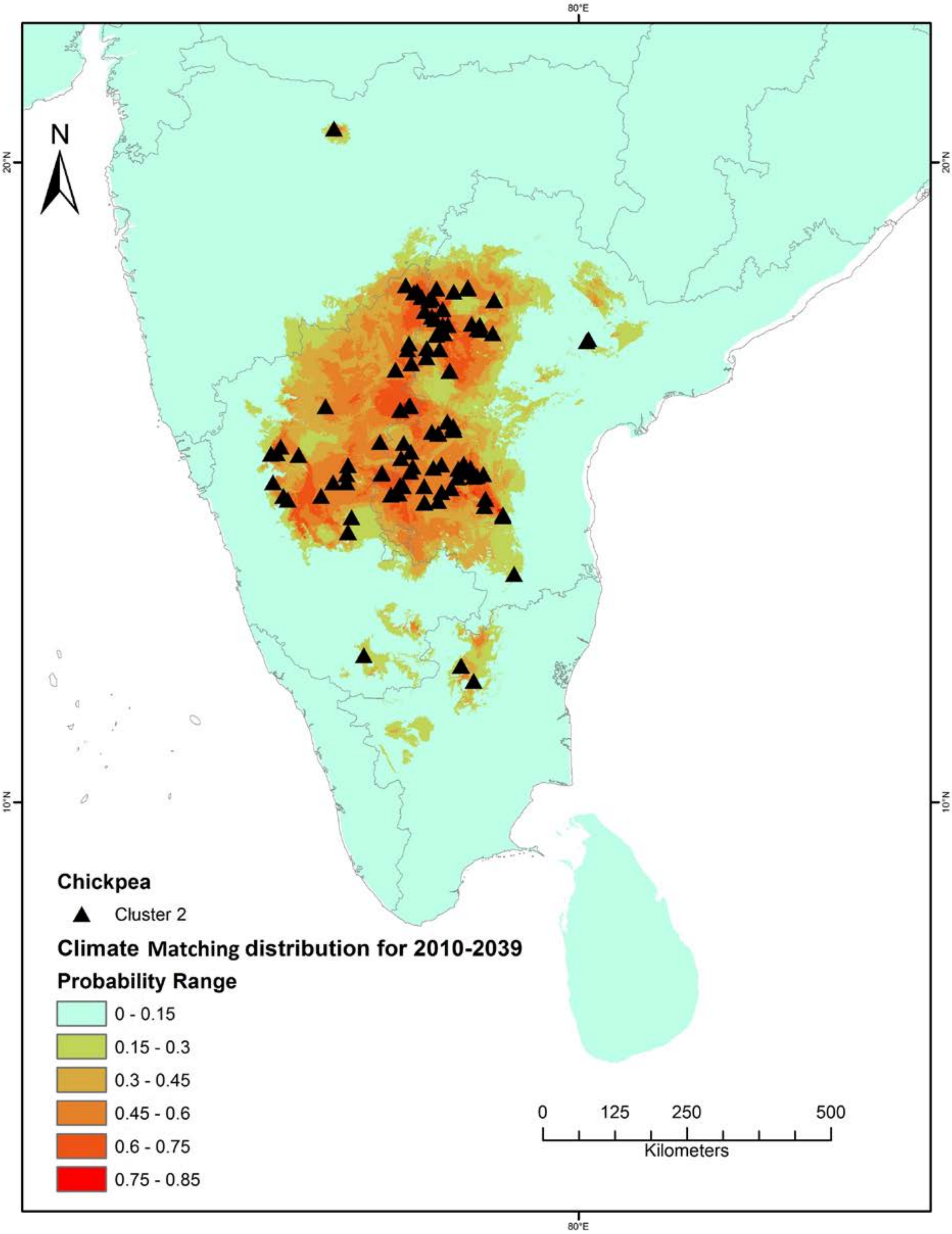


Figure 18. Climate matching distribution for chickpea cluster 2. The results of climate matching may be seen in the light of results depicted in Fig.17 and Fig.19.

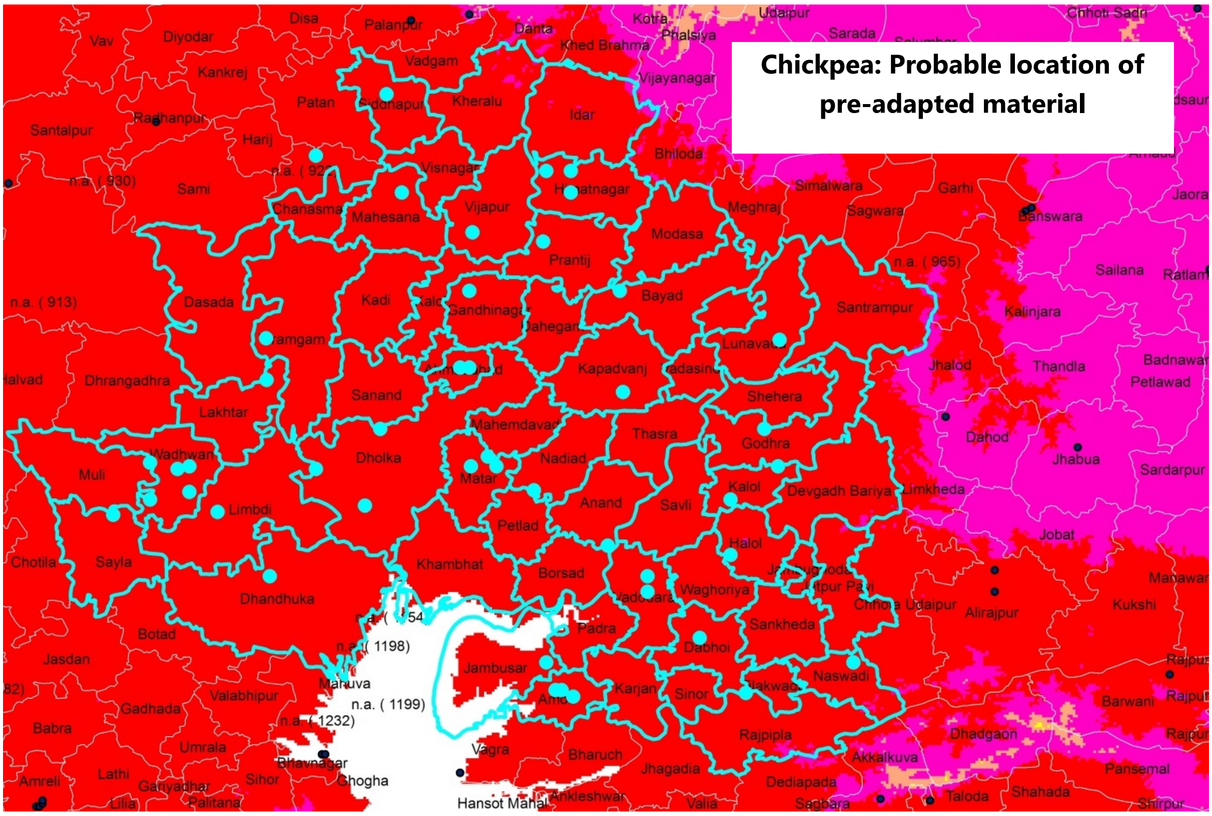
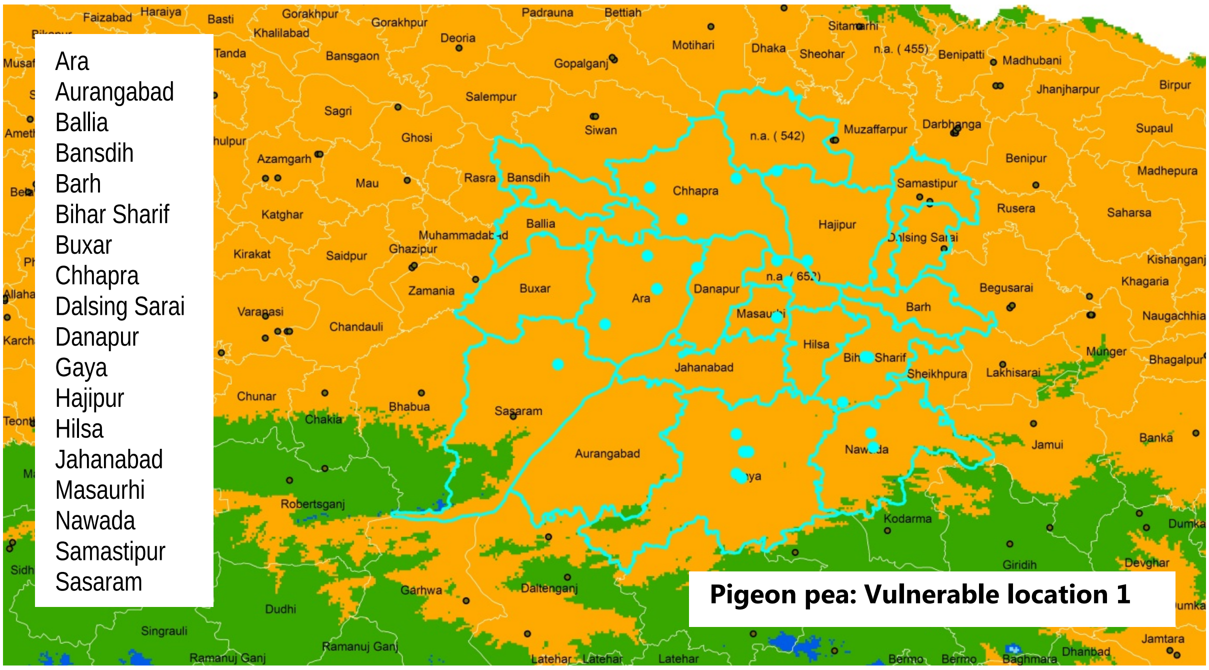


Figure 19. Sites of sourcing pre-adapted chickpea germplasm. Accessions short-listed are given in the table below.

Accession	Longitude	Latitude	Cluster	Accession	Longitude	Latitude	Cluster
SM11016	72.95	23.6	15	SM10992	71.96	22.99	16
SM11020	72.87	23.67	15	SM11191	72.59	23.03	16
SM11011	72.95	23.67	15	IC527926	72.62	23.03	16
SM10976	73.52	21.97	16	SM11024	73.63	23.12	16
IC270245	72.9	21.98	16	IG8250	72.62	23.28	16
SM11050	72.92	21.98	16	SM15679	73.11	23.28	16
SM11047	72.87	22.07	16	SM11018	72.86	23.44	16
SM11048	73.87	22.07	16	SM11192	72.63	23.47	16
SM10977	73.37	22.15	16	SM11000	72.4	23.6	16
IC395719	73.2	22.3	16	SM11015	72.12	23.72	16
SM15682	71.97	22.35	16	SM15004	72.35	23.92	16
SM11021	73.2	22.35	16	SM11049	72.958	21.958	16
SM15048	73.07	22.45	16	SM10983	71.708	22.625	16
SM10988	71.46	22.55	16	SM10991	71.708	22.708	16
SM10982	71.8	22.56	16	SM10999	72.625	22.708	16
SM10997	72.28	22.58	16	IC103797	72.708	22.708	16
SM10987	71.58	22.6	16	SM11026	73.625	22.708	16
SM11043	73.47	22.6	16	SM10993	71.958	23.125	16
SM11054	72.83	22.63	16	SM11045	73.47	22.42	17
SM10995	71.67	22.7	16	SM10998	72.33	22.83	16
SM10981	72.12	22.7	16	SM11028	73.58	22.83	16
SM10989	71.58	22.72	16	SM11022	73.12	22.95	16
SM11173	72.68	22.74	16				



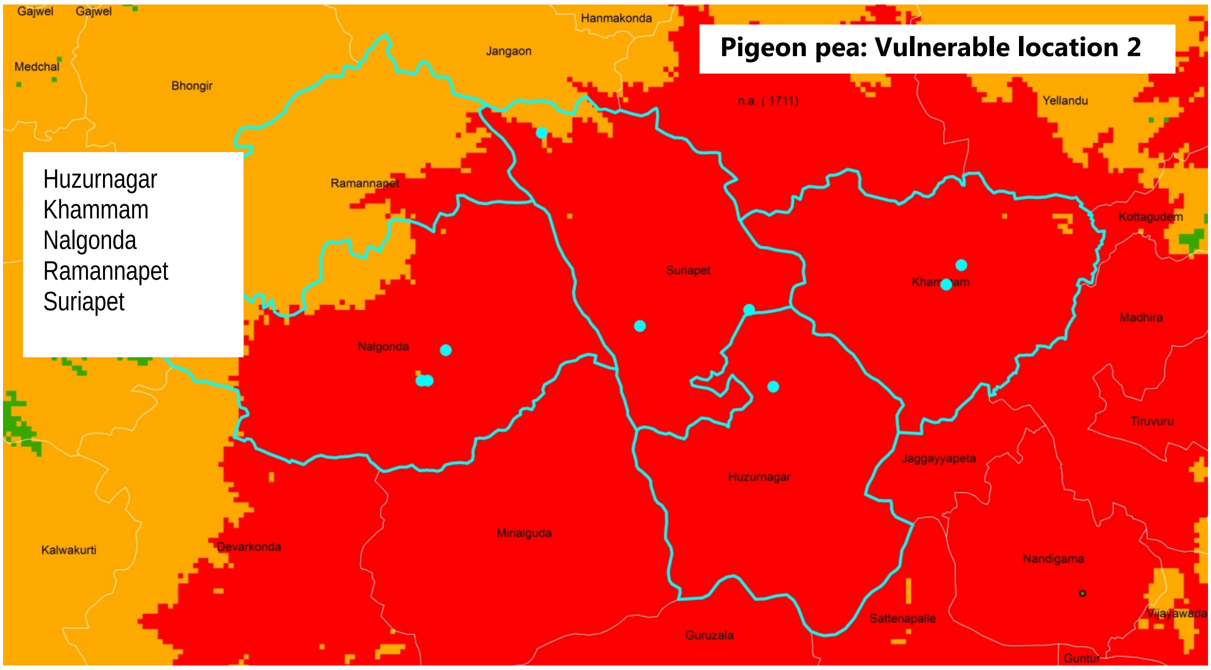


Figure 20. Two of the vulnerable sites identified in pigeon pea. Also given are the names of taluks from where collection activities are to be planned.

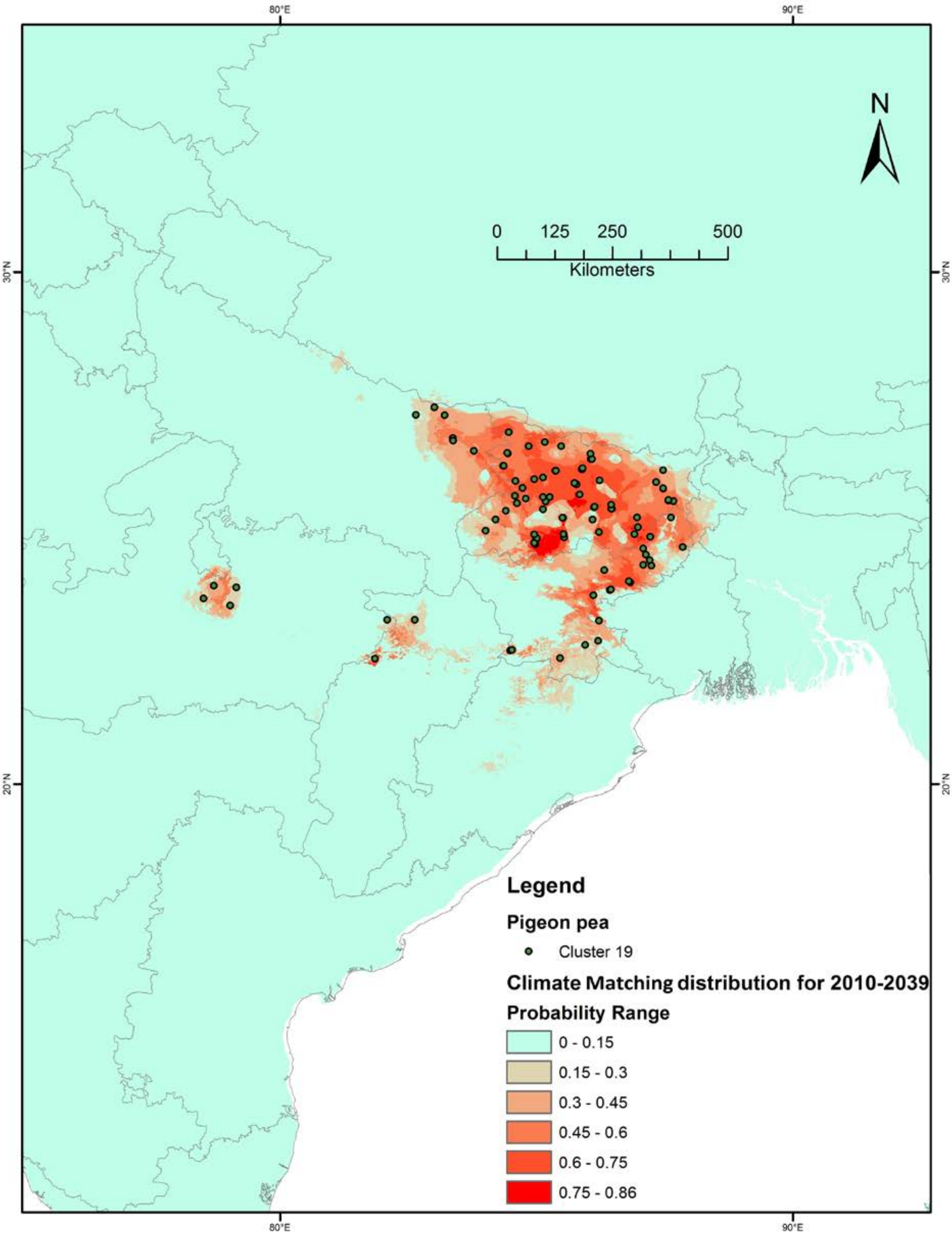
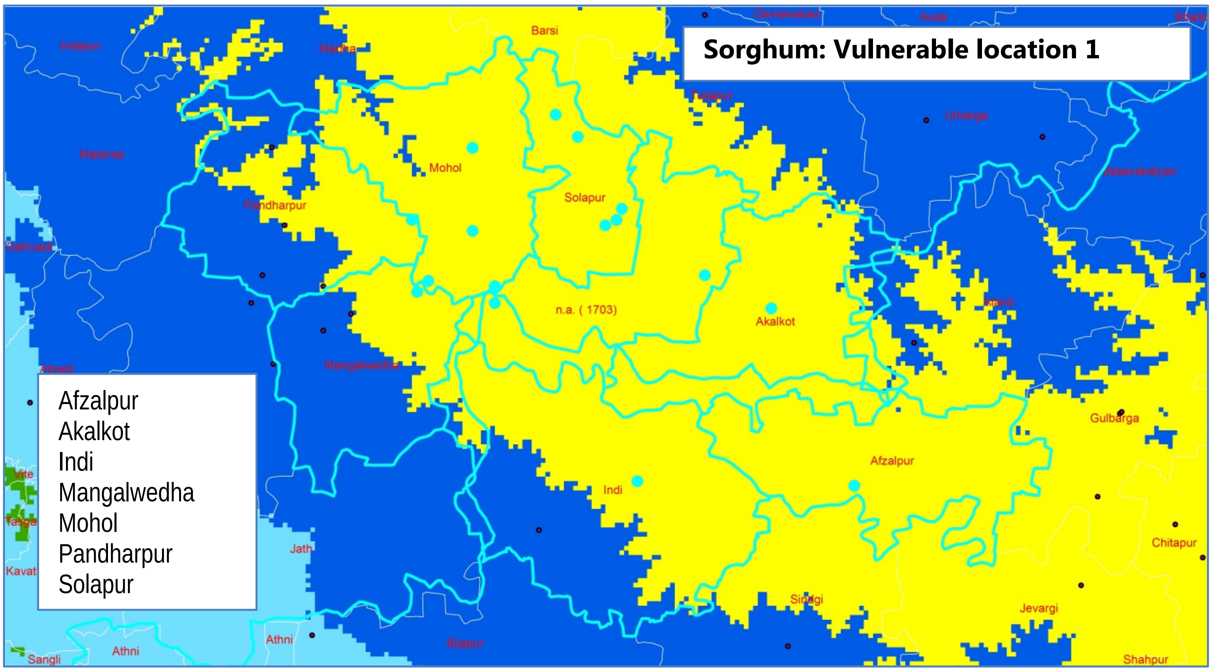


Figure 21. Climate matching distribution for pigeon pea cluster 19.



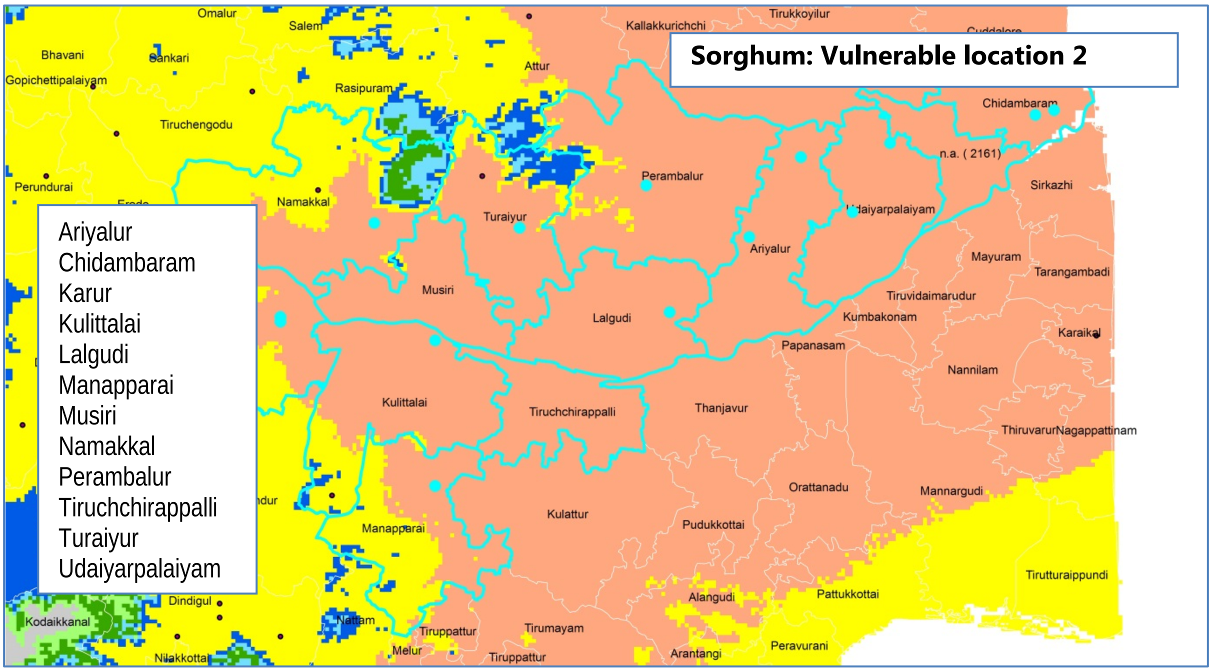


Figure 22. Two of the vulnerable sites identified in sorghum. Also given are the names of taluks from where collection activities are to be planned.

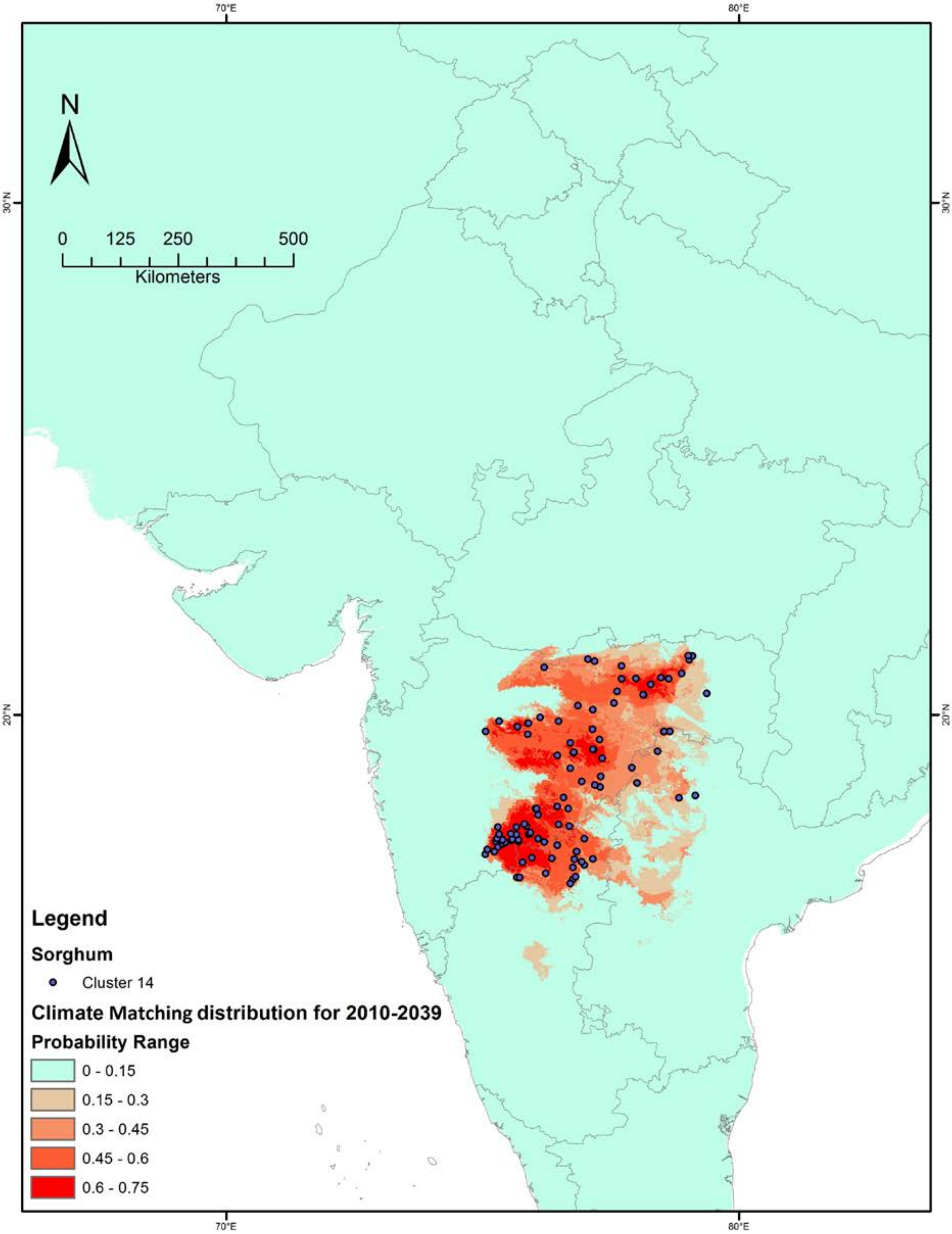


Figure 23. Climate matching distribution for sorghum cluster 14. The results of climate matching may be seen in the light of results depicted in Fig.22 and Fig.24.

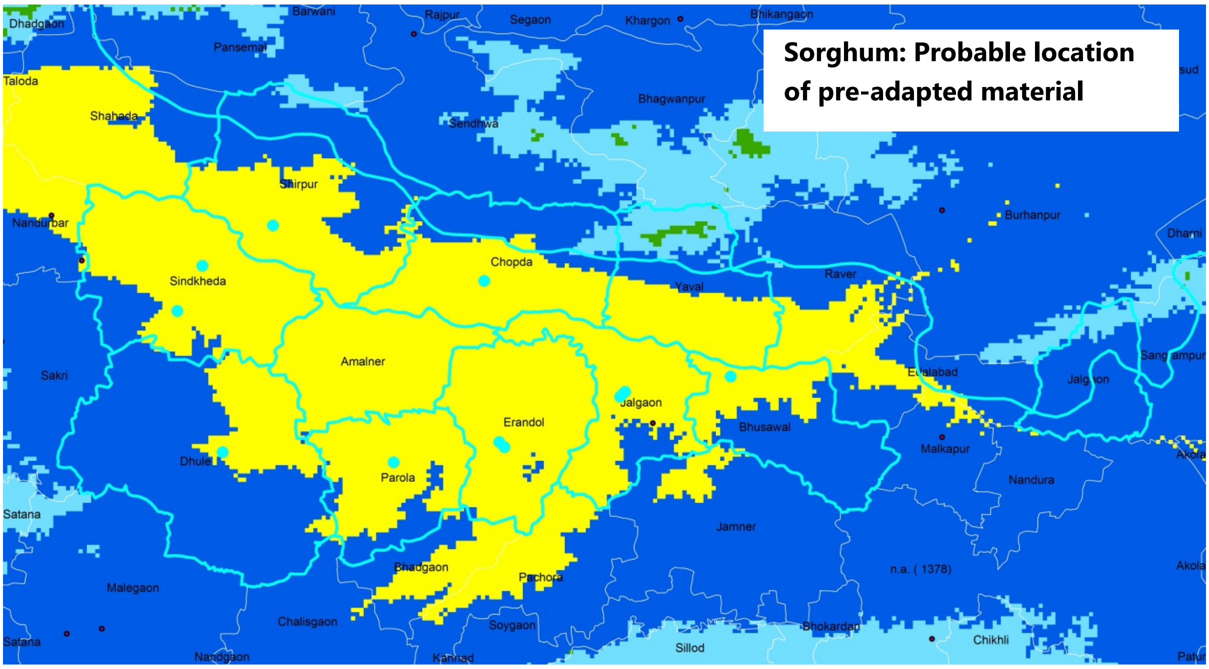


Figure 24. Site of sourcing pre-adapted sorghum germplasm. Accessions short-listed are given in the table below.

Accession	Longitude	Latitude	Cluster
24346	75.11	20.88	16
40725	74.77	20.9	16
24341	75.33	20.91	16
40688	75.32	20.92	16
21997	75.56	21.01	16
290510	75.5667	21.0167	16
4542	75.57	21.02	16
40674	75.78	21.05	16
24348	74.68	21.18	16
40703	75.29	21.24	16
40692	74.73	21.27	16
40697	74.87	21.35	16

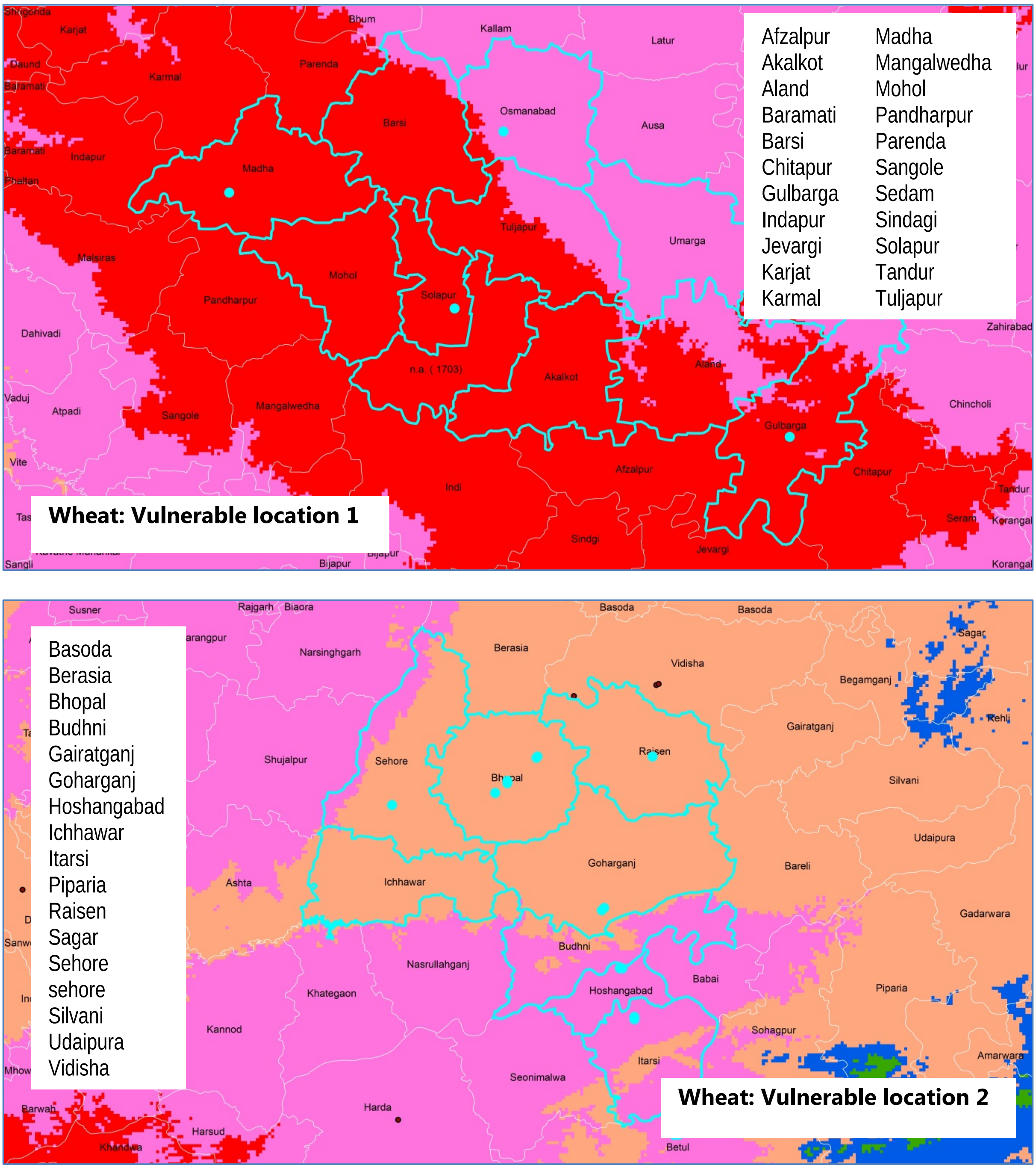


Figure 25. Two of the vulnerable sites identified in wheat. Also given are the names of taluks from where collection activities are to be planned.

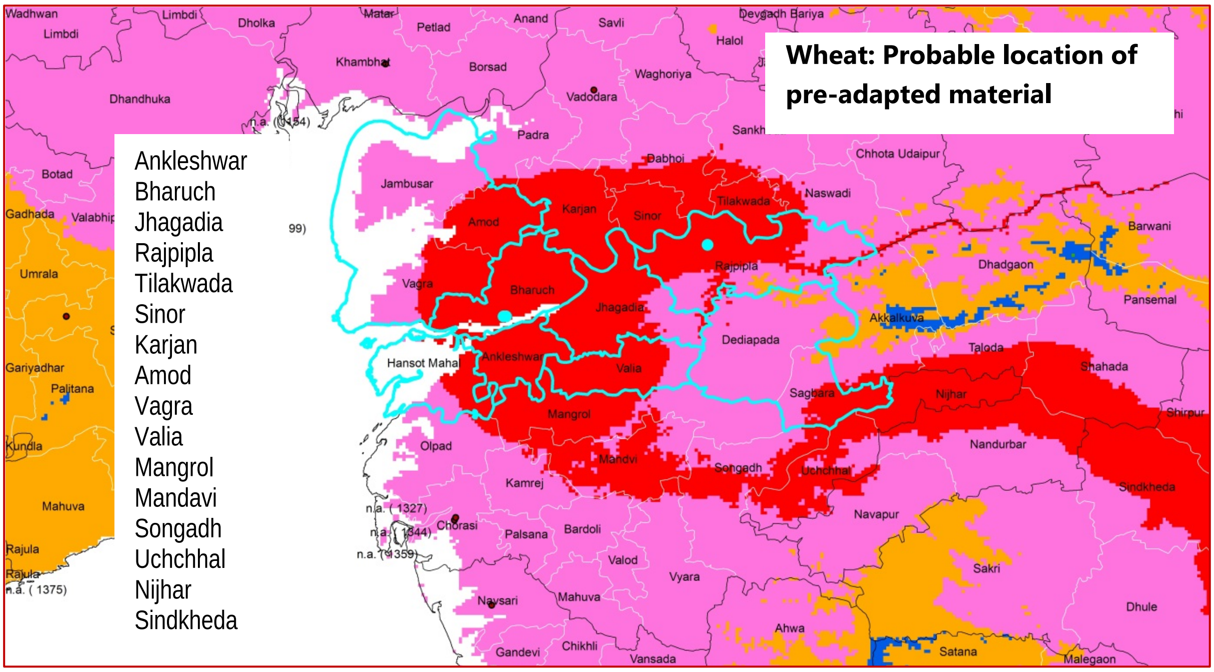


Figure 26. Site of sourcing pre-adapted wheat germplasm. Accessions short-listed are given in the table below.

Accession	Cluster	Longitude	Latitude
CWI22746	22	72.96	21.7
PI 41342	22	72.96667	21.7
IC 28689	22	72.9666	21.7
IC 336999	16	73.50128	21.88954

Exploration and collecting germplasm

Based on the analysis illustrated in the previous section, following collection missions were planned:

#	Exploration/ collection Mission	Crop	State(s)	Plan
1.	NBPGR/CRP7/1	Pearl millet	Rajasthan	Oct, 2013
2.	NBPGR/CRP7/2	Sorghum	Rajasthan	Oct, 2013
3.	NBPGR/CRP7/3	Pigeon pea	Bihar, AP	Nov- Dec 2013
4.	NBPGR/CRP7/4	Wheat	MP/UP Maharashtra/ Karnataka	Apr, 2014 March, 2014
5.	NBPGR/CRP7/5	Chickpea	AP/ Karnataka/ Maharashtra West Bengal	March, 2014

Exploration and collection of landraces of pearl millet and sorghum from the parts of Rajasthan (25.10.2013 to 1.11.2013)

Thirteen pearl millet landraces were collected from villages Bidoli, Ramgarh Pachwara, Danaw Kala, Malai Ramgarh, Sawariyawala, Gazipur, Bairkhon, Khareri, Ghasipura, Hamidpur, Jakhrana and Bidarkha using bulk method. None of these landraces was in cultivation. Farmers, particularly female folk, shared their saved seeds from the storage bins. They informed us that these have not gone out of cultivation but not grown on a commercial scale. The landraces were called by the vernacular name *bajra* or *bajri* or *bajara*, but not any specific name which is the otherwise the usual practice. Not much information on their cultivation history and special traits could be elicited. But it was confirmed that these were inherited since few generations.

Eighteen sorghum landraces were collected from villages Faagi, Jaisingh Purawas, Dhan Kabund, Bairkhon, Agabli, Khareri, Jaswant Nagar, Goalpara, Devara, Nagar, Krishna Nagar, Mainpur Kidhari, Kakreli, Nayagaon, Hamidpur, Massit and Jakhrana. Eleven accessions were sampled from farmer's field by random method and the rest were collected using bulk method as these were shared by farmers, particularly female folk, from the storage bins. They informed us that these have not gone out of cultivation but not grown commercially. The landraces were called by the vernacular name *jawar, jwar, jowar, chara jawar*, etc., but not any specific name which is the otherwise the usual practice.

Figure 27. Farmers proudly showing the pearl millet traditional cultivars.

Figure 28. Sorghum traditional cultivars in the field and from the storage bin.

Not much information on their cultivation history and special traits could be elicited. Unlike pearl millet, it could not be confirmed if these were inherited since generations.

Exploration for chickpea in the doab areas of Andhra Pradesh - Karnataka (11.8.2014 to 14.08.2014)

As per the planned collection missions based on 2012-13 report, we could not take up trips in Maharashtra during 2013-14 *rabi* to collect chickpea because of crop loss due to hail-storm. It was then decided that before conducting the actual exploration trips, collection of ground-level information is essential regarding the cropping pattern and continued existence of landraces and traditional varieties. It was also decided that farmers may not sow all the traditional varieties and hence collections from their stocks may also be attempted.

Figure 29. Religious function at village Manchali (Andhra Pradesh). Top left: Cow ritual (supposed to use traditional seeds of paddy, pulses and millets to feed cow, but they were missing); top right: Discussion with villagers in village Yeragera (Karnataka); Bottom: Drummers leading a procession of local festival.

One of the identified areas for chickpea germplasm collection was the transitional area of AP and Karnataka (on either banks of river Tungabhadra). With the available preliminary information, a visit of four days was planned keeping Raichur as major point (due to presence of University of Agricultural Sciences, Raichur). An occasion of socio-religious congregations was selected to interact with people.

Startling facts came out of the interactions with farmers, farming women, farm laborers, community leaders, etc. First and the foremost, chickpea is no more grown in the area. Those who cultivated chickpea had improved varieties. Landraces or cultivars introduced long ago and adapted locally are not available. Second fact was, people are facing the effects of climate change. In 2009, there was a flood in river Tungabhadra, preceded by incessant rains. Third, no farmer had any idea of actions to be taken because they were blissfully unaware of climate change. Farmers focus was cotton or any other cash crop. In such scenario, finding landraces of chickpea in this region was ruled out. Alternatively, communications were established with some religious places in the locality, where it was told that old varieties and landraces are grown on a small scale. Efforts will be made to collect, if any, chickpea germplasm lines from such places.

Genetic identity and differences among collected landraces

Climate analog tools help predict locations based on past data on climatic variables. There are many other factors that influence the continued existence of landraces collected erstwhile from a specific location. If we find that the landraces are still in cultivation, then it becomes important to examine if there are any genetic differences among samples collected from different farmers of a given location. The fundamental purpose of employing climate tools is to capture as much genetic diversity as possible from the vulnerable locations to conserve them and to assemble climate ready pre-adapted germplasm to utilize them.

Thirteen pearl millet and eighteen sorghum accessions were collected from villages of Rajasthan. Simple sequence repeats markers, gold standard in DNA fingerprinting, were employed to assess if the accessions collected from various farmers actually the same. Eighteen accessions of sorghum were screened using thirty markers and twelve were found to be informative. Similarly, thirteen pearl millet accessions were screened using seventeen markers and five were found to be informative. Except one marker in each case, all others were found polymorphic generating multiple allelic patterns. The results are only indications to diversity among landraces collected from a restricted area and need in depth analysis.

Capacity building

NBPGR organized a 5-day Regional Training Workshop on "GIS and Climate Analogue Tools for PGR Management and Enhanced Use" during 2-6, December 2013 at NBPGR, New Delhi. The aim of the Workshop was to impart contemporary knowledge on GIS, climate data, climate analogues and their applications in PGR management and utilization along with hands-on experience on various software, databases, clustering and analyses.

Participants of the workshop with organizers on the occasion of inauguration: Dr. PN Mathur, Dr. KC Bansal, Dr. JS Chauhan, Dr. Sunil Archak, Dr. M Dutta, Dr. PC Agarwal and Dr. RK Tyagi.

Objectives of the Workshop

- Impart contemporary knowledge on GIS, climate data, climate analogues and their applications in PGR management and utilization
- Hands-on experience on various software, databases, clustering and analysis
- Analysis of actual data, interpretation and decision making in PGR management
- The goal was to enhance the participants' capabilities to manage and utilize PGR effectively in the face of climate change demands.

Training Methods

The climate analogues approach is adopted to compare climate models with experimental data. Use of climate databases and software including the analogue tools connect sites with statistically similar climates, across space and time. A statistical index is used to systematically identify climate analogues across the world, for certain regions, or among specific locations. The exercise can be crop specific or season specific, and one can use any of the global climate models. Analogous sites are then compared to identify vulnerable sites and to propose collection and evaluation activities. Participants had an opportunity to listen to presentations by experts on select topics (25% of the time) and work hands-on (75% of the time).

Venue

Workshop was conducted at National Bureau of Plant Genetic Resources, Pusa Campus, New Delhi. The training facility was created replete with adequate number of internet connections for all the participants and resource persons and a back-up wi-fi . The facility was created to cater to hands-on sessions.

Participants

The participants included eight persons from ICAR, one each from SAU and CSIR, and four from neighboring countries of the South East Asia (Vietnam, Laos and Cambodia) engaged in PGR management and interested in employing climate analogue tools. Indian participants were supported by dedicated funds available in the project whereas foreign participants shall be fully sponsored by our collaborator in the project, Bioversity International. Trainees were from various disciplines including plant breeding, agronomy, statistics, botany, computer science, etc. The list is given below:

Dr. Moola Ram Assistant Professor Agriculture University, Sumerpur	Dr. Salini K Scientist CRIDA, Hyderabad
Dr. Suma Mogali, Scientist UAS, Dharwad	Dr. Amit Chawla Scientist IHBT, Palampur
Dr. Anuradha Sane Pr. Scientist IIHR, Bangalore	Dr. Raj Pal Meena Scientist DWR, Karnal
Dr. N Sivaraj Pr. Scientist NBPGR RS, Hyderabad	Dr. DP Semwal Sr. Scientist NBPGR, New Delhi
Mr. Shashikant Sharma Technical Officer NBPGR, New Delhi	Mr. Ankur Biawas Scientist IASRI, New Delhi
Mr. Rajeev Gambhir Technical Officer NBPGR, New Delhi	Mr. Mom Sovanna CARDI, Phnom Penh Kingdom of Cambodia
Ms. Pheunphit Soisouvanh Rice and Cash Crop Research Centre Vientiane Lao PDR	Mr. Khuat Huu Trung Agricultural Genetics Institute Hanoi, Vietnam
Mr. Nguyen Tien Hung Plant Resource Center Ankhanh, Hoaiduc, Hanoi, Vietnam	

Pedagogy

During the training programme, about 5 hours of theory and 15 hours of hands-on sessions are held indicating 75% of time dedicated to practical learning. All the participants were asked to carry their laptops so that necessary software is loaded and input sample data transferred. They were provided with (i) softcopies of all the required manuals; (ii) research papers; and (iii) massive amount of data in a 16GB USB drive. Major way of training has been interactive and the goal of keeping the training with a workshop flavor appears successful.

The topics covered include: Role of GIS in PGR management and use; Introduction to GIS, databases, data Preparation, geo-referencing data and importing data to a GIS platform; Applications of remote sensing technologies in climate change studies; Climate analogues: finding climate matching sites; Introduction to DIVA-GIS; installation and basic functions; PGR data analysis in DIVA-GIS; Use of geo-spatial tools for mapping of biodiversity; Introduction to climate databases (current and future) and their application for identification of climate analogue sites; Introduction to Maxent for prediction of analogue sites, etc. Exclusive time was allotted to Group presentations and Presentation by participants about their on-going work.

Our principal resource person was Ms. Sarika Mittra from Bioversity International and one objective of the programme was to develop similar core competence in NBPGR. Other resource persons who delivered lectures were Dr. Vasudeva Rao (Network coordinator of Agricultural. Ornithology, Hyderabad) and Dr. RN Sahoo (Agricultural Physics, IARI).

A theory lecture in progress

A hands-on session in progress

Participants having a quick working-lunch

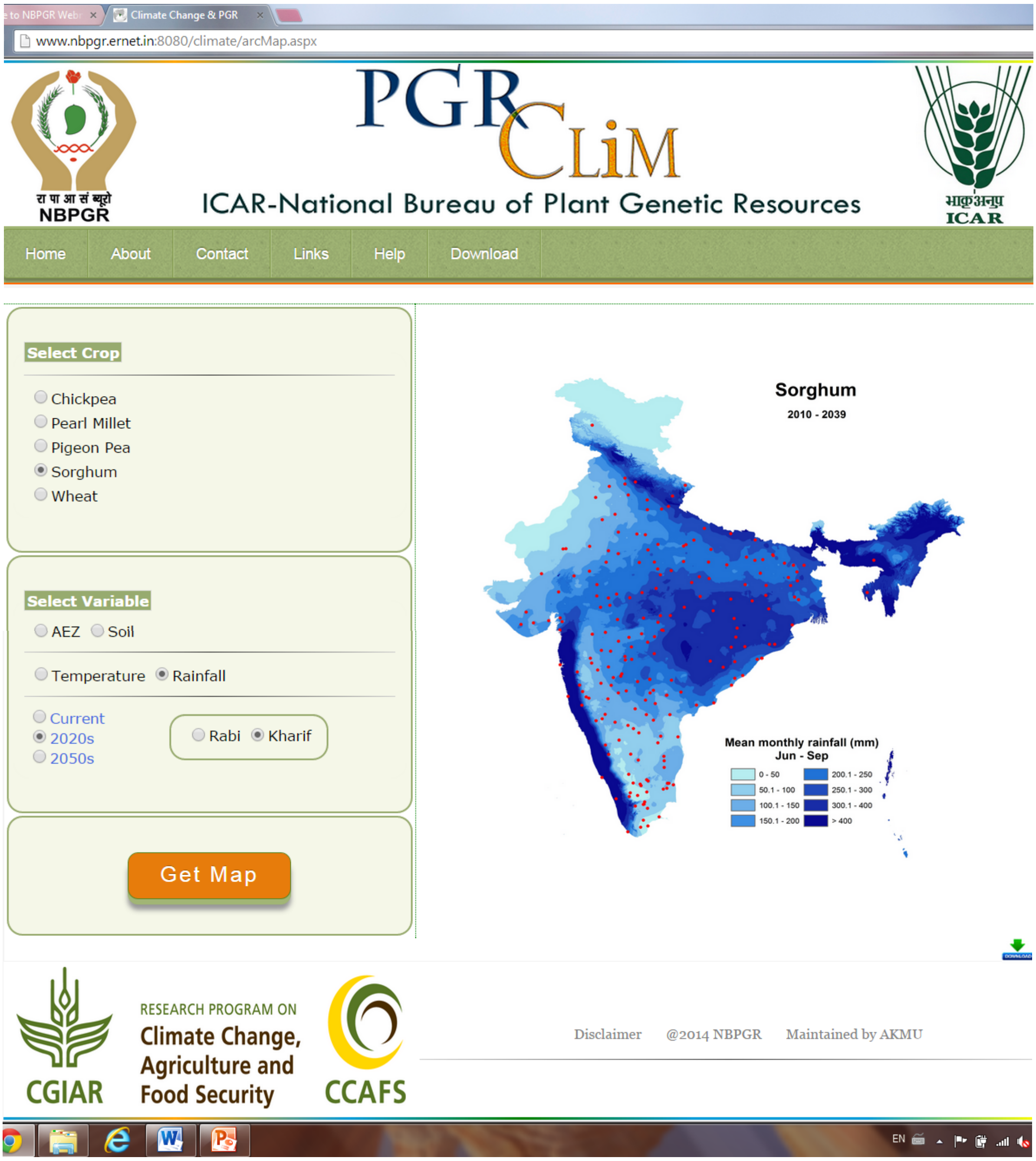
Participants discussing over tea

Participants received certificates from Dr. SK Datta, DDG (CS), ICAR

Dr. PN Mathur and Dr. KC Bansal interacted with participants

Interactive online information system

PGR-Clim aims to provide an easy interface to access important climate change information with respect to plant genetic resources management. The alpha version of this web-based program is limited to collection information of five crops (sorghum, pearl millet, wheat, chickpea and pigeon pea). The program allows the user to choose a crop and visualize how climate is predicated to change over time and stimulate them to assess impacts and measures. PGR-Clim is our first informatics efforts towards linking PGR and climate change.



With PGR-Clim you can view germplasm collection sites in case of five crops on:

- India map
- Soil map
- Agro-ecological zones
- Current and future temperatures
- Current and future rainfall

PGR-Clim can accessed at http://www.nbpgr.ernet.in:8080/climate

Conclusions and future perspectives

Aim of the concluded study was to employ climate analog tools to super-impose location information of the genebank accessions on present and future climate maps. This exercise was carried out in five crops — sorghum, chickpea, pigeon pea, pearl millet and wheat. The analyses assumed that sites of past collections continue to cultivate the crop; and the local landraces must have adapted to the extant climate. The temperature maps illustrate that (*A*) there are sites in the current climate that already experience higher temperature and (*B*) there are locations that will experience higher temperature in the future climate. This information is not new for crop cultivation and various adaptation strategies have been suggested by researchers keeping in view yield and farmers' income. However, for PGR management, significant aspects are (i) adding value to the genebank collections from locations *A* described above as potentially pre-adapted accessions and (ii) documenting potentially vulnerable locations *B* described above and planning exploration and collecting exercise. These two sets of operations would allow the genebank to be ready with necessary germplasm accessions in the event of changed climate, even if the predictions are not accurate.

The study has identified vulnerable locations for all five crops and could list the sites (in terms of *taluks*) for exploration programmes to be planned. Exploration visits for three crops — sorghum, pearl millet and chickpea — were also accomplished collecting thirty-one accessions. Potentially pre-adapted germplasm accessions were designated and a list is provided. Capacity building in terms of training the researchers to employ climate analog tools in their work was also accomplished. The results of the study are not lost in the report or publications. An open access interactive online application has been developed to view the climate maps developed in the study. With all these outputs, this study is only the beginning in applying climate analog tools for PGR management.

Evaluation of the accessions as potentially pre-adapted is not a straightforward exercise. Breeders would be interested to know which particular trait/s of the genotype is contributing to the adaptability. In the absence of *future climate location* on-site evaluation is not possible. Furthermore, we need to employ better tools that take into consideration multiple factors. Identifying vulnerable sites based on better informed and robust tools and conducting exploration and collecting missions is expected to ensure collection and conservation of potentially threatened germplasm. An analysis of what to collect in terms of crop wild relatives and cultivated populations; extent of variation in terms of genetic variability; and contribution to adaptive capacity in terms of novel genes and alleles need to be carried out. Such studies will be able to evaluate the process of prediction based on climate models and their utility in PGR management.

Potential sources of germplasm pre-adapted to climate change are farmers' fields as well as semi-feral plant populations

National Bureau of Plant Genetic Resources (NBPGR) is the nodal organization in India to carry out research, education and service activities in managing plant genetic resources. Its headquarters is located in New Delhi with ten regional stations spread across the country. NBPGR is a constituent institution under the Indian Council of Agricultural Research. NBPGR houses the national genebank that is conserving more than 400,000 accessions belonging to various crops.