Sustaining and Improving Rural Livelihoods through Adaptive Approaches to Land, Nutrient, and Water Management

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Disclaimer

This report reproduces the findings of the following reports in abridged form:

1) Climate Change Adaptation Approaches for Sustaining and Improving Rural Livelihoods in Gujarat;

2) Evaluation of Soil Nutrient Budgets at Field, Farm, and Regional Level in Humid Tropics of Kerala and Development of a Model for Management of Soil Health; and

3) Integrating Hydrology, Climate Change, and IWRM with Livelihood Issues: Development of Methodology and a DSS for Water-Scarce Bundelkhand Region in India

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List of Abbreviations

AEZ	Agro-Ecological Zones
AR	Assessment Report
BADC	British Atmospheric Data Centre
BIS	Bureau of Indian Standards
BT	*Bacillus thuringiensis*
CBDR	Common But Differentiated Responsibilities
CDM	Clean Development Mechanism
CGWB	Central Ground Water Board
CID	Cognitive interpretive diagram
CMIP	Coupled Model Inter-comparison Project
CPU	Central Processing Unit
CRA	Climate Resilient Agriculture
CRU	Climate Research Unit
CWRDM	Centre for Water Resources Development and Management
DAP	District Agriculture Plan
DIP	District Irrigation Plan
DSS	Decision Support System
DEM	Digital Elevation Model
DPAP	Drought Prone Area Programme
DPR	Detailed Project Report
ESRI	Environmental System Research Institute
ET0	Potential Evapotranspiration of Reference Soil
ETA	Actual Evapotranspiration
EU	European Union
FAO	Food and Agriculture Organization
FCM	Fuzzy Cognitive Mapping
FSI	Forest Survey of India
GCM	General Circulation Models
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	Greenhouse Gas
GIDC	Gujarat Industrial Development Corporation
GIS	Geographic Information System
GoG	Government of Gujarat
GPCC	Global Precipitation Climatology Centre
GWP	Global Water Partnership
GWRDC	Ground Water Resource Development Corporation
HadGEM	Hadley Centre Global Environmental Model
ICAR	Indian Council of Agricultural Research
ICZMP	Integrated Coastal Zone Management Project
IIASA	International Institute for Applied Systems Analysis
ICNMS	Integrated Crop Nutrient Management Software
INM	Integrated Nutrient Management
INCCA	Indian Network for Climate Change Assessment
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IPSL	Institut Pierre Simon Laplace
IRMA	Institute of Rural Management Anand
ISI-MIP	Inter-Sectoral Impact Model Inter-comparison Project

ISRO	Indian Space Research Organisation
IWMP	Integrated Watershed Management Programme
IWRM	Integrated Water Resource Management
JFM	Joint Forest Management
KVK	*Krishi Vigyan Kendra*
LGD	Length of Growing Period Days
LAI	Leaf Area Index
LISS	Linear Imaging Self-Scanning
LULC	Land Use Land Cover
LUP	Land Use Planning
LUT	Land Utilization Type
MASL	Meters Above Sea Level
MCM	Million Cubic Meters
MIROC	Model for Interdisciplinary Research on Climate
MoRD	Ministry of Rural Development
NAPA	National Adaptation Programmes of Action
NBSS	National Bureau of Soil Survey
NDMA	National Disaster Management Authority
NGO	Non-Governmental Organization
NICRA	National Innovations on Climate Resilient Agriculture
NIH	National Institute of Hydrology
NorESM	Norwegian Earth System Model
NMCG	National Mission for Clean Ganga
NMSA	National Mission for Sustainable Agriculture
NPP	Net Primary Production
NRSC	National Remote Sensing Centre
NWDT	Narmada Water Dispute Tribunal
NWRWS	Narmada Water Resources Water Supply
PCARRD	Philippine Council for Agriculture, Forestry and Natural Resources Research and Development
PIM	Participatory Irrigation Management
PMKSY	*Pradhan Mantri Krishi Sinchayee Yojana*
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SEZ	Special Economic Zone
SCI	System of Crop Intensification
SHG	Self-Help Group
SHPN	Soil Health Philanthropy Network
SIR	Special Investment Region
SoI	Survey of India
SPPWCP	Sardar Patel Participatory Water Conservation Project
SQ	Soil Quality
SSCN	*Sujalam Sufalam* Canal Network
SSP	*Sardar Sarovar* Project
SW	Sub-Watershed
SWRD	State Water Resources Department
TIFAC	Technology Information, Forecasting and Assessment Council
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey
VO	Village Organization

WASMO	Water and Sanitation Management Organization
WATCH	Integrated Project Water and Global Change
WDE	Reference Evapotranspiration Deficit
WEAP	Water Evaluation and Planning
WC	Watershed Committee
WUA	Water Users Association

Executive Summary

This study aims at identifying adaptations required by farming communities that may provide resilience to climate variability and change, and projecting environmental perturbations for the State of Gujarat, and Kozhikode and Tikamgarh districts of Kerala and Madhya Pradesh. Scenarios of agriculture for various representative concentration pathways (RCPs) in the 21^{st} century are developed. This report summarises findings of the following three reports: (i) Climate change adaptation approaches for sustaining and improving rural livelihoods in Gujarat; (ii) Evaluation of soil nutrient budgets at field, farm, and regional level in humid tropics of Kerala and development of a model for management of soil health; and (iii) Integrating hydrology, climate change, and IWRM with livelihood issues: Development of methodology and a DSS for water-scarce Bundelkhand region in India.

The Agro-Ecological Zones (AEZ) Methodology

For climate change impacts on crop suitability and agro-ecologically attainable yield, the study applies the AEZ methodology, which is jointly developed by Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA). The AEZ approach is a GIS-based modeling framework that combines land evaluation methods with socio-economic and multiple-criteria analysis to evaluate spatial and dynamic aspects of agriculture. It provides a standardized framework for the characterization of climate, soil and terrain conditions relevant to agricultural production. Crops modeling and environmental matching procedures are used to identify crop-specific environmental limitations under assumed levels of inputs and management conditions. The suitability of land for the cultivation of a given crop depends on crop requirements as compared to the prevailing agro-climatic and agro-edaphic conditions. The AEZ assessment combines these two components by successively modifying grid-cell specific agro-climatic suitability according to edaphic suitability of location specific soil and terrain characteristics. The AEZ simulation modeling includes generation of a range of scenarios for crop productivity for years 2041–2070 (2050s) and 2071–2100 (2080s) using the climatic condition based on four RCPs (2.6, 4.5, 6.0, and 8.5) adopted by the Intergovernmental Panel on Climate Change (IPCC). This includes identification of areas which specify climate, soil, and terrain constraints to crop production; estimation of the extent and productivity of rain-fed and irrigated cultivable land and potential for expansion; quantification of cultivation potential of land currently in forest ecosystems; and impacts of climate change on food production, and geographical shifts of cultivable land.

The Fuzzy Cognitive Mapping (FCM) Methodology

The fuzzy cognitive mapping (FCM) approach is used to understand communities' perception of climate related impacts on various asset classes, i.e. natural, human, financial, physical, and social assets. The assets sensitive to climate variability and change, and assets that serve as adaptive capacities were identified. FCM is a perception-based technique used to model complex and hard-to-model systems. It is an important tool that aids in visualizing how interrelated variables affect one another and represent feedbacks. Fuzzy cognitive maps are the product of local knowledge, useful in supplementing and complementing scientific data, and easy to apply in data deficient situation and complex environments, particularly where human behavior needs to be understood in order to comprehend complex problems. The community participants prepared cognitive maps for three central variables/concepts. Individual fuzzy cognitive maps were then coded into separate spread sheets with the same concepts listed in vertical and horizontal axes; forming adjacency matrices. All individual fuzzy cognitive maps were aggregated through an arithmetic mean at each interconnection of the adjacency matrix. In order to simplify and understand the structure of the complex maps concepts were condensed by replacing sub-groups with a single unit, and thus social cognitive maps were formed. The condensed social cognitive maps were analyzed using FCMapper software. Cognitive interpretive diagram (CID) was prepared using the visualization software Visone-2.16. Simulations were run using FCM Wizard software.

The Soil Nutrient Balance Methodology

The assessments for soil nutrient flow were carried out to evaluate the soil fertility status and nutrient balance/ budgeting of major crops/ cropping systems at different spatial scales (plot, farm, and district level) in Kerala. Several field experiments for the same were conducted during 2013 at CWRDM, Kozhikode farm campus. Cultural and management practices were followed according to the recommendations of the Kerala Agricultural University Practices Package. The soil nutrient monitoring exercise was carried out using the NUTMON-Toolbox (Vlaming et al. 2001; Surendran et al. 2007). Data collected from the field experiment with respect to all inflows and outflows are being compared using transfer functions or in-built regression equations of the NUTMON-model by linking soil nutrient input with rainfall for calibration and validation. Using the NUTMON-Toolbox, researchers can analyze the environmental and financial sustainability of agricultural systems, which can help raise awareness among policy makers. The assessment came out with a decision support system (DSS) for managing soil fertility and sustain the crop productivity.

Spatial and Temporal Patterns of Climatic and Bio-physical Parameters

Climatic variability is prepared for the use in the AEZ assessment. Temporal interpolations of the gridded monthly climatic variables into daily data provides the basis for the calculation of soil-water balances and agro-climatic indicators relevant to crop production. Table 1 shows results for annual mean temperature and precipitation in the study areas for the reference (1981–2010) and projected climate for periods 2050s and 2080s across different RCPs (2.6, 4.5, 6.0, and 8.5).

There has been rise in both temperature and precipitation across regions. The soil characteristics are read from 3-arc second grid cells in case of Gujarat and 1 arc second in case of Kozhikode and Tikamgarh districts. Soil units are characterized by the following soil parameters: organic carbon, pH, water storage capacity, soil depth, soil catalytic exchange capacity and clay fraction, interchangeable total nutrients, lime and gypsum content, percentage of sodium exchange, textural class, and granulometry. The AEZ analysis uses soil series information for the study areas. The results show that, the central part of Gujarat contains sandy loam, sandy clay loam, silt clay and sandy clay soils. Clay soil is the major soil in Saurashtra, whereas, sandy clay loam, clay loam, confined mainly on coastal region of

Saurashtra. Northern part of Gujarat contains sandy loam, sandy clay loam, clay loam soil and sand. The Kutch region consists of sandy loam, sandy clay loam, sand, silt clay, loam and clay.

Table 1: Annual mean temperature and precipitation

Parameters	RCPs	Gujarat			Kozhikode			Tikamgarh		
		Reference climate	Rise in		Reference climate	Rise in		Reference climate	Rise in	
			2050s	2080s		2050s	2080s		2050s	2080s
Annual mean temperature (˚C)	2.6	27.1	28.4	28.4	27.2	28.1	28.1	25.6	26.8	26.8
	4.5		28.8	28.4		28.0	28.9		27.5	28.0
	6.0		28.8	28.8		28.4	29.2		27.2	28.2
	8.5		29.6	31.4		29.1	30.6		28.2	30.2
Annual mean precipitation (mm)	2.6	933	1009	1003	3211	3312	3297	910	1155	1090
	4.5		985	1073		3315	3478		1082	1180
	6.0		968	1095		3279	3384		1097	1200
	8.5		1043	1119		3424	3580		1137	1180

The soils of the Ur River watershed through slow erosion of hard massive granites. Corresponding to their placement in the Entisols and Inceptisols, the soils in this area mostly have a fine sandy texture. Nearly 635 km^2 of the area is covered by sandy loams and another 266 km^2 by sandy-clay-loams. There are small patches of silty-clay loam covering only about 32 km^2 of area. Kozhikode district of Kerala with undulating terrain and laterite soils, coupled with high intensity rainfall leads to top fertile soil loss through severe erosion and nutrient loss through leaching, which might have been one of the contributing factors for low productivity. There are also other possible reasons for this low productivity.

Gujarat's water resources are characterized by colossal regional variation in the context of wealth and scarcity. Gujarat has a total of 50.1 billion cubic meters of water including surface water, groundwater and storage capacity of reservoirs (excluding *Sardar Sarovar*). Surface water resources contribute 38.1 billion cubic meters while groundwater resources contribute 12 billion cubic meters. The River/ water bodies cover 3.92% of the total geographical area of the Ur River watershed. The high relief area in the eastern and north eastern part occupied by Archaean and Deccan Trap have steep gradient allowing high run-off and therefore have little groundwater potential.

Agro-Climatic Analysis, Crop Suitability, and Agro-Ecologically Attainable Yield

The agro-climatic analysis by reference climate (1981–2010) and the projections using different RCP for periods (2050s and 2080s) are calculated for potential evapotranspiration of the reference soil, annual actual evapotranspiration, reference evapotranspiration deficit, and the total number of growing period. Agro-climatic constraints cause direct or indirect losses in product performance and quality. Performance losses in a rain-fed crop due to agro-climatic constraints have been formulated on the basis of the principles and procedures originally proposed in FAO (1978–1981a,b) and on experiences in each country. The adequacy of the terrain is estimated from the characteristics of the terrain slope and precipitation. For this AEZ study, the calculations are crop specific/ land utilization types (LUTs) are performed for a supposedly high input level, for both rain-fed and irrigated conditions. Separate files are generated by crop, input level, and water supply system and stage/ time period. Each database contains information in terms of adequate extent and potential output by suitability classes. Evapotranspiration parameters for the reference (1981–2010) and projected (2050s and 2080s) climate are presented in Table 2.

Table 2: Evapotranspiration parameters

Parameters	RCPs	Gujarat			Kozhikode			Tikamgarh		
		Reference climate	Change in		Reference climate	Change in		Reference climate	Change in	
			2050s	2080s		2050s	2080s		2050s	2080s
Potential evapotranspiration of reference soil (mm)	2.6	1949	1968	1968	1553	1603	1614	1782	1776	1780
	4.5		1968	1988		1604	1626		1747	1750
	6.0		1988	2066		1619	1659		1797	1845
	8.5		1988	2066		1629	1689		1811	1890
Annual actual evapotranspiration (mm)	2.6	586	569	580	1039	1045	1039	621	595	621
	4.5		580	586		1043	1073		609	628
	6.0		586	598		1021	1057		613	621
	8.5		592	598		1054	1092		626	629
Reference evapotranspiration deficit (mm)	2.6	1364	1391	1391	514	557	575	1160	1181	1159
	4.5		1391	1405		560	552		1137	1121
	6.0		1405	1459		597	602		1184	1224
	8.5		1391	1459		575	597		1184	1261

The assessment of crop suitability is an important component of evaluation studies, including changes in the geographical distribution of crops under climate change in the coming decades. It is well known that crops will respond to specific changes in temperature and precipitation in the places where they are currently grown. On the other hand, it is hoped that not all crops and cultivars will remain adequate within their current geographic range and trend to migrate towards higher latitudes and a push out of production in areas already in the production margin. However, most of the crop modeling platforms currently available present fixed simulations of the crop network, that is, they do not allow dynamic movements of ideal crop ranks and tend to underestimate farmers' adaptation responses.

The AEZ assessment tests the match of prevailing conditions with the parametric requirements of land utilization types (LUTs). A total of 15 matching are tested for the full range of possible starting dates and resulting in optimum match, sub-optimum match, and not suitable conditions. The “optimum and sub-optimum match categories” are considered for further biomass and yield calculations. Differences in crop types and production systems are empirically characterized by the concept of LUTs. A LUT consists of a set of technical specifications for crop production within a given socioeconomic setting. Under rain-fed conditions, water stress may occur during different stages of the crop development reducing biomass production and the yields achieved. In the AEZ assessment, water requirements for each LUT are calculated and taken into account in the calculation of LUT-specific water balance and actual evapotranspiration in a grid-cell.

The agro-climatic constraints cause direct or indirect losses in the yield and quality of produce. The agro-edaphic constrains estimate factors for yield reductions caused by constraints due to prevailing soil and terrain-slope conditions. The soil suitability is assessed through crop/ LUT specific evaluations of major soil qualities. Terrain suitability is estimated from terrain-slope and rainfall concentration characteristics. For this AEZ study, the calculations are crop/ LUT specific and are performed for an assumed high input level and four water supply systems separately, including rain-fed conditions, sprinkler irrigation, gravity irrigation and drip irrigation. The terrain-slope suitability rating used in the AEZ assessment captures the factors described which influence production and sustainability.

The final step in the AEZ assessment crop suitability and land productivity assessment reads the LUT specific results of the agro-climatic evaluation for biomass and yield calculated for different soil classes and it uses the edaphic ratings produced for each soil/slope combination. The inventories of soil resources and terrain-slope conditions are integrated by ranking all soil types in each soil map unit with regard to occurrence in different slope classes. The results of crop evaluations are stored as separate databases each organized by grid cells. The fertility of a soil is determined by both its physical and chemical properties. An understanding of these factors and insight in their interrelations is essential for the effective utilization of climate, terrain and crop resources for optimum use and production.

Climate Change Impacts on Crop Suitability and Attainable Yield

The agricultural scenario of Gujarat and Kerala is unique and characterised by diversity of crops and multiplicity of cropping situations. This section summarises the following results: (i) suitability index depicting area and percentage of occurrence of very suitable and suitable agricultural land; and (ii) agro-ecological attainable yield for current and future climates for RCP 4.5. Ensemble mean of five climate models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) are calculated to avoid extreme variations across models in the result. The AEZ results show that projected climate change affects crop production differently for different crops in different parts of the study areas.

In Gujarat, the projected areas show a drastic reduction everywhere except Saurashtra, which shows an increase in harvested area of only a couple of thousand square kilometers. The harvested area of mustard, peanut, bajra, castor, pigeon, mango, wheat, and white potato decreases ranging from 63 to 100 %. Mustard, BT cotton, mango, wheat, and white potato have never been grown in the rain-fed condition and will be suitable for irrigated conditions only. Sorghum will be promising crop in most parts of Gujarat. Regarding irrigation and production conditions, the substantial decrease in harvested areas and decrease of yield are reflected with only sorghum, cotton, BT cotton and maize promising a yield increase between 8 and 32 %.

Major crops grown in Kerala are coconut, areca nut, oil palm, rubber, coffee, tea, cardamom, paddy, tapioca, cashew, etc. However, the low crop productivity associated with high production costs is a great concern in Kerala’s agriculture. Additional stresses come from climate variability and change, resulting in impacts on water availability over time and space. The AEZ analysis for Kozhikode district shows that for Ensemble mean-ESM2M and RCP 4.5 scenario, under rain-fed conditions, the yield of banana, areca nut, rubber, coffee, and black pepper shows a decline between 2.89 and 86.18 %. However, coconut and rice, under rain-fed conditions, shows very minor increase of 3.17 and 0.99 % respectively. Under the irrigated conditions, the yield of coconut, areca nut, coffee, and black pepper shows a decline between 3.83 and 86.18 %. The yield of rubber and rice shows very minor increase of 1.55 and 1 % respectively. However, if we look at all the models and different RCPs showed that in most of the cases the yield tend to decline except a few.

The results shows analysis of the AEZ model for the Ur River watershed in crop suitability index and output density of various Kharif crops. The pearl millet and sorghum (grain) crop showed maximum area under very high and high suitability index with output density of 4046 kg/ha and 5484 kg/ha respectively. The maize (grain), fodder maize and fodder sorghum are medium suitable for most of the area of the Ur River watershed. The output density will vary for maize, fodder maize, and fodder sorghum as per their suitability. These crops also show very high suitable area along the Ur River watershed.

Adaptive Approaches to Land, Nutrient, and Water Management across Cases

Farmers have implemented various agricultural techniques such as crop rotation and land leveling, which have reduced crop failure, soil hardness and soil erosion, and increased agricultural production and income. Increased precipitation has had a positive impact on land conditions in the state of Gujarat, as soil moisture has increased and, as a result, agricultural production has increased. The use of drip irrigation and sprinklers helped farmers economize water use, increase soil moisture, improve soil quality and eventually reduce crop failure and increase agricultural production. The use of manure also helps to reduce soil hardness and increase soil fertility and agricultural production. Social forestry and joint forest management (JFM) have helped improve tree cover in the state. Several NGOs have also been active with communities in the JFM program in Gujarat. Efforts need to be intensified to increase the natural resource base, promote sustainable and organic farming practices.

The major water scarcity mitigation tools that changed the Gujarat water availability scenario since 2000 relate to the progress made with respect to the completion of the *Sardar Sarovar* dam on the Narmada River, and the implementation of the *Sujalam Sufalam Yojana*. Under *Sujalam Sufalam Yojana*, the filling of ponds, dams and rivers by the excess water of Narmada, and the construction of verification dams and other structures of water collection along the rivers takes place. Communities mainly face the issue of reduced water availability and low agricultural production during the summer and winter. They have adopted various adaptation practices such as micro-irrigation, water resources management, and better water infrastructure to increase agricultural production. The regular supply of water through these micro-irrigation practices has helped to increase agricultural production. Many farmers in the study area use the drip irrigation system and sprinklers on their farms to use water optimally. The water rechange movement and construction of the check dam has increased the availability of water during the seasons of scarcity, increasing the agricultural production and the availability of fodder.

In Kerala, the soil health cards have been distributed to the farmers with fertilizer recommendation for several crops. Collected data from all these farms were fed into the data processing module of the NUTMON-model and the nutrient balances were computed using the

NUTMON-model for regional level nutrient budgeting. The results showed that in majority of the farms, N and K were in negative balance, whereas, P was positive confirming that the existing nutrient management practices are not a sustainable one in the long run. Similar is the case for Kozhikode district as a whole. The per-hectare N and K balances was found to be -9.5 for N and -17.2 for K in kg ha^{-1} yr^{-1}, whereas, P registered a positive balance (+ 7.4 kg $ha^{-1}yr^{-1}$) in Kozhikode district. In a nutshell, the NUTMON-Toolbox at different spatial scales exhibited a trend of depletion of N and K from soil reserve, whereas, P was positive, indicating the need for carefully redefining N and K management strategies.

A decision support system (DSS) was developed as an output by combining all the data bases generated from the project, apart from using all available secondary data sources. The DSS *viz*., CWRDM-Integrated Crop Nutrient Management Software (CWRDM-ICNMS) will help in generating nutrient recommendation for most of the crops in Kerala by considering all the inflows and outflows from the farm. The DSS will serve as a tool to identify the depletion of nutrients and will help to suggest the management options using a systematic approach. To overcome the negative impacts of climate change, apart from the developed DSS of nutrient management, several other adaptation strategies needs to be focused on to improve or at least sustain the productivity. The output from the project is a cost effective, eco-friendly conservation and management technology for higher input use efficiency, agricultural productivity & profitability without deteriorating natural resources for the entire farming community in Kerala. In this background, assessment of the soil fertility status and nutrient balance/ budgeting of major crops/ cropping systems is done at different spatial scales in Kerala, which aid with a DSS for managing soil fertility and sustaining the crop productivity. This was done in a holistic manner through soil fertility assessment in terms of nutrient stocks/ flows as an individual crop/ cropping system/ mixed crop and farm as a whole through field experiments and also at a district/ regional level to know about the status of their soils and the strategies needed to sustain the fertility, besides exploring the possibilities for increasing the crop productivity in an environmentally sustainable way.

Water management through Integrated Water Resource Management (IWRM) plan and the Water Evaluation and Planning (WEAP) model was implemented in Tikamgarh district. The watershed has been experiencing dry conditions for past few years as a result of low rainfall, but more importantly due to inefficient water usage practices. These practices altogether increase the pressure on existing water resources like surface ponds and groundwater. The demand thus exceeds the water supply possible in an existing area and increase the proportion of unmet demands. The given IWRM plan proposes hydrological measures and some changes in cropping pattern to utilize the available water resources in its best possible way. The proposed plan has been derived by considering the topographic, physiographic, climatic, soil and agricultural status of the area.

The DSS developed for the Ur River watershed, named as "*Jal-Jan-Jeevan*", includes various modules related to mapped information on all natural resources of the watershed, questionnaire based support to the stakeholders, assessment of vulnerability to the climate change, livelihood option, success stories and recommendations to the user for improving their livelihood status. It is an integrated resourceful application for the line departments and to the farmers of the area. The developed DSS can certainly be useful in the planning of the activities of soil and water resources of the area, farming activities and for formulating the schemes related to the livelihood of the people by considering the climate change vulnerability.

Guidance Toward Policies and Governance

The high growth of agriculture in Gujarat has attracted much attention from agricultural planners and policy makers. These remarkable results were made possible by meticulously planned and coordinated action plans that ensured eight hours of uninterrupted power supply to agricultural fields throughout the state (under the *Jyoti Gram* scheme). The soil health card program is also once an initiative that attempts to increase soil productivity by seeking to improve soil health. Across the State 20 soil testing laboratories provide free testing facilities to farmers. Based on the soil test analysis report, soil health cards were prepared with the maintenance of computerized soil test data, fertilizer recommendation, soil recovery, crop planning, etc. Researchers, scientists, experts, agricultural officials, and ministers interact with farmers during *Krishi Mahotsav* and provide information and advice on soil health, organic agriculture, modern technology, agricultural inputs, irrigation, etc. There must be a shift towards sustainable cropping patterns such as the crop intensification system to reduce groundwater depletion, while integrated nutrient management must be adopted to maintain sustainability. System of crop intensification (SCI), micro-irrigation, and water and soil conservation is needed to sustain agriculture production in Gujarat. To ensure long-term land productivity, immediate action is required to adopt sustainable agricultural practices. Agricultural practices must be sustainable rather than exploitative, leading to environmentally sustainable growth. Some of the technological and management interventions that could improve soil quality include structural methods for soil conservation such as soil and land fill and terraces in undulating areas, agronomic practices for the conservation and management of soils and waters. It is unlikely that these initiatives will pay enough dividends, unless appropriate soil conservation measures and appropriate cropping patterns are adopted.

Appropriate changes at the macro level in the water governance structures and the adoption of the river basin approach to the integrated planning and management of water resources is needed. At the micro-level we suggest strengthening of community organizations—Watershed Committees (WCs) in rain-fed areas, Water Users Associations (WUAs) in irrigated areas, and joint forest management (JFM) committees in forest areas. These community organizations will be the organizational mechanism through which people can be involved in the management of water resources. Watershed management and minor irrigation projects would be most suitable for drought prone, tribal, and hill areas, which should be allowed and encouraged to be developed by the local communities, with technical and financial help from the government and non-government organizations (NGOs). The management of these projects should be with the local communities, through WCs/ WUAs. In areas with scarcity of water, the respective community organizations should have the right to inspect and monitor the use of groundwater by private landowners to ensure that groundwater beyond permissible limits is not being withdrawn. Since the overall thrust of the policy is towards people’s participation at all stages, the highest priority should be accorded to the training of those who are to manage the water resources at all levels. The training must sensitize all partners to the demands of a people's planning approach to water resource development. Training should also ensure the technical empowerment of all local institutions and communities who are to plan for, develop and manage water resources. These include *gram panchayats*, *gram sabhas*, NGOs, watershed associations, WCs, WUAs, etc. It should cover training in information systems, sectoral planning, project planning and formulation, project management, operation of projects and their physical structures and systems and the management of the water distribution systems.

For effective and economical management of water resources, the frontiers of knowledge need to be pushed forward in several directions by intensifying research efforts in various areas, including the following: (i) hydro-meteorology, (ii) assessment of water resources, (iii) groundwater hydrology and recharge, (iv) water quality, recycling and reuse, (v) prevention of salinity ingress, (vi) prevention of water-logging and soil salinity, (vii) water harvesting in rural areas in an integral manner, (viii) water harvesting and groundwater recharge in urban areas, (ix) economical and easy to operate and maintain designs for water resource projects, (x) better water management practices and improvements in operational technologies, (xi) crops and cropping systems, and (xii) sewage treatment on smaller scales and reuse of water after treatment.

Furthermore, suitably empower *gram panchayats* all over India to play a leading role at the grassroots level in developing and implementing concerned programs. Introduce soil and water conservation practices on a large scale for achieving long-term sustainability of the systems, including revitalization and management of the Common Property Resources. Create favorable environment to attract public and private funds for investment in Climate Resilient Agriculture (CRA). Much of the corporate social responsibilities funds from leading private sector players in the country should be channelized to promote CRA in vulnerable regions. Increase concessional credit to small and marginal farmers for adoption of climate resilient agricultural practices would be helpful. To streamline and create awareness about managing the climate risks through weather-based agro-advisories, and affordable weather insurance products need to be ensured.

Concluding Remarks and Way Forward

Temporal variability of climatic factors shows heterogeneous changes across RCPs and climate models. However, the spatial variability of each of the agro-climatic factors tends to have a similar trend in all the results obtained from different RCPs and models. In Gujarat, current climatic conditions are projected to increase annual mean rainfall and temperature in future. Projecting higher annual actual evapotranspiration in this region is directly related to higher temperature as well higher water availability from rainfall. Net primary production under rain-fed condition has a close relation with actual evapotranspiration because it is related to plant photosynthetic activity which is also driven by radiation and water availability. The projection for annual mean rainfall and temperature in Kozhikode district illustrates a rise in future. The projection for annual actual evapotranspiration and reference evapotranspiration deficit also show a rise in the region. The Ur River catchment of Bundelkhand region is witnessing fluctuations in extremes weather conditions–long drought spell and intense monsoon rainfall. The future projection shows an increase in annual mean rainfall and temperature in Tikamgarh district.

Cropping patterns in the State of Gujarat have shifted to unsustainable agricultural practices. Growing crops not very suitable for rainfall, soil type, and reliance on groundwater have caused serious environmental perturbations calling for immediate sustainable agricultural interventions. Agricultural productions is very low in Kerala compared to other Indian states or international averages. There are several possible reasons for this low productivity, such as, low fertile lateritic soils, nature of topography with undulating terrain, coupled with high-intensity rainfall, leads to top fertile soil loss through severe erosion and soil nutrient loss through leaching.

The State of Gujarat has come up with various major and minor projects adding to the surface storage capacity of its rivers while enabling ground water recharge in its parched regions. From Drought Prone Area Programme (DPAP) to Integrated Watershed Management Programme (IWMP) the focus has shifted from piecemeal solutions to a more integrated approach towards watershed management through GIS-based planning and management of watershed and convergence with other developmental schemes. However, robust grassroots institutions for watershed management are yet to emerge. The government and other stakeholders took bold steps towards the augmentation and management of available water in Gujarat in the last decade. To assess the soil fertility status and nutrient balance/ budgeting of major crops/ cropping systems at different spatial scales in Kerala, a decision support system (DSS) has been developed for managing soil fertility and sustain the crop productivity. The overall outcomes of the study in the Ur River watershed can be summarized into three broad sections *viz*., watershed scorecard, DSS, and Integrated Water Resources Management (IWRM) plan.

There is an urgent need to return to water efficient crops and help prevent further degradation of water and agricultural land. Farmers need to be educated to shift towards the cropping patterns based on results of the AEZ modelling. There needs to be a shift towards sustainable cropping patterns like the system of crop intensification to reduce groundwater depletion while integrated nutrient management needs to be adopted for maintaining sustainability. To ensure long-term land productivity immediate steps need to be taken towards sustainable agricultural practices. Many attempts are required to strengthen farmland productions and maintain ecological balance to survive against the climate-related impacts and shocks. Investments in climate smart agriculture, climate smart livestock management, better water conservation practices, quality agricultural inputs, micro-irrigation practices, development and management of natural resources through watershed and afforestation activities, conservation of biodiversity including crop biodiversity, etc. will not only increase production from farmland, but also prove to be transformational adaptation practices.

Across three cases, the study analyzes the future of agriculture in the arid, semi-arid, and humid agro-ecological zones of India. However, sub-humid, dry sub-humid, and mountain ecosystems are not covered in the study. Although India has a huge crop diversity, only a limited number of crops are considered for study. In addition, there are several critical sociocultural dimensions in different regions of the country. Therefore, a nationwide study with data from high-resolution soil series is the need of the hour.

Chapter 1: Introduction

Climate variability and concentrations of greenhouse gases in the atmosphere are not of concern to humans unless there are human implications and risks. Anthropogenic climate change concerns us because of the potential impacts on environmental and social systems. New scientific findings have shown that cumulative total anthropogenic carbon emissions should be limited to one trillion tones if global average temperatures should remain below the 2˚C limit (range of 1.3-3.9˚C) according to the agreed temperature increase in Copenhagen Agreement. Estimates of future warming depend more on anthropogenic total carbon emissions than on a specific stabilization scenario (Allen et al. 2009). Lean and Rind (2009) suggest that short-term climate trends (2009–2014) will show a rise in temperature of 0.15˚C (+/- 0.03˚C), at 50 % higher rate than projections of the Intergovernmental Panel on Climate Change (IPCC). However, due to the decrease in solar activity resulting from the natural cycle of the Sun, the 2014–2019 increase would be 0.03˚C (+/- 0.01˚C). According to Allen and Soden (2008), based on a study using forecasting models that a warmer atmosphere will have more humidity and rainfall events will become more common in the tropics. Precipitation events will be more extreme than previously thought. The researchers compared to model predictions [using multiple models of intermediate model comparison models 3 (CMIP3) models] of daily rainfall over tropical oceans with data collected from satellite observations. They found that observations and model simulations do not fit perfectly, with the simulated index of extreme rainfall being lower than observations. The Indian Ocean Dipole (IOD) is an important driver of tropical weather patterns in the Indian Ocean. The authors suggest that anthropogenic climate change will lead to a strong interdependence between IOD and Asian variability of monsoon precipitation. IOD events can result in heavy rain events in western India (Abram et al. 2008). It is noted that higher temperatures will have significant negative effects on crop yields, even without the projected impacts of associated drought. Experimental models of most major grains suggest that projected temperature increases will reduce yields by 2.5 to 16 % for every 1˚C in seasonal temperatures while emphasizing the already vulnerable populations of the India, China, and Indonesia (Battisti and Naylor 2009).

Climatic variability and change can affect different sectors of the economy in several ways, for example, by introducing severe and frequent flooding due to abnormal precipitation. The increase in the maximum temperature can increase the mean sea level that can directly affect large populations in peninsular and coastal areas. It is assumed that climate change can increase between 15 and 40 % of rainfall and raise the average annual temperature between 3 and 6˚C (Ajay and Sharma 2013). The change in water and the seasonal cycle can directly affect the agricultural production that affects diverse processes. Therefore, global climate change imposes a major food security challenge in all countries, directly or indirectly affecting agricultural production. In these circumstances, many researchers, policy makers, planners, and stakeholders increasingly believe that the interaction between climate change and food security is critical to sustainably addressing the problem in the coming decades (Ajay and Sharma 2013; Behnassi 2014). Between 1969 and 2005, the surface temperature of India has increased by 0.3˚C at a rate of 0.08˚C per decade. At the same time, the impact of climate change also witnessed the increasing occurrence of natural calamities such as floods, cyclones, droughts and heat waves (Goswami et al. 2006). Such extreme natural events have the potential to drastically reduce agricultural production, exacerbating food insecurity problems. A study in eastern India estimated a decrease of about 24 to 58 % in household incomes, along with an increase of about 12 to 33 % in poverty in farm households in a single year of drought (Bhandari et al. 2007). It is also understood that small farmers are perhaps the most vulnerable to climate change due to their inaccessibility to technologies, inputs, information, and finance for mitigation and adaptation. Two-thirds of all farmers' landowners measure less than 1.0 hectares, the livelihoods of a large number of farmers are directly vulnerable to climate change Given the agrarian structure and potential threats of climate change for development Agricultural and food security, it is important that India addresses the issue immediately (Birthal et al. 2014).

The climate system is a common global phenomenon, and climate change is a global phenomenon that manifests itself through land, air, ocean, and life, with which climate systems intertwine. There is much certainty about climate-induced changes, although predictions about the precise nature of their changes are uncertain. As a common property resource, climate systems would also be subject to the principle of "tragedy of the commons". There is a need for a global solution and the application of common but differentiated responsibilities (CBDR) to sustain this global common. The United Nations Framework Convention on Climate Change (UNFCCC) recognized the climate system as a global group whose stability could be affected by industrial emissions and other greenhouse gas emissions. The convention established a framework for intergovernmental efforts to address the issue of climate change and today the Convention has 192 countries involved in combating climate change. In 1997, a second and far-reaching treaty on climate change was signed and adopted in Kyoto, where it imposed binding targets on greenhouse gas emissions for major world economies, greenhouse gas reduction commitments According to protocol vary from nation to nation. It established flexible mechanisms to achieve these objectives through international emissions trading, intergovernmental emissions trading, the clean development mechanism (CDM) and joint implementation. The protocol was intended to be effective against a complicated problem and was also politically accepted, except for the United States of America that remained outside the protocol. The global community must follow the UNFCCC and the Kyoto Protocol to address the impacts of climate change. The UNFCCC has two policy frameworks to address climate change. One is through "mitigation" where there is a prevention of dangerous interference with the climate system and the second is through the "adaptation" process where there is a reduction of vulnerability to climate change. Adaptation relates to development issues and related policies (UNFCCC n.d.). These actions reduce pressure on the climate system and increase the adaptability of humans to the impacts of climate change. The adoption of technological advances in agriculture, supported by high investments in irrigation, infrastructure, and institutions over the last decades, has pushed India out of the threat of food insecurity. The stress imposed by climate change will most likely severely affect developing and least developed countries in the coming decades, which depends heavily on agriculture but have limited agricultural land. Developing and least developed countries do not have the means to address the challenges related to climate change, making them the most vulnerable to the effects of climate change. The UNFCCC and the Intergovernmental Panel on Climate Change (IPCC) have also identified that vulnerable communities are urgently needed to increase their adaptive capacity. These countries also demonstrated that they have underdeveloped technological, financial, and institutional capacities to initiate effective strategies for mitigation and adaptation to climate change.

There are numerous scientific evidences showing that climate change affects humans in a number of sectors, increasing food and water insecurities, affecting human health, the economy and the livelihoods of poor and vulnerable communities. It is necessary to communicate the causes and impacts of climate change to increase resilience. The world continues to negotiate a global international climate agreement and countries begin to implement their national greenhouse gas emission reduction targets as actions under the precautionary principle. However, skepticism remains mainly among those who deny responsibility for the climate system, and want to annoy it without looking at the implication of their actions. Today there is peer-reviewed scientific evidence and new findings are connecting the points between anthropogenic greenhouse gas emissions and their effects on the natural climate system and impacts on human beings.

Human societies today have to adapt to rapidly changing climates and the risks posed are not for the Earth, but for humans. It is necessary to strengthen resistance to the impacts of climate change. Measures can be taken in two major forms of mitigation and adaptation. The UNFCCC defines mitigation as "an anthropogenic intervention to reduce sources or increase sinks of greenhouse gases". Climate adaptation is "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate the damage or exploit beneficial opportunities". Types of adaptation can be distinguished, such as autonomous and planned adaptation. Climate change mitigation is an action to reduce the intensity of radiative forcing in order to reduce the potential effects of temperature rise due to the increase of greenhouse gases (GHGs). Adapting to global warming and climate change seeks to reduce the vulnerability of natural and human systems to the effects of climate change. However, if action against climate change is not accepted, and if the climate system warms up faster or reaches a critical level that precipitates a return, then it could be too late. Measures taken now must focus on making economic sense, which can delay global warming and may have additional benefits in reducing the risks of extreme events. India requires equitable access to sustainable development for developing countries without being hampered by emissions cuts at the local level. At the local level, there has been a lot of action in the energy sector to mitigate climate change on the part of the government through clean energy projects, it has done a bit to facilitate adaptation and increase the resilience of poor and vulnerable communities.

This study seeks to identify adaptations that provide resistance to variability and climate change, and provide a topology of adaptations. In this regard, climate-related impacts and adaptations have been captured to explain the vulnerability of rural livelihoods in the State of Gujarat, Kozhikode district of the State of Kerala, and Bundelkhand region in central India. A new methodological approach has been developed to assess livelihood vulnerability by combining the fuzzy cognitive mapping (FCM) with the proposed sustainable livelihoods framework, which explains communities' understanding of climate-related impacts and adaptations by capturing interconnected interactions which occur in the climate-human-environment interaction space. This approach illustrates livelihood assets sensitive to climate risks/ shocks, and livelihood assets that provide resistance to climate risks/ shocks. This approach also allows the creation of models of impacts and adaptations based on the perceptions of the communities. Climate impacts and adaptations have been analyzed and the vulnerability of livelihoods has been estimated. A typology of adaptations for case studies has also been provided. Millennium Development Goal 7 - Target 9 addresses environmental sustainability and predicts that future agricultural growth will be largely achieved through improvements in the productivity of diversified agricultural systems with regional specialization and sustainable management of natural resources, especially the land and water.

This study also seek to evaluate soil nutrient balance at the field, farm, and region level and to develop a decision support system (DSS) considering all the uncertainties in the soil nutrient flow. The problem of soil erosion is serious in Kerala, narrow strip of land near the sea with ingredients such as high rainfall and increased human activities that have accelerated soil erosion, resulting in land degradation and loss of superior fertile soil. Land nutrient losses to water (and subsequent impacts on downstream watercourses) have accelerated globally over the past 50 years due to the development of the landscape for agricultural and urban activities. In many agricultural systems, nutrient management of different fields belonging to single-farm households can vary considerably (Smaling et al. 1996). Farmers' decisions on fertility management are influenced by both socioeconomic and biophysical environments, resources and production objectives (i.e. land use and crop selection). Therefore, field and farm scale nutrient studies at different spatial scales can provide information on how environmental conditions and agricultural management affect the variation in nutrient fluxes between and within the fields of a farm. This information is also indispensable to adequately understand variations in nutrient flow studies at higher spatial scales and their limitations (Smaling 1993; Wijnhoud 2007). However, these studies on nutrient balance in India are surprisingly scarce compared to other European and African countries, and in particular, to date no systematic studies have been conducted considering all entrances and exits of Kerala. Therefore, with this background, the present project is proposed to evaluate soil nutrient balance at the field, farm, and region level and to develop a DSS considering all the uncertainties in the soil nutrient flow. This will help sustain soil fertility and make land users produce in a more profitable and environmentally benign way in moist Kerala tropics.

The study also seek to improve the water situation in the Bundelkhand region, it is felt that an integrated approach to water and waste water management has to be undertaken. The water management approach has to be built around the concept of efficient management and sustainability (quality and quantity), and building of institutional systems at various levels (village, block, district levels) for community based management of water challenges. Prior to designing any interventions, it is important that the current status and its driving forces are well understood. Thus, the development of a DSS linking water resources with livelihood issues and future climate change impacts will provide the decision makers to decide upon alternate management options under various scenarios. This project is an effort to conduct a rapid assessment of the current status of water in the Ur River catchment of Bundelkhand region, and to develop a methodologies and a DSS for introducing an integrated approach to water management with livelihood issues using the Water Evaluation and Planning (WEAP) system.

A DSS shall be developed considering hydrological, technological, economic, and social factors to recommend community-based water management policies for holistic development of the region.

1.1 Objectives of the Study

The chief objectives of this study are:

- Generation of a range of scenarios for climate change
- Generation of a range of scenarios for land based production systems
- Development of decision support system for Integrated Water Resource Management
- To quantify the nutrient inflows and outflows (*viz*., soil erosion and leaching) in different cropping systems at different spatial scales in Kerala soils
- Development of decision support system for ensuring sustenance of soil fertility and successful transfer of agro technology
- Elaboration of adaptation options for enhancing livelihoods of rural communities, who are primarily dependent on land and water resources
- Providing guidance toward policies and governance of land and water

1.2 Study Areas

The study areas comprise of the Gujarat plain and hills of the agro-climatic region of India, Kozhikode district, one of the coastal districts of the state of Kerala, and Tikamgarh district of the State of Madhya Pradesh. Gujarat plains and hills agro-climatic region, which also coincides with the borders of Gujarat State, encompasses a wide range of climatic and agro-ecological conditions which is called microcosm of India. This has resulted in a rich diversity of rural livelihoods exposed to a variety of possible future impacts of climate change. In addition, since socio-economic data are usually collected by administrative units, ecological and statistical data can easily be integrated with this case throughout the study area. The study was carried out on two spatial scales. Data generation and first-level scenarios are performed at 30-arc seconds resolution for the Gujarat set. Gujarat has a total area of around 196,024 km^2, of which, about 60% area is under agricultural cultivation. Although the image of Gujarat is of high economic growth, it cannot eliminate the subsistence needs of the poor and perform welfare functions for its citizens. There is a critical need for Gujarat to implement adaptation projects in the agriculture, water resources, and coastal areas to increase resilience.

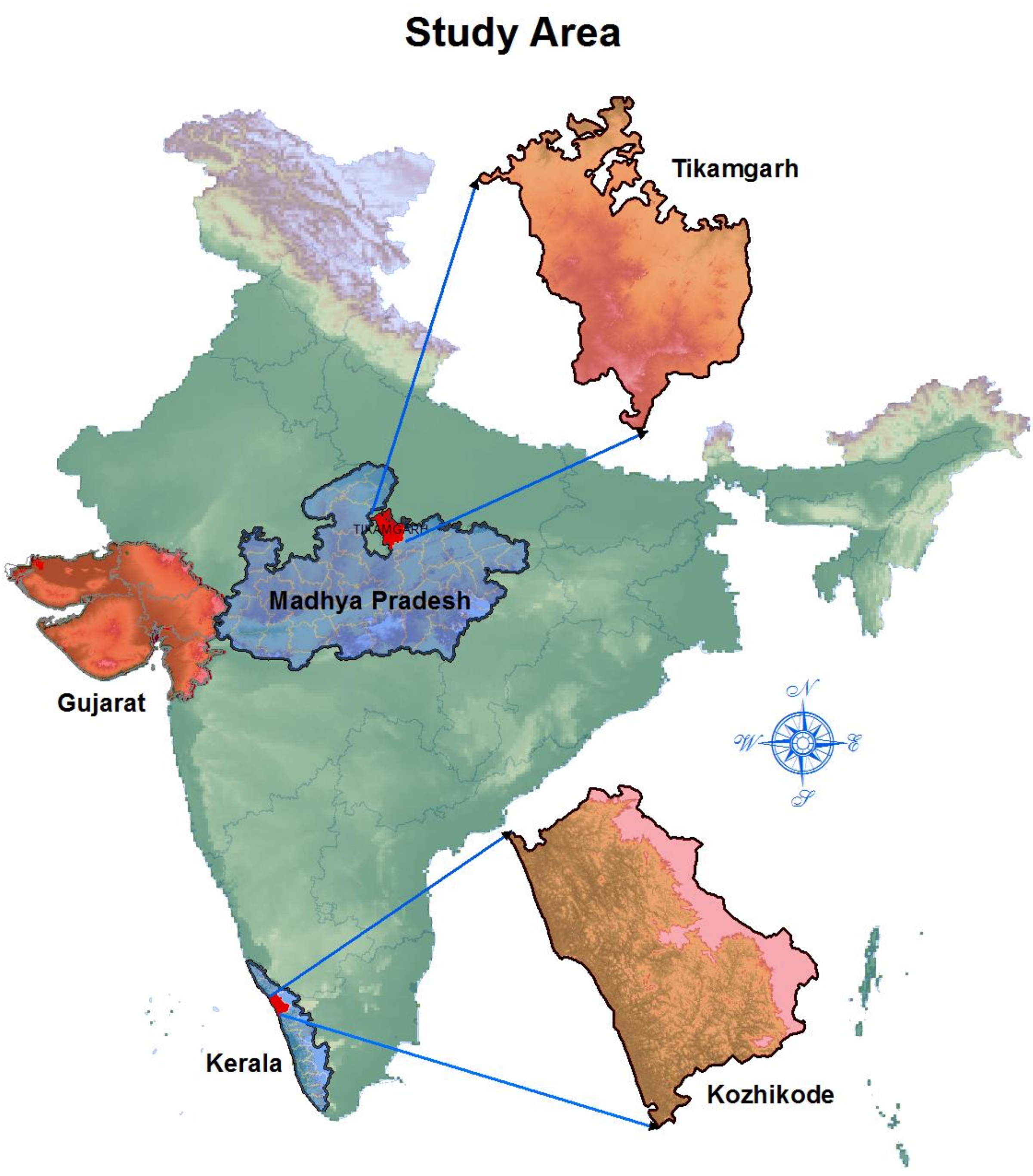


Figure 1.1: Administrative map of India showing the study areas

The state of Gujarat comprises 27 districts and 225 talukas (sub-district) comprising 18,618 villages and 242 towns. Kutch is the largest district of the state holding 23% of its total geographical area. The Dangs is the smallest district holding less than one percent of its total geographical area. The proper management of land, water, forests, minerals, pastures, and wildlife is crucial for sustainable development. For the purpose of this study, the state is broadly classified into north, central, south, Saurashtra, and Kutch regions. Large parts of the state comprise the plains concentrated more or less in central and northern Gujarat. Gujarat, a western state in India with the longest coastline with a large part of the state falling under arid and semi-arid with exposure to the coasts of the sea, the state becomes relatively more vulnerable to climate change. It is therefore imperative to address climate change to maintain the harmony of agricultural growth, food security, human health, biodiversity and the overall development of the state. The western India is expected to receive more precipitation as temperatures rise. Therefore, the necessity of the time forces us to understand to a great extent the agricultural impact of the variation in the intensity, duration, and occurrence of the precipitation. Given the likelihood of extreme climatic conditions such as droughts, floods and cyclones that can wipe out permanent crops that leave impoverished and defenceless farmers, it is important to address this issue by forecasting the future agricultural scenario. The first level data and scenario generation is done at 1:250,000 scale for the whole of Gujarat. Within this region, nested case-based scenario generation for adaptation is done at a higher scale to represent livelihoods in different sub agro-climatic regions according to various scenarios of climatic, biophysical and development futures. The nested case-based detailed study has been carried out in three districts namely Surendranagar, Mahesana, and Valsad, to capture diverse impacts, adaptation interventions, and to assess livelihood vulnerability to climate variability and change, while providing insights for decision making.

Kozhikode district is bounded on the north by Kannur district, on the east by Wayanad district, on the south by Malapuram district, and on the west by Lakshadweep Sea. The district is divided into 3 talukas and 12 developmental blocks and 77 panchayats for administrative purposes. The district has one corporation (Kozhikode) and two municipalities namely Koyilandi and Vadakara. It has a total of 117 revenue villages. The district can be divided into three geographical regions—highlands, midlands, and low lands. The district is drained by six rivers of which one is of medium nature and all others are minor ones namely Chaliyar, Kuttiyadi, Mahe, Kadalundi, Kallayi, and Korapuzha. The district has a humid climate with a very hot season extending from March to May. The most important rainy season is during the South-West Monsoon which sets in the first week of June and extends up to September. The North-East Monsoon extends from the second half of October through November. The district has a rich heritage in agriculture as it was a port city famous for pepper & species trade. Agriculture plays a major role in the district economy. The total geographical area of the district is 234,641 hectares in which the net area sown is 155,677 hectares. Kozhikode district is endowed with a coast line of 71 km, stretching from Chaliyar to Azhiyoor; and it offers enormous resources for the development of fisheries. The district is rich in brackish water area and there is great scope for shrimp farming too. In the coastal belt, fishing is the main occupation of a large number of people. Around 25,000 fishermen are directly involved in fishing activities. Topographically the district has three distinct regions-the sandy coastal belts, the rocky highlands formed by the hilly portion of the Western Ghats and lateritic midland. Of the total area of 2346.4 km^2, the sandy coastal belt is 362.85 km^2, lateritic midlands 1343.50 km^2 and rocky highlands 637.65 km^2. The productivity of almost all the crops except rubber is lower in Kerala compared to other Indian states. Low fertile lateritic soils, nature of topography with undulating terrain, coupled with high intensity rainfall, leads to top fertile soil loss through severe erosion and nutrient loss through leaching might have been one of the contributing factors for low productivity.

The majority of the population of the district is dependent directly or indirectly on agriculture for their livelihood. The district is a leading producer of commercial agricultural commodities in the country. The main crops grown in the district are paddy, coconut, pepper, cashew, tapioca, areca nut, and plantation crops like rubber. Paddy occupies the largest area among annual crops, however, a drastic reduction in paddy area occurred during the past decade. Even though the percentage of area sown under paddy is decreasing year after year, due to the conversion of paddy fields for other purposes, using high yielding varieties, a substantial increase in paddy production has been achieved. NBSS & LUP has classified Kozhikode district into 3 agro-ecological zones and 4 agro-ecological units. For understanding the role of a different process a budgetary approach offers good tool through analyzing the turnover of nutrients in the soil-plant system at different spatial scales. However, such studies on calculating the nutrient balances as inflow and outflow *viz*., loss of nutrients through soil erosion and leaching loss are very limited in Kerala region and have not been linked to nutrient balance studies earlier. Hence, to address the above issues this project is being proposed to give solutions by identifying the root cause and assessing the nutrient inflows and outflows from the system i.e. at field level, farm level, and regional level. By keeping these facts in view the present project has been proposed to assess the soil fertility status and nutrient balance/ budgeting of major crops *viz*., banana, tapioca, and coconut based cropping systems at different spatial scales in Kerala using suitable nutrient budgeting software. This will be done in a holistic manner by soil fertility assessment in terms of nutrient stocks/ flows as an individual crop/ cropping system/ mixed crop and farm as a whole and also as a district/ watershed/ regional level to know about the status of their soils and the strategies needed to sustain the fertility besides explore the possibilities for increasing the crop productivity in an environmentally sustainable way.

In the Tikamgarh district of the State of Madhya Pradesh, out of six tehsils, part of four tehsils comes under the project area. These tehsils are Jatara, Palera, Baldeogarh, and Tikamgarh. The total number of villages in the project area is 194 villages and 3 urban settlements. The Jatara block covers an area of 324.94 km^2 which is about 33% of the total watershed area followed by Tikamgarh block which covers 315.97 km^2 (32%); Baldeogarh covers 272.65 km^2 (27%) and Palera covers a very small portion of the watershed of around 8% of the total watershed area. The major part of working population is engaged in agriculture and allied activities. The study area has an average literacy rate of 43%, lower than the Tikamgarh average of 61%, and Madhya Pradesh literacy rate 64%, male literacy is 52%, and female literacy is 34%. The Ur River watershed which is a tributary of the River Dhasan has been selected as a pilot watershed for carrying out the comprehensive water balance study.

The study area represents the typical topography and geology of the Bundelkhand region. The Ur River watershed is situated in Tikamgarh district of the State of Madhya Pradesh and lies on the Bundelkhand Plateau between the Jamni, a tributary of the Betwa and the Dhasan rivers.

The total geographical area of the watershed is about 991 km^2. The maximum length of the watershed is about 119 km from north to south with an average width of about 80 km. Elevation of the area lies between the 200 to 400 meters. Geographically, the Ur River Watershed forms nearly the centre of the Bundelkhand region that lies between the Vindhyan plateau in the south and the great Ganga-Yamuna plains in the north. The highest peak in the southwest rises to 403 meters. This is situated near in the southern part of Tikamgarh tehsil. But there are several other spots in the western part of this area, with elevation of around 380 to 400 meters. The Ur River flows in a south to north-east direction. The Ur River watershed is bounded by Chhatarpur district to the east, Lalitpur district to the west; Jhansi district to the north and Sagar district to the south. The Bundelkhand region in Central India is under limelight because of the continuous drought situation resulting in acute water and power shortages and large-scale migration of local population elsewhere in search of livelihood. This region has been facing recurrent droughts since the last decade due to changing rainfall pattern and distribution being one of the prime reasons among many others. The water resources management under drought scenario is a challenging task for the decision makers and planners since it is not at all possible to avoid droughts leading to widespread water scarcity. The phenomenon of drought coupled with the impacts of the climate change could prove to be disastrous for the fragile ecosystems and economy of the region. To improve the water situation in the region, it is felt that an integrated approach to water and waste water management has to be undertaken. The water management approach has to be built around the concept of efficient management and sustainability (quality and quantity), and building of institutional systems at various levels (village, block, district levels) for community-based management of water challenges. Prior to designing any interventions, it is important that the current status and its driving forces are well understood. Thus, the development of a decision support system (DSS) linking water resources with livelihood issues and future climate change impacts will provide the decision makers a tool to decide upon alternate management options under various scenarios. This project is an effort to conduct a rapid assessment of the current status of water in the Ur River catchment of Bundelkhand region, and to develop a methodology and a DSS for introducing an integrated approach to water management with livelihood issues using the Water Evaluation and Planning (WEAP) system. A DSS has been developed considering hydrological, technological, economic, and social factors to recommend community-based water management policies for the holistic development of the region.

Chapter 2: Methodology

2.1 The Agro-Ecological Zones (AEZ) Methodology

The Agro-Ecological Zone (AEZ) methodology is developed by Food and Agriculture Organization of the United Nations (FAO), in collaboration with the International Institute for Applied Systems Analysis (IIASA). The AEZ simulation modelling procedure includes the generation of a range of scenarios for crop productivity by the year 2040s and 2080s using the climate condition based on RCPs 4.5 adopted by the IPCC. However, the climatic scenarios were represented in four models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) in the four RCPs (2.6, 4.5, 6.0, and 8.5). This phase quantifies the impact on individual crops, largely by predicting changes in crop yield/ yield due to climatic, physical and other atmospheric factors. In addition, other important factors; yield gap, quantification of the gaps between the potentially achievable yields of the crops and the current yield of the crops. The yield gap, based on the current state of production and actual potential capacity, suggests a greater reach to improve crop productivity. The modelling simulation, which is also the longest phase of the study, undertakes the following activities to obtain results (Figure 2.1).

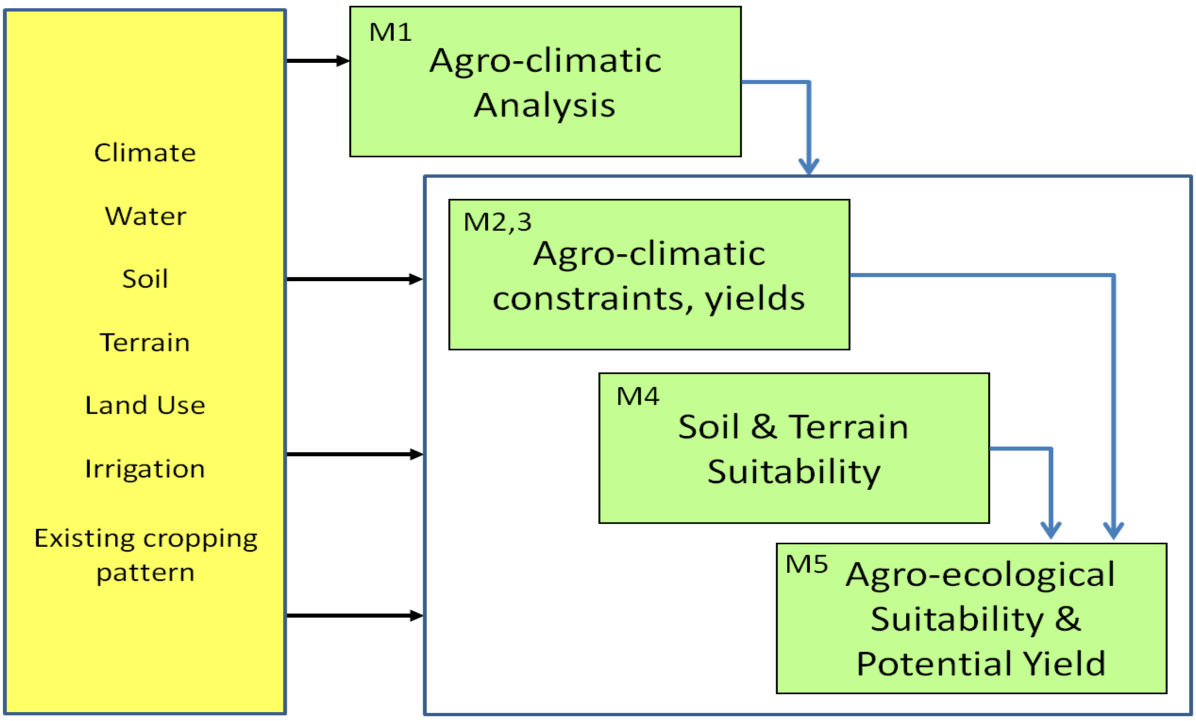


Figure 2.1: Overall structure and data integration of the AEZ approach

i. Adaptation of agro-system models to regional data and context which includes
   a) Compilation of a land resources database for the AEZ simulations based on geographic layers of climate, terrain, soil types and soil attributes, land use/cover;
   b) Review and adaptation of the AEZ land utilization types to conditions of study area; and

c) Compilation of climate input variables for various climate change scenarios derived from base period climate data and RCM outputs for 2050s

ii. Contribute to assembling and simulation of scenarios for bio-physical parameters

iii. Simulate impacts of climate change for agro-climatic conditions and bio-productivity based on gridded data of land resources and climate change scenarios for the study area

iv. Provide information from simulation analysis to contextualize the case-based investigations

v. Incorporate case-based information to adaptation simulation experiments at the regional scale

The AEZ approach is a GIS-based modelling framework that combines land assessment methods with socio-economic analysis and multiple criteria to evaluate spatial and dynamic aspects of agriculture. The AEZ methodology is developed by the Food and Agriculture Organization of the United Nations (FAO) in collaboration with the International Institute for Applied Systems Analysis (IIASA) (Fischer et al. 2012). It is the instrument for evaluating the agro-ecological potentials of agricultural crops, as well as specific crops of biofuels and perennial grasses. The AEZ methodology comprises an inventory of land resources to evaluate all viable agricultural land use options for specific management conditions and input levels and to quantify the expected production of relevant cropping activities. The characterization of land resources includes components of the climate, soils, and landform, which are basic for the provision of water, energy, nutrients and physical support to plants. Based on this agronomic assessment and using the available socioeconomic data to formulate constraints, objectives and production options, the spatial allocation of resources can be optimized against multiple objectives (Fischer et al. 2012). The results of the AEZ assessment are estimated by grid cell and aggregates at national, regional and global levels. This includes identifying areas with specific climate, soil and land restrictions for crop production; Estimating the extent and productivity of arable land irrigated and fed with rainwater and potential for expansion; Quantification of the potential of cultivation of the lands currently in forest ecosystems; And the impacts of climate change on food production, geographical changes in arable land. Performance evaluation of alternative types of variables such as land use, a specific criterion function often does not adequately reflect the actions of decision makers, who are multi-purpose nature in many practical problems related to resource planning. Therefore, the model analysis of multiple interactive criteria should be applied to the analysis of the AEZ models. It is at this level of analysis that socio-economic considerations can be effectively taken into account, thus providing a spatial and integrated approach to ecological-economic planning for sustainable agricultural development.

The agro-ecological zones methodology has been in use since 1978 to determine the potential of agricultural production and the carrying capacity of the world's land surface. An agro-ecological zone, as originally defined, comprises all parts of the grid cells in a georeferenced map that has uniform soil and climate characteristics. The AEZ methodology follows the scientific approach: it provides a standardized framework for the characterization of climatic, soil and land conditions relevant to agricultural production. Crop modelling and environmental adaptation procedures are used to identify crop specific environmental constraints on input levels and management conditions. In addition, the recent availability of global digital databases of climatic parameters, topography, soil, terrain and ground cover allows for revisions and improvements in calculation procedures.

More specifically, the AEZ approach attempts to address several questions, such as what would be the techniques of availability and adoption of agricultural technology for the various crops in the future? What kinds of genetic crop truths will be available? How will climate change affect crop and yield areas? How can crop scientists and researchers reduce the negative consequences of socio-economic and climatic factors on crop growth? It is also useful to generate a scenario based on assumptions predicted related to such changes in the future allows evaluations and a distribution of the results. It would facilitate political considerations and decision-making in the face of future uncertainty. The AEZ approach estimated using grid cell and added to national, regional and global coverage, provides the basis for several applications. These include the following process:

- Selection and identification of areas with specific climate, soil, and terrain constraints to additional crop and production, and land utilization types (LUTs) relevant to temperate and boreal environments
- Estimation of the extent of rain-fed and irrigated cultivable land and potential for expansion, and extension of the crop/ LUT definitions to cover irrigated conditions
- Quantification of crop productivity under the assumptions of three levels of farming technology and management
- Expansion of crop ecological adaptability inventory
- Application of soil-specific moisture regimes, frozen soil conditions, and snow stocks for the calculation of length of growing periods
- Evaluation of land in forest ecosystem with cultivation potential for food crops
- Regional impact and geographical shifts of agricultural land and productivity potentials and implication for food security resulting from climate change and variability
- Application of gridded monthly average for long-time series and reference climate year-by-year climatic resources databases
- Enhancement of the assessment procedures for year-by-year crop suitability analysis
- Expansion of the agro-climatic constraints inventory to cover additional crop/ LUTs and temperate and boreal environments
- Assessment of agro-climatic crop suitability by grid-cell (enabling calculations of biomass, constraint-free yields, agro-climatically attainable yields, crop water requirements and deficits)
- Expansion of land suitability assessment procedures for irrigated crop production

Based on the suitability of land for the cultivation of a given crop/ LUT depends upon crop requirements as compared to the prevailing agro-climatic and agro-edaphic conditions. The AEZ assessment includes these two components by successively modifying grid-cell specific agro-climatic suitability according to the edaphic suitability of location specific soil and terrain characteristics. The structure of the AEZ methodology follows a stepwise review of results. The modules generate the layers of agro-climatic factors that are associated with plant production through a spatial grid of reference climate and projected future climate. First, the available monthly climate data can be read and converted into a required format for subsequent calculations. Temporal interpolations can be used to transform the monthly data into daily estimates required for the characterization of the thermal and soil moisture regimes. The latter includes calculation of the reference potential and actual evapotranspiration through daily soil water balances.

Module I: Agro-climatic data analysis: Climate data analysis and compilation of general agro-climatic indicators

Module I calculates and stores climate-related variables and indicators for each grid cell. The module processes the spatial grid of reference climate, baseline and future climate projected to create layers of agro-climatic indicators relevant to plant production. First, the monthly data available on climate are read and become necessary variables for subsequent calculations. Temporary interpolations are used to transform the monthly data into daily estimates required for the characterization of the thermal and soil moisture regimes. The latter includes calculation of the reference potential and actual evapotranspiration through daily soil water balances. The characterization of the thermal regime generated in Module I includes periods of thermal growth, accumulated temperature sums (for the average daily temperature, respectively above 0˚C, 5˚C, and 10˚C), delimitation of permafrost zones and quantification of annual temperature profiles. Soil water balance calculations determine potential and actual evapotranspiration for a reference crop, the length of growth period days (LGD), including characterization of LGD quality, latency periods and cold brakes, and dates Start and end of one or more LGDs. Based on a subset of these indicators, a classification of multiple cropping zones is produced for irrigation and irrigation conditions.

Module II: Biomass and yield calculation: Crop-specific agro-climatic assessment and potential water-limited biomass/yield calculation

In Module II, all land utilization types (LUTs) are evaluated for biomass and limited yields in water. The concept of land use characterizes a range of subtypes within a plant species. It includes differences in the length of the crop cycle (i.e. days from sowing to harvest), growth and development parameters. Subtypes differ with the assumed level of inputs. For example, low-input varieties can be considered traditional crop varieties. It may have different qualities that are preferred but have low yield efficiencies (crop index). Due to management limitations, the crops are grown on relatively irregular plots and exhibit a lower leaf area index. In contrast, with high input levels, high-yielding varieties are deployed with advanced field management and machinery that provides optimum plant densities with high leaf area index. In module II, first, calculate the maximum achievable biomass and the yield that is determined by the radiation and temperature regimes. It also followed the calculation of the respective water balances of rain crops and the establishment of optimal crop calendars for each of these conditions. Crop water balances can be applied to estimate actual crop evapotranspiration, accumulated water deficit during the growing cycle (irrigation water requirements for irrigation conditions), and biomass and available yields for the rain-fed conditions. First, a time window is determined when the conditions permit the cultivation of LUT (e.g. predominant LGD in each grid cell). The growth of each LUT is tested for days during the allowable time window with a separate analysis for irrigation and rainfall conditions. The growth dates and the length of the cycle that produced the highest yield (limited or irrigated) define the optimal cultivation schedule of each LUT in each cell.

In addition, due to detailed calculations for a fairly large number of LUTs, Module II requires a considerable amount of computer time for processing and is the most demanding component of the CPU in the AEZ evaluation. The results of Module II include the maximum yields defined by temperature/ radiation defined by LUT, the yield reduction factors that represent the sub-optimal thermal conditions, the yield impacts due to soil water deficit, and the estimated amounts of water deficit soil, potential, and actual LUT evapotranspiration, and sums during each LUT crop cycle and optimal crop calendars.

Module III: Agro-climatic constraints: Yield reduction due to agro-climatic constraints

Module III calculates for each grid-cell-specific multiplier. The reduction of the yields of the various agro-climatic constraints is evaluated as defined in the AEZ methodology. This process is carried out in a separate module to make explicit the effect of constraints due to soil viability, pests and diseases and other constraints and allow timely reprocessing in case new or additional information becomes available. Five groups of agro-climatic restrictions are considered, including:

a) Yield adjustment due to year-to-year variability of soil moisture supply; this factor is applied to adjust yields calculated for average climatic conditions
b) Yield losses due to the effect of pests, diseases and weed constraints on crop growth
c) Yield losses due to water stress, pest and diseases constraints on yield components and yield formation of produce (e.g. affecting quality of produce)
d) Yield losses due to soil workability constraints (e.g. excessive wetness causing difficulties for harvesting and handling of produce)
e) Yield losses due to occurrence of early or late frosts

The agro-climatic restrictions are expressed as factors of reduction of yield according to the different restrictions and their severity for each crop and by the level of inputs. Due to the paucity of empirical data, estimates of restriction ratings have been obtained through expert opinion. At this stage, the results of agro-climatic suitability can be mapped for spatial verification and additional use in applications.

Module IV: Agro-edaphic constraints: Yield reduction due to soil and terrain limitations

This module evaluates the reduction of crop specific performance due to constraints imposed by soil and soil conditions. Soil suitability is determined on the basis of soil attributes data obtained from NBSS & LUP. Soil nutrient availability, soil nutrient retention capacity, soil rooting conditions, soil oxygen availability, soil toxicities, soil salinity and sodicity, and soil management constraints. The soil evaluation algorithm evaluates for soil types and slope classes the coincidence between the soil requirements of the crops and the respective qualities of the soil derived from the attributes of the soil. Thus, classification procedures result in a quantification of suitability for all combinations of crop types, entry level, soil types and slope classes.

Module V: Integration of climatic and edaphic evaluation: Agro-ecological suitability and potential yields

Module V executes the final step in the AEZ assessment. The specific LUT results of the agro-climatic evaluation for biomass and yield calculated in Module II/ III for different soil classes are read and the edaphic classification produced for each soil/ slope combination in Module IV is used. Soil resource inventories and slope-land conditions are integrated by ordering all soil types in each unit of the soil map with respect to the occurrence in different slope classes. Considering simultaneously the slope distribution of all mesh cells belonging to a particular unit of the soil map, an overall coherent distribution of soil-ground slope combinations is obtained by map units of individual soils and cells of 30-second arc grid for rainfall and irrigation conditions.

Cultivation activities are the most critical in soil erosion due to its dynamics and management. The land slope adequacy rating used in the AEZ study explains the factors that influence the sustainability of production and is achieved through: (i) the definition of permissible slope ranges for the cultivation of several crops/ LUT and the establishment of maximum limits of slope; (ii) for slopes within permissible limits, which explains the likely reduction in yield due to loss of fertilizer and higher soil; and (iii) to distinguish between a series of agricultural practices, from manual cultivation to fully mechanized cultivation. In addition, the degree of adequacy of the slope of the terrain varies according to the amount and distribution of precipitation, which is quantified in the AEZ study using the Fournier index. Application of the procedures in the modules described above results in expected yield and adequacy distribution with respect to irrigation and rainfall conditions for each 5-minute cell and each crop/ LUT. The adequacy of the soil is described in five classes: very adequate (VS), adequate (S), moderately adequate (MS), marginally adequate (mS) and unsuitable (NS) for each LUT. Large databases are created, which are used to obtain additional characterizations and aggregations. Examples include calculating land with crop potential, tabulating the results by ecosystem type, quantifying the risks of climate production using time series reference climate of suitability results, the impact of climate change on Crop production potentials and irrigation water requirements for current and future climates.

2.1.1 Description of Input Datasets

This section discuss data used for climate analysis as well as land and water resources.

Climate Data

For the AEZ assessment time series data are used from the University of East Anglia Climate Research Unit (CRU), the World Precipitation Climatology Center (GPCC) and the EU Integrated WATCH Project. Data sets from the Climate Research Unit (CRU) TS v3.21 (time series) were obtained from the British Atmospheric Data Center (BADC), which are month-to-month climate variations over the last century covering the period January 1901 through December 2012. The CRU TS v3.21 data are calculated in grids of 0.25x0.25 degrees. The CRU TS v3.21 variables used in the AEZ assessment v4 are the average daily temperature, daytime temperature range, cloud cover, vapor pressure and wet day frequency. For monthly precipitation, v6 of the full GPCC reanalysis product is used.

The data of CRU TS v3.21 and the complete re-analyze data product of GPCC v6 were downloaded and spatial interpolation was completed at 5-arc minutes resolution during the period 1981–2010. The daily data were obtained at a resolution of 0.5-degrees in the data repository of the Integrated Project WATCH and the precipitation distribution was calculated within the month and the deviation of the daily temperatures (minimum temperature, maximum temperature, and average daily temperature) of each month of the period 1981–2010. Annual mean temperature and precipitation data were extracted from the WorldClim 30-arc seconds raster databases (Hijmans et al. 2005). WorldClim is a set of global climatic layers with a spatial resolution of 30-arc seconds, which was obtained through interpolations of observed data and are representative of the period 1950–2000. For precipitation, Annual precipitation grids were calculated using the distribution of the WorldClim precipitation within one year of each 30-arc seconds cell scaled to the respective value of the Isohetical Map.

Climate Change Scenarios

The IPCC AR5 (IPCC 2013) climate model outputs for four Representative Concentration Pathways (RCPs) were used to characterize a range of possible future climate distortions for agro-climatic resources inventories and crop potential assessments for the time periods 2041–2070 (2050s) and 2071–2100 (2080s).

Considering the importance of the fundamental linkages between climate and socio-economic development, the climate change research community seeks to develop a new framework for the creation and use of scenarios to improve interdisciplinary analysis and assessments of climate change, their impacts and response options. To define a range of future scenarios, RCPs are combined with alternative paths of shared socioeconomic development (Moss et al. 2010). RCPs are a set of four greenhouse gas (non-emission) trajectories developed for the climate model community as the basis for long-term, short-term modeling experiments adopted by the IPCC for its fifth assessment report (AR5). RCP 4.5 bears the name of a possible level of radiative force values in the year 2100 (4.5 W/ m^2). The development of RCPs has been completed and these pathways are documented in a special issue of Climate Change (van Vuuren et al. 2011), and the simulations of climate models based on them were carried out as part of phase 5) (Taylor et al. 2011). Multiple model sets for each of the RCP climate forcing levels can be analyzed on the spatial data basis of the IPCC AR5 CMIP5 process, data bias correction and 0.25-degree scale reduction as used in the Inter-Sectoral Impact Model Inter-comparison Project (ISI-MIP) (Hempel et al. 2013). ISI-MIP data have been acquired at a resolution of 0.25-degrees of five climate models (ESM2M, HadGEM2, IPSL, MIROC, and NorESM) and for RCP 4.5 of ISI-MIP servers (a total of 20 combinations of RCP models and Climatic) and were used to generate input climate data in the AEZ v4 for 2041–2070.

For the analysis of the impacts of climate change on agricultural production potential, the available climatic predictions of the General Circulation Models (GCM) were used to characterize future climates. Results of the GCM model for individual climate attributes were processed to calculate the differences of the respective media for 2041–2070, with the GCM control climate for 1981–2010. An inverse distance interpolation was performed to a 30-minute arc grid in these "deltas" of the center points of each grid cell in the original GCM. The changes for monthly climate variables were applied to the observed reference climate (representing the period 1981–2010) to generate maximum, minimum and mean values of future climate data.

Soil and Land Data

New soil series 370 class and older soil series 144 class provided by National Bureau of Soil Survey and Land Use Planning (NBSS and LUP) ICAR-Nagpur were merged as some of the attributes were not available in the new series. Elevation data is acquired from National Remote Sensing Centre (NRSC), Hyderabad–ISRO. Cartosat-1 (Version-3R1) Satellite data is been used for DEM/ Elevation information. The accuracy of the vertical resolution is 1-arc second (~ 32 meters). Slope data is acquired from National Remote Sensing Centre (NRSC), Hyderabad–ISRO. Cartosat-1 (Version-3R1) Satellite data is been used for DEM/ Elevation information. The accuracy of the vertical resolution is 1-arc second (~ 32 meters). Using the elevation data and ArcMap software by Environmental System Research Institute (ESRI), slope is generated. LULC 2007–2008 is acquired from National Remote Sensing Centre (NRSC), Hyderabad–ISRO. It is classified using Resourcesat-1: AWiFS Ortho images at the spatial resolution of 56-meters. It was further resampled at 1-arc second. LULC 2011–2012, Resourcesat-1: LISS-III (Ortho) multispectral satellite images are acquired from National Remote Sensing Centre (NRSC), Hyderabad–ISRO and panchromatic layers of Landsat are acquired for Earth Explorer USGS. Further images processing and classification for LULC 2011–2012 is done at Institute of Rural Management Anand (IRMA), Anand. The spatial resolution of LISS-III (24-meters) image was brought to 15-meters after fusion with Landsat panchromatic data. It was further resampled at 1-arc second. Secondary data have been collected from Department of Soil Survey and Soil Conservation, Government of Kerala. Profiles showing similar characters within narrowly defined limits were grouped together into series. In mapping on the reconnaissance scale base map, it is unusual that areas large enough to delineate on the map would be dominantly one series. In most cases, it is found that more than one series occurs in a limited area mixed up in a manner which is difficult to distinguish in a scale of 1:50,000 mapping. So the mapping units were delineated as soil associations, i.e. the series occurring together in a regular repeating geographic pattern were grouped into an association. The soil association is named in accordance with two or three major series which occur in a region. This geographic association of soil series may contain several sharply contrasting soil types and phases. These maps were further processed and interpretative maps were prepared. The soil survey information which furnishes details of the soil series occurring in the area together with the soil analytical data enables classification of soil and land into land capability, land irrigability, soil conservation priority, and crop priority classes as well as soil taxonomic classes. This also helps in the rational planning of cropping patterns and soil management measures aimed at maximum production under varying conditions of the soil. The database generated will be useful for broad land use planning and agricultural development.

The AEZ assessment uses soil series group information for the Ur river watershed. A soil series group is the soil classification unit prepared by combining soils according to the soil series classification in Soil Taxonomy System that has similar physical and chemical characteristics and has similar utilization potential. There are total 12 soil series available in the watershed. The soil series information was stored as a 5-arc seconds raster in a Geographical Information System (GIS), which is linked to an attribute database containing representative soil profile data for a top-soil (assumed 0-30 cm) and a sub-soil layer (30-100 cm or less). Topography map prepared by ASTER data with 30-meters resolution with the help of ArcGIS software was used for input the AEZ model. Elevation of the area lies between the 200 to 400 meters. Geographically, the Ur River Watershed forms nearly the centre of the Bundelkhand region that lies between the Vindhyan plateau in the south and the great Ganga-Yamuna plains in the north. The highest peak in the south-west rises to 403 meters. This is situated near in the southern part of Tikamgarh tehsil. But there are several other spots in the western part of this area, with an elevation of around 380 to 400 meters. Slope map prepared by the NRIS data created by All India Land Use and Soil Survey was also used for input to the AEZ model. The slope of the watershed lies between 3 and 35 %. Therefore, Slope shows a large plain surface which is spread with local patches of a fairly sharp gradient. The sloping downwards from the elevated southwest to the lower northeast is very gentle. In general, the gradient remains below 3% throughout in this watershed. The LULC maps have been prepared through LISS-IV Satellite imagery having a 5.8-meters resolution. The two images of the different time period were used to quantify the Kharif land-use and Rabi land-use (Kharif season- 30-Sep-2012 and Rabi season- 4-Jan-2013). Unsupervised classification technique was used to prepare LULC mapping. Cultivation, forest, Rabi crop, Kharif crop, and LULC change detection maps were also prepared by this technique.

2.2 The Fuzzy Cognitive Mapping (FCM) Methodology

2.2.1 Assets Sensitivity and Adaptive Capacity: Fuzzy Cognitive Mapping (FCM) Approach

Fuzzy cognitive mapping (FCM) is a technique used to model, study and understand complex systems. It is an important tool that helps visualize how interrelated variables affect each other and represent feedback. FCM is very flexible in nature and caters to a broad spectrum of user groups. Both experts and local people who have a deep understanding of their system can make cognitive maps. The FCM approach is used to document the perceptions of communities about the direct and indirect impacts of variability and climate change on different livelihood assets. The FCM approach better captures the dynamics of a system (Singh and Nair 2014). It is a semi-quantitative model that captures cause-effect relationships such as the influence of climate and meteorological phenomena on certain aspects of ecosystems and humans (Özesmi and Özesmi 2004). FCM captures the operation of a complex system based on the perception of the people. Fuzzy cognitive maps are the product of local knowledge, valuable in complementing and supplementing scientific data, and easy to apply in poor data and complex environments, particularly where human behavior needs to be understood to understand complex problems (Papageorgiou and Kontogianni 2012; Singh and Nair 2014). Cognitive mapping has been used in numerous studies to examine people's perceptions of complex social systems (Roberts 1973; Bauer 1975; Malone 1975; Axelrod 1976; Bougon et al. 1977; Hart 1977; Rappaport 1979; Klein and Cooper 1982; Nakamura et al. 1982; Montazemi and Conrath

1986; Brown 1992; Carley and Palmquist 1992; Cosette and Audet 1992; Özesmi and Özesmi 2004; Amer et al. 2013; Singh and Nair 2014; Diniz et al. 2015; Singh and Chudasama 2017).

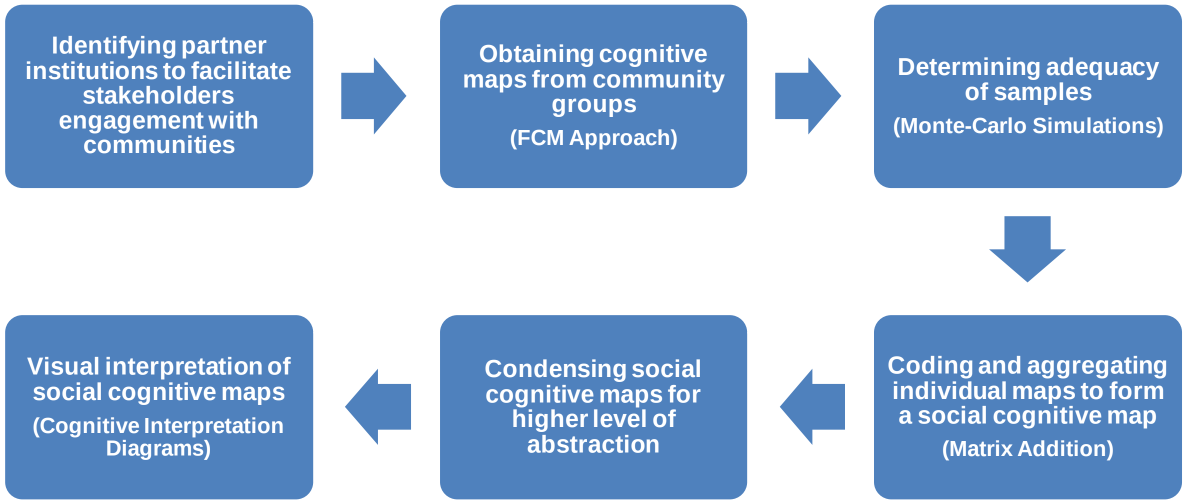


Figure 2.2: The methodological approach followed for the FCM study

The local community members, following the group discussion, were divided into groups of four to five individuals. These groups were formed based on simple wealth-ranking, wherein, the individuals with the same landholdings/ number of cattle were clubbed together. Besides, community groups were also segregated based on gender. Consensuses of the local community were obtained on changes in summer and winter temperatures, and precipitation in last few years. We chose about 10 years as the recall window for climate change having realized respondent's probable inability to accurately report climate variability of an earlier period.

We adopt a multi-step FCM approach as outlined by Özesmi and Özesmi (2004); Papageorgiou and Kontogianni (2012); Amer et al. (2013); Jetter and Kok (2014); Singh and Nair (2014); Diniz et al. (2015); and Singh and Chudasama (2017). The major steps involved in the FCM approach are:

i. ***Obtaining individual fuzzy cognitive maps from community groups:*** The community participants prepared cognitive maps for three central variables i.e. increased/decreased summer temperature, increased/decreased winter temperature, and increased rainfall variability, around which they established direct and indirect connections between the variables. Furthermore, the weights were given by stakeholders to each connection on the scale of 1–10, with 1 being minimum impact and 10 being the maximum impact.
ii. ***Determining adequacy of samples:*** An average accumulation curve of the total number of cognitive maps versus the number of new variables/ concepts added per cognitive map shows the manner in which the variables/ concepts had accumulated and determined the sample size (Özesmi and Özesmi 2004; Singh and Chudasama 2017).
iii. ***Coding Maps into Adjacency Matrices:*** Individual fuzzy cognitive maps were then coded into separate excel sheets with concepts listed in vertical and horizontal axes; these formed adjacency matrices. The values were coded into the square matrix when a connection existed between two concepts (Özesmi and Özesmi 2004; Singh and Nair 2014; Singh and Chudasama 2017).

iv. ***Aggregation of Individual Cognitive Maps:*** All individual fuzzy cognitive maps were aggregated through arithmetic mean at each interconnection of the adjacency matrix, and normalized to create an augmented matrix in order to obtain a social cognitive map that includes all concepts from the individual cognitive maps (Kosko 1988; Özesmi and Özesmi 2004; Singh and Nair 2014; Singh and Chudasama 2017).

v. ***Condensing Social Cognitive Map:*** Cognitive maps with a large number of concepts become counterproductive in terms of gaining insights. Therefore, in order to simplify and understand the structure of the complex maps concepts are condensed by replacing sub-groups with a single unit (Özesmi and Özesmi 2004; Singh and Nair 2014; Singh and Chudasama 2017).

vi. ***Visual Representation of Condensed Social Cognitive Map:*** The condensed social cognitive maps were analyzed using FCMapper software. Cognitive interpretive diagram (CID) was prepared using the visualization software Visone-2.16 (Singh and Nair 2014; Singh and Chudasama 2017).

The FCM approach shows communities perceptions' of climate-related impacts across diverse asset classes i.e. natural, human, financial, physical, and social assets. The assets sensitive to climate variability and change, and assets that serve as adaptive capacities were identified. It provides an overview of the concepts that affect people's livelihoods and the relationships among those concepts.

2.2.2 FCM Sampling

The below table shows general sampling plan for the areas chosen for the FCM study.

Table 2.1: Overview of the FCM sampling and communities' participation

Number of Districts covered	3
Number of Villages covered	25
Number of male groups interviewed	142
Number of female groups interviewed	62
Total number of community groups interviewed	204
Number of fuzzy cognitive maps drawn	358
Number of community respondents	1265 (approx.)

We obtained 36 fuzzy cognitive maps for the summer, winter, and rainfall seasons from Surendranagar district to conduct a case study on micro-irrigation. Of the total, 25 and 11 maps were constructed by groups of men and women respectively. The chief livelihoods of the farmers in the district are agriculture and livestock rearing. We obtained 41 fuzzy cognitive maps for the summer, winter, and rainfall seasons from Mahesana district to conduct a case study on water budgeting. Of the total, 33 and 8 maps were constructed by groups of men and women respectively. We obtained 34 fuzzy cognitive maps for the summer, winter, and rainfall seasons from Mahesana district to conduct a case study on participatory irrigation management (PIM). Of the total, 25 and 9 maps were constructed by groups of men and women respectively. The participants interviewed in Mahesana were engaged in different livelihoods, ranging from agriculture to livestock rearing. From the Valsad district, 95 fuzzy cognitive maps were obtained from the wadi farmers, landless workers working in the wadi, and people involved in the value chain and entrepreneurs. The stakeholders depend mainly on fruit and vegetable production such as mango and cashew, and it is enterprising.

2.3 Soil Nutrient Balance Methodology

The assessments for soil nutrient flow were carried out to evaluate the soil fertility status and nutrient balance/ budgeting of major crops/ cropping systems at different spatial scales (plot, farm, and district level) in Kerala. Several field experiments were conducted during 2013 at CWRDM, Kozhikode farm campus. Cultural and management practices were followed according to the recommendations of the Kerala Agricultural University Practices Package. The soil nutrient monitoring exercise was carried out using "NUTMON-Toolbox" (Vlaming et al. 2001; Surendran et al. 2007). It is an integrated multidisciplinary methodology that aims at different actors in the process of managing natural resources in general and soil nutrients in particular. Using the NUTMON-Toolbox, researchers can analyze the environmental and financial sustainability of agricultural systems, which can help raise awareness among policy makers. The applied fertilizer dose was 70:25:25 kg of N, P_2O_5, and K_2O, respectively. Post-harvest initial soils and plant products were analyzed in the experimental field crops for their physico-chemical properties. Nutrient analysis was limited to N, P, and K only using the standard analytical procedures mentioned in Annex I and was used to calculate nutrient exports using the model.

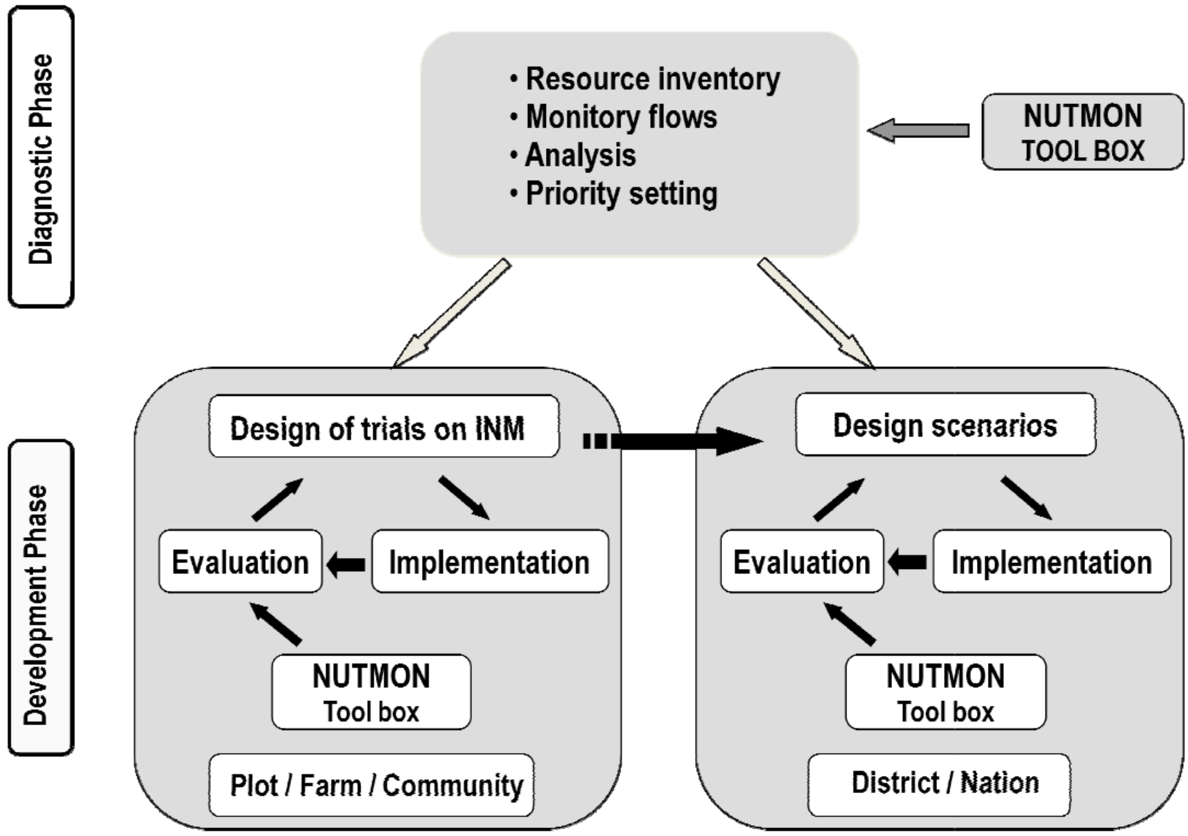


Figure 2.3: Soil nutrient budgeting/ balance methodology

The NUTMON-Toolbox aims at quantification of nutrient flows, nutrient stocks and economic performance indicators for farms. However, the complexity of farms usually does not allow for quantification of all flows and stocks, thus necessitating simplification. This framework simplifies reality to the extent that major nutrient flows and pools were included and minor flows and pools were neglected. Farm-NUTMON is a tool encompassing a structured questionnaire, a database, and two simple static models (NUTCAL for calculation of nutrient flows and the ECCAL for calculation of economic parameters). Finally, a user-interface facilitates data entry and extraction of data from the database to produce input for both models. The tool calculates flows and balances of the macro-nutrients N, P, and K through independent assessment of major inputs and outputs using the following equation:

Net soil nutrient balance = S *(Nutrient INPUTS)* - S *(Nutrient OUTPUTS)*

This is based on a set of five inflows (IN 1-5 mineral fertilizer, organic inputs, atmospheric deposition, biological nitrogen fixation and sedimentation), five outflows (OUT1-5 farm products, other organic outputs, leaching, gaseous losses, erosion, and human excreta), and six internal flows (consumption of external feeds, household waste, crop residues, grazing, animal manure, and home consumption of farm products).

Chapter 3: Spatial and Temporal Patterns of Climate, Soil, Land, Forest, and Water Conditions

3.1 Spatial and Temporal Patterns of Climatic Parameters

Climatic variables were prepared for the use in the AEZ assessment through spatial and temporal interpolations. Temporal interpolations of the gridded monthly climatic variables into daily data provides the basis for the calculation of soil water balances and agro-climatic indicators relevant to crop production.

3.1.1 Annual Mean Temperature (˚C)

Table 3.1 shows annual mean temperatures (˚C) for the reference climate (1981–2010) and temperature projections for different RCPs (2.6, 4.5, 6.0, and 8.5) during the periods 2050s (2041–2070) and 2080s (2071–2100) for the State of Gujarat, and Kozhikode and Tikamgarh districts. The annual mean temperature in Gujarat for the reference climate is 27.1˚C. The projection for different RCPs (2.6, 4.5, 6.0, and 8.5) shows a rise in temperature in the whole Gujarat. The projection for period 2050s illustrates a rise in temperature from 1.3 to 2.7˚C, and projection for period 2080s shows a rise from 1.3 to 4.6˚C. The annual mean temperature in Kozhikode district for the reference period is 27.2˚C. The projection for different RCPs shows a rise in temperature in the district. The projection for period 2050s illustrates a rise in temperature from 0.9 to 1.9˚C, and projection for period 2080s shows a rise from 0.9 to 3.4˚C. The annual mean temperature in Tikamgarh district for the reference period is 25.6˚C. The projection for different RCPs shows a rise in temperature in the district. The projection for period 2050s illustrates a rise in temperature from 1.2 to 2.6˚C, and projection for period 2080s shows a rise from 1.2 to 4.6˚C.

Table 3.1: Annual mean temperature (˚C) for reference climate (1981–2010) and projections for future climate scenarios during 2050s (2041–2070) and 2080s (2071–2100) for the study areas

Study areas	Temperature (˚C) during reference climate* (1981–2010)	**E-Mean of temperature projections during 2050s (˚C)				**E-Mean of temperature projections during 2080s (˚C)			
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Gujarat	27.1	28.4	28.8	28.8	29.6	28.4	28.4	28.8	31.4
Kozhikode	27.2	28.1	28.0	28.4	29.1	28.1	28.9	29.2	30.6
Tikamgarh	25.6	26.8	27.5	27.2	28.2	26.8	28.0	28.2	30.2

*Reference climate (CRUTS32: 1981–2010); **E-Mean: Ensemble mean-ESM2M of all five models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) are taken into consideration to avoid extreme variations in the result.

3.1.2 Annual Mean Precipitation (mm)

Table 3.2 shows annual mean precipitation (mm) for the reference climate (1981–2010) and projections of precipitation for different RCPs (2.6, 4.5, 6.0, and 8.5) during the periods 2050s

(2041–2070) and 2080s (2071–2100) for the State of Gujarat, and Kozhikode and Tikamgarh districts. The annual mean precipitation in Gujarat for the reference climate is 933 mm. the projection for different RCPs (2.6, 4.5, 6.0, and 8.5) shows a rise in precipitation in the whole Gujarat. The projection for period 2050s illustrates a rise in precipitation from 76 to 110 mm, and projection for period 2080s shows a rise from 70 to 186 mm. The annual mean precipitation in Kozhikode district for the reference period is 3211 mm. The projection for different shows a rise in precipitation in the district. The projection for period 2050s illustrates a rise in precipitation from 68 to 213 mm, and projection for period 2080s shows a rise from 86 to 369 mm. The annual mean precipitation in Tikamgarh district for the reference period is 910 mm. The projection for different RCPs shows a rise in precipitation in the district. The projection for period 2050s illustrates a rise in precipitation from 172 to 245 mm, and projection for period 2080s shows a rise from 180 to 290 mm.

Table 3.2: Annual mean precipitation (mm) for reference climate (1981–2010) and projections for future climate scenarios during 2050s (2041–2070) and 2080s (2071–2100) for the study areas

Study areas	**Precipitation (mm) during reference climate* (1981–2010)**	****E-Mean of precipitation projections during 2050s (mm)**				****E-Mean of precipitation projections during 2080s (mm)**			
		RCP 2.6	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**	**RCP 2.6**	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**
Gujarat	933	1009	985	968	1043	1003	1073	1095	1119
Kozhikode	3211	3312	3315	3279	3424	3297	3478	3384	3580
Tikamgarh	910	1155	1082	1097	1137	1090	1180	1200	1180

*Reference climate (CRUTS32: 1981–2010); **E-Mean: Ensemble mean-ESM2M of all five models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) are taken into consideration to avoid extreme variations in the result.

3.2 Spatial Patterns of Soil, Land, Forest, and Water Resources

3.2.1 Spatial Patterns of Soil

The soil is the outermost layer of the surface of the soil on which the plants grow. It consists of eroded rock, mineral nutrients, decaying plants, animal matter, water and air. This abiotic factor is equally important in crop agriculture and is treated under the heading of adaptation to soil and climate or crop requirements. Most plants are terrestrial in that they are anchored to the ground through their roots, with which they absorb water and nutrients. But epiphytes and floating hydrophills do not need soil to live. Variations in the physical, chemical, and biological properties of the soil have different effects on the growth and development of plants, depending on the natural adaptation. There are two soil properties that have pronounced direct effects on plant growth and crop production: physical and chemical properties. There are also biological factors or living organisms in the soil such as earthworms, insects, nematodes, and micro-organisms such as bacteria, fungi, actinomycetes, algae, and protozoa. These organisms help to improve soil structure, slope, aeration, water permeability, and soil nutrient availability. The physical and chemical properties of the soil are called edaphic factors of the plant medium. Physical properties include soil texture, soil structure, and bulk density that affect the soil's ability to retain and supply water, while chemical properties consist of soil pH and cation exchange capacity that determines its capacity to supply nutrients. It is now known that this abiotic factor (soil) is not essential for the growth of plants. Rather, it is the nutrients that are present in the soil that makes the plants grow and allow them to complete their life cycle. Soil is one of the basic components that support agriculture. They are the main raw materials from which food is produced (Simpson 1983). Unlike the raw materials of most industries, it can be used again year after year, century after century. Soils have more meaning for mankind than as habitat for cultivation (Brady 1970). The foundations of the house, the factories, and the large structures depend on the lower part of the ground on which it is built. They are used as beds for roads and highways and have influence on the length and life of these structures. In rural areas, soils are often used to absorb household waste through septic sewer systems. Soil also plays an important role in carbon sequestration.

Climate Change and Soil

The increase in the concentration of greenhouse gases in the atmosphere and its effects on global warming is currently one of the most debated issues. Reducing atmospheric carbon dioxide (CO_2) can be achieved by reducing emissions or by removing CO_2 from the atmosphere. One of the key strategies for reducing the concentration of greenhouse gases in the atmosphere is the application of terrestrial ecosystems as a carbon sink. The soil is the second largest carbon sink after the oceans. Depending on local conditions, the soil is both a source and sink of greenhouse gases. This balance between the sink and the function of the source is very delicate. Depending on the region, climate change could result in more carbon stored in plants and soil due to vegetation growth, or more carbon released into the atmosphere. The soil not only contains twice as much carbon in the world as the atmosphere, the CO_2 flux between the soil and the atmosphere is also large and is estimated at 10 times the carbon dioxide flow of fossil fuels. Soil types stored in water and permafrost have large carbon stocks but are also important emitters of methane (CH_4) and nitrous oxide (N_2O). After all, when plants photosynthesize, they extract carbon from the atmosphere. But atmospheric carbon also affects the soil, since the carbon that is not used for the growth of plants on the ground is distributed through the roots of a plant that deposits carbon in the soil. If not altered, this carbon can stabilize and remain for thousands of years. Healthy soils can thus mitigate climate change. Sustainable land use and restoration of key ecosystems can help us mitigate and adapt to climate change.

Climate change is often seen as occurring in the atmosphere. Rising temperatures can lead to increased vegetation growth and more carbon stored in the soil. However, higher temperatures could also increase the decomposition and mineralization of organic matter in the soil, reducing the organic carbon content. In other areas, carbon-containing organic matter in stable peatland is prevented from decomposing due to the low levels of oxygen in the water. If these areas dry out, organic matter can break quickly, releasing carbon dioxide (CO_2) into the atmosphere. Increasing the concentration of carbon dioxide in the atmosphere can cause microbes in the soil to work faster to break down organic matter, potentially releasing more carbon dioxide. Although it is not clear what the overall effect will be, as different regions absorb and emit different levels of greenhouse gases. But there is a clear risk that a warming climate can lead the soil to release more greenhouse gases, which can further heat the climate in a self-reinforcing spiral. If managed properly, soil can help us reduce greenhouse gases and adapt to the worst effects of climate change. But if we stop caring for the soil, we can quickly exacerbate problems related to climate change.

I. Soil Units/ Series/ Groups

Saurashtra contains a major area of calcaro-vertic cambisols and a small area of eutric cambisol, calcaric cambisol and vertic cambisol. All these fall under the soil group of cambisol. It is a brown colored soil and the horizon starting between 25 and 100 cm below the soil surface. Cambisols are medium textured and have a good structural stability, high porosity, good water holding capacity, and good internal damage (FAO 2001). It is suitable for the production of food and oil crops. The major crops cultivated in these soils are groundnut, cotton, wheat, and sesame. North Gujarat contains a major area of calcaric cambisols and a small area of eutriccambisols, vertic cambisols, calcaric regosols. The major crops suitable for this area are groundnut, cotton, wheat, mustard, castor, pearl millet, and maize. Central Gujarat contains eutric Fluvisols, calcaric cambisols, calcaro-vertic cambisols, calcaric fluvisols. Fluvisols are the soil developed in periodically flooded areas of the alluvial plain. They are highly fertile soil. It is generally found along Mahi flood plain in central Gujarat. Major crops suitable for these crops are rice, wheat, maize, cotton, tobacco, millet, lentils, and gram. Eutric Cambisols are the dominant soil in the southern Gujarat followed by eutric vertisols. Other types of soil which are present in small areas are calcaric Fluvisols, vertic cambisols, calcaric cambisols, and calcaro-vertic cambisols. Vertisols are the products of rock weathering that have the characteristics of smectitic clay. It is very hard in dry season and is sticky in the wet season. Tillage is difficult in this soil. Vertisols can be productive if managed well. Crops suitable for these soils are cotton, rice, sugarcane, and groundnut. Kutch region contains large area under calcaric cambisols. Other soils like calcic vertic solonetz, eutric cambisols, and calcaric regosols are found in small areas in Kutch. Crops like cotton, groundnut, green gram, and castor are suitable for these soils.

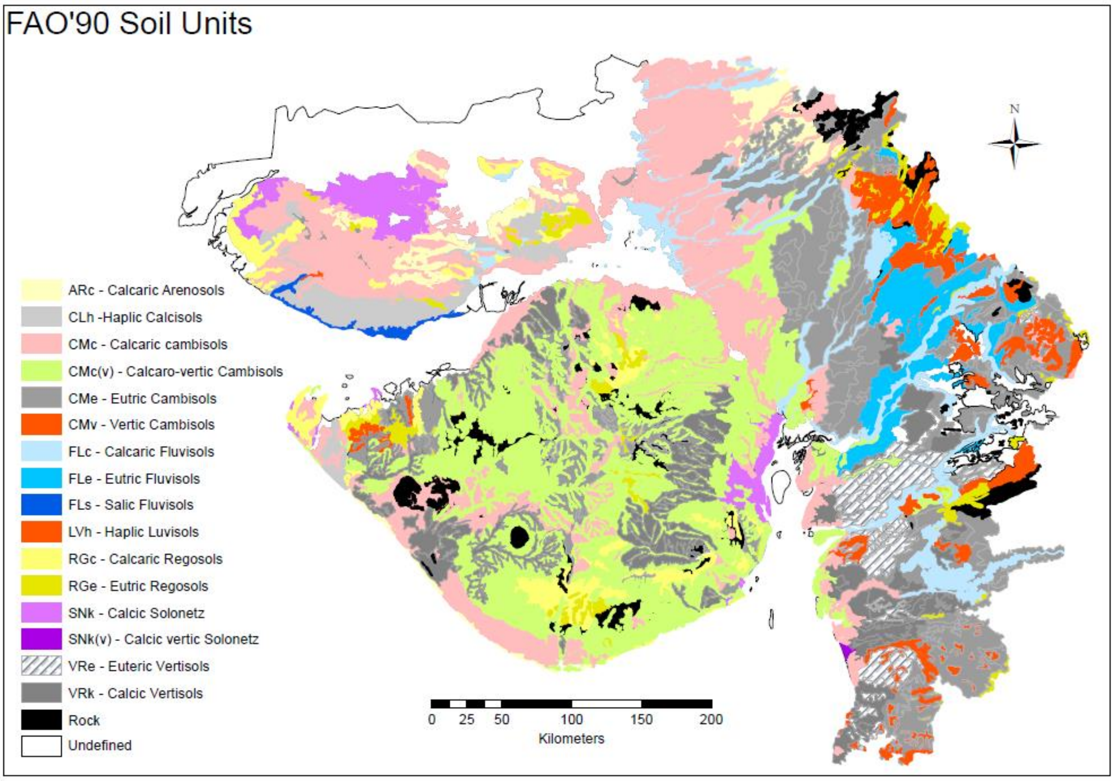


Figure 3.1: FAO'90 soil units map of Gujarat

Soils encountered in Kozhikode district are the result of complex geologic processes accelerated by luxuriant rainfall and vegetation. Since the area was subjected to prolonged periods of erosion and deposition different types of soils are formed. Twenty-six soil series are identified in different physiographic positions of Kozhikode district. These soil series are grouped into 18 soil associations. Secondary data have been collected from Department of Soil Survey and Soil Conservation, Government of Kerala. Profiles showing similar characters within narrowly defined limits were grouped together into series. In mapping on the reconnaissance scale base map, it is unusual that areas large enough to delineate on the map would be dominantly one series. The soil association is named in accordance with two or three major series which occur in a region. This geographic association of soil series may contain several sharply contrasting soil types and phases. These maps were further processed and interpretative maps were prepared. The soil survey information which furnishes details of the soil series occurring in the area together with the soil analytical data enables classification of soil and land into land capability, land irrigability, soil conservation priority and crop priority classes as well as soil taxonomic classes. This also helps in the rational planning of cropping patterns and soil management measures aimed at maximum production under varying conditions of the soil. The database generated will be useful for broad land use planning and agricultural development.

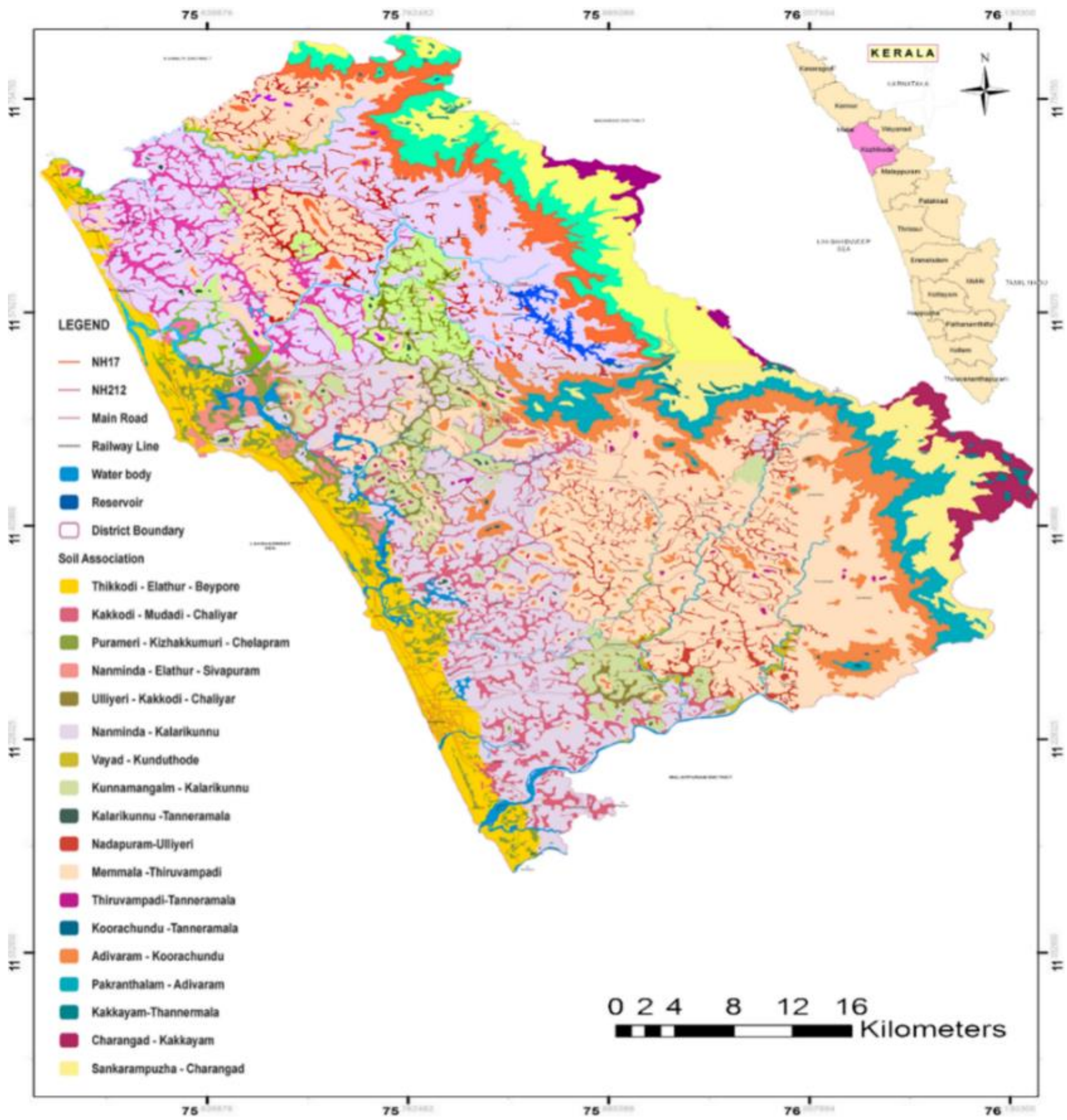


Figure 3.2: Soil series map for Kozhikode district (showing 18 soil groups)

The AEZ analysis uses a soil series group information for the Ur River watershed. A soil series group is the soil classification unit prepared by combining soils according to the soil series classification in Soil Taxonomy System that has similar physical and chemical characteristics and has similar utilization potential. There are total 13 soil series available in the watershed. The soil series information was stored as a 5-arc second raster in a GIS, which is linked to an attribute database containing representative soil profile data for a top-soil (assumed 0-30 cm) and a sub-soil layer (30-100 cm or less).

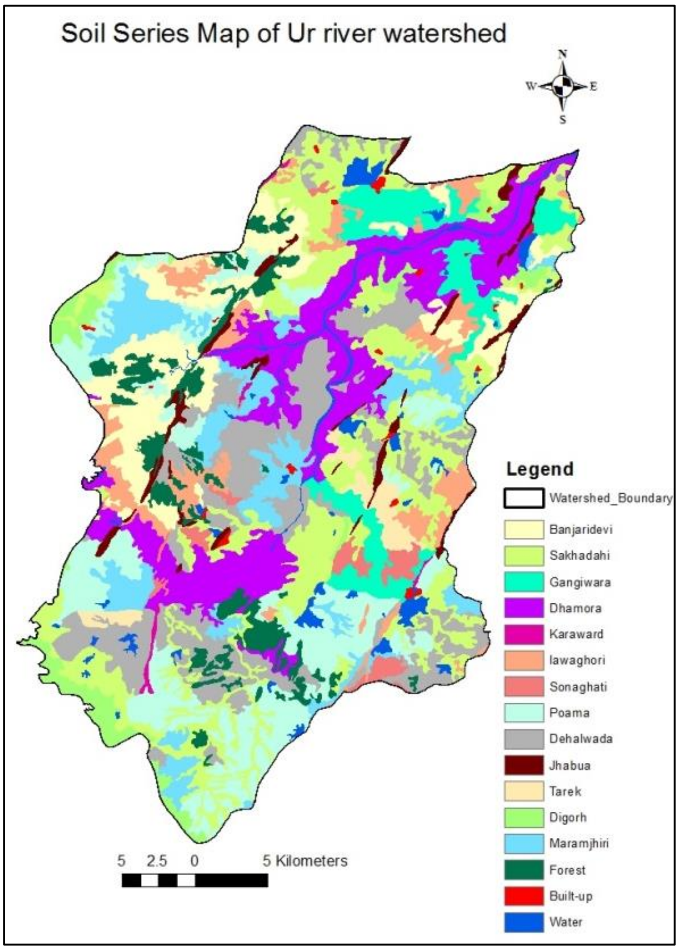


Figure 3.3: Soil series of the Ur River Watershed

II. Soil Texture

Soil texture is one of the most important physical properties of soils. Soil texture is related to a number of important soil characteristics, such as water retention capacity, soil drainage, and soil fertility. Most of the soils in southern Gujarat are made up of clay except for parts of southeast Gujarat, where sandal clay and clay are found. The central part of Gujarat contains sandy silt, sandy loam, clay loam and sandy clay. Clay soil is the main soil in Saurashtra, while sandy clay, clayey silt, is confined mainly to the coastal region of Saurashtra. The northern part of Gujarat contains sandy silt, sandy loam, clayey clay soil, and sand. The Kutch region consists of sandy clay, silty sandy clay, sand, silty clay, loam, and clay.

This Characterization is consistent with the evolution of the soils of the Ur River watershed through a slow erosion of hard massive granites. Corresponding to their placement in the Entisols and Inceptisols, the soils in this area mostly have a fine sandy texture. Nearly 635 km^2 of the area is covered by sandy loams and another 266 km^2 by sandy-clay-loams. There are small patches of silty-clay loam covering only about 32 km^2 of area.

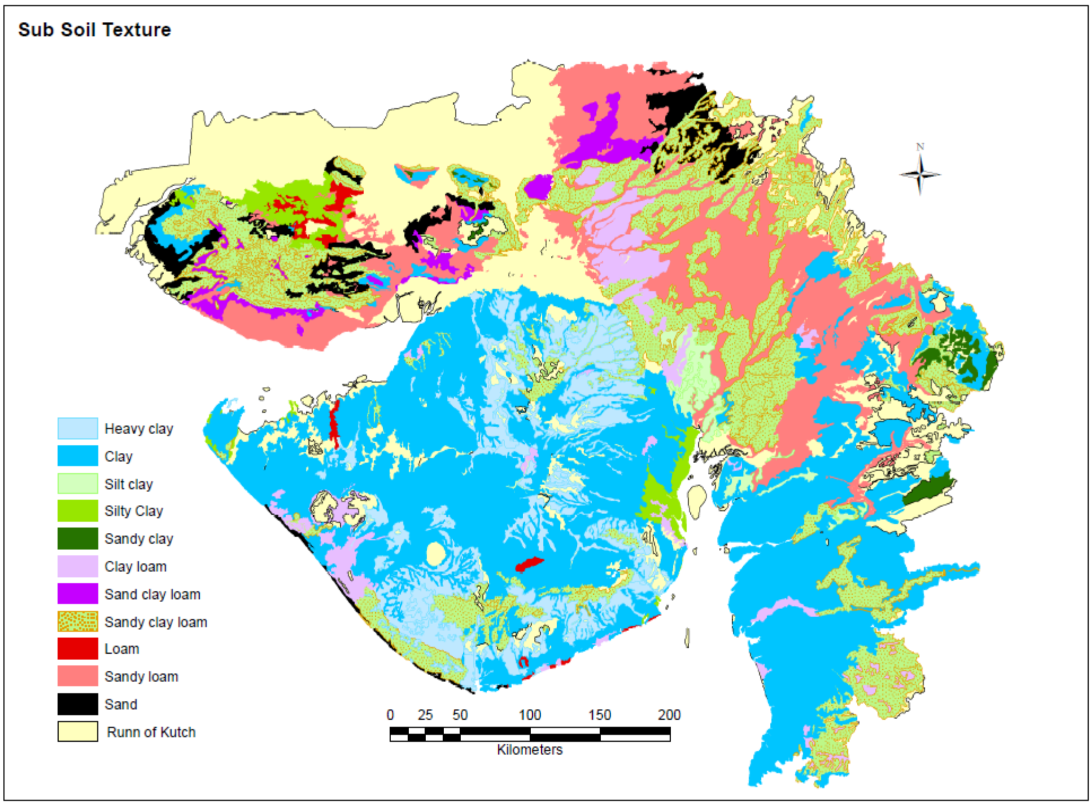


Figure 3.4: Soil texture map of Gujarat

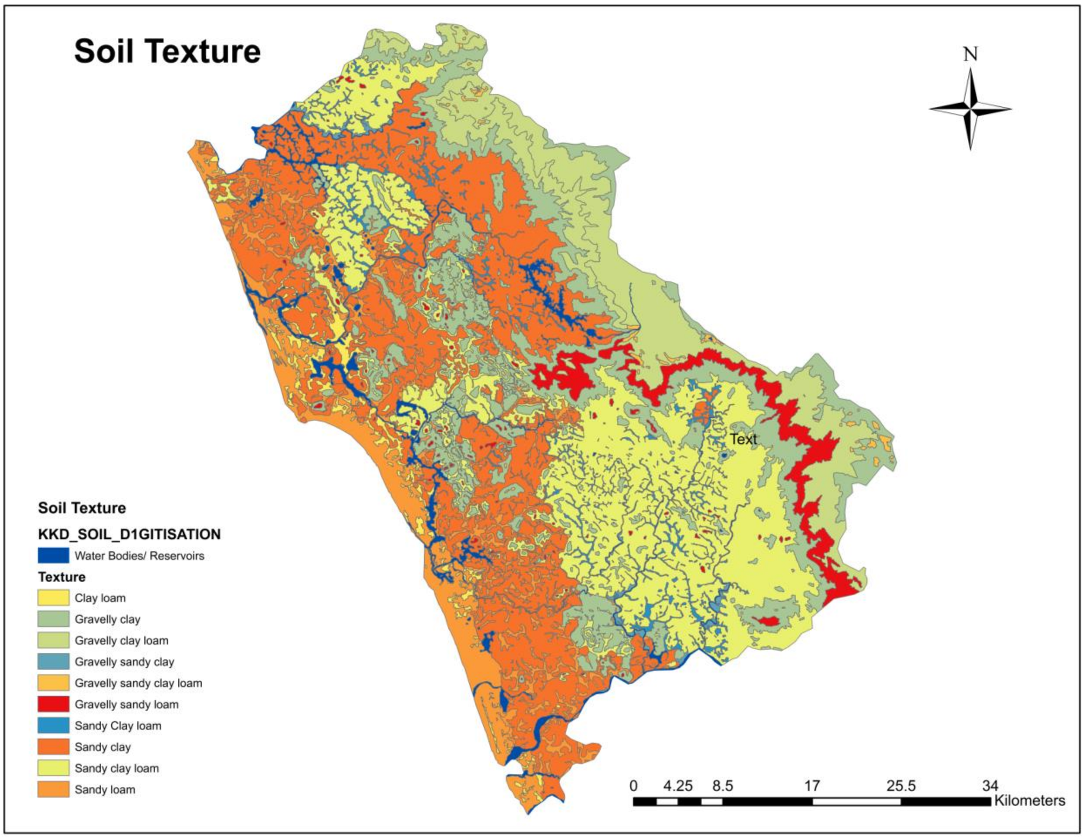


Figure 3.5. Soil texture map of Kozhikode district

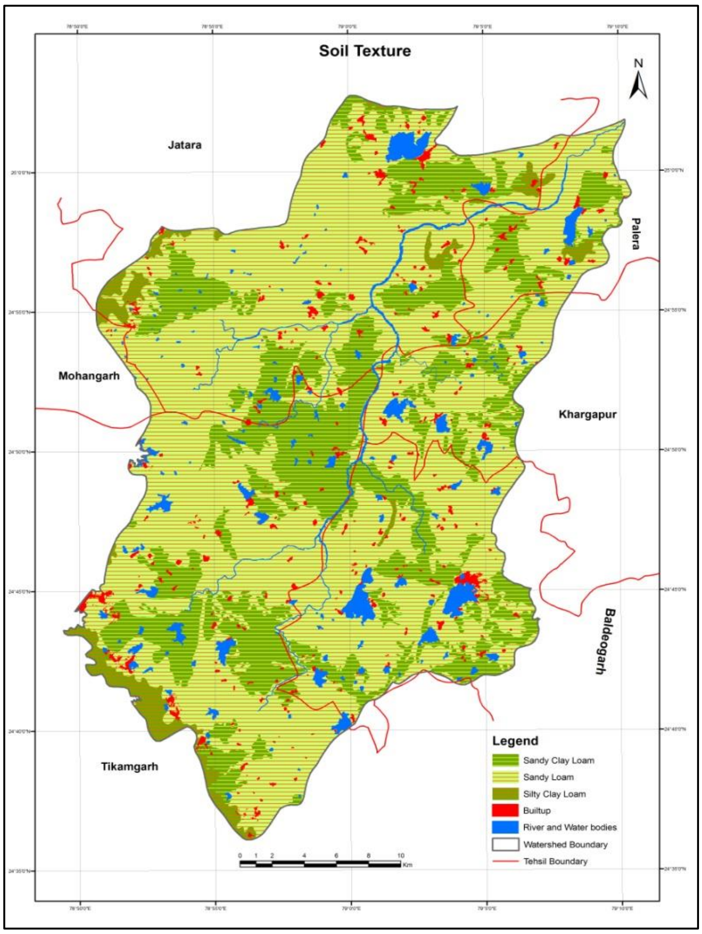


Figure 3.6: Soil texture map of the Ur River Watershed

III. Soil Salinity

Soil salinity is an important factor affecting soil health and crop productivity. Saline soils are mainly found on lands that are subject to salt water flood during part or all year and on lands where groundwater is to some extent saline. Most saline soils are present in western Kutch, western and eastern part of Saurashtra, and the coastal region of southern Gujarat, the eastern part of central and northern Gujarat. The inadequate drainage resulting in the falling and rise in groundwater tables as a consequence of canal irrigation is the main cause of the interior salinity of the soil in the delta areas along the west and south coast of Saurashtra, Mahi in central Gujarat and eastern region of southern Gujarat. Invasion of salt water and inadequate drainage also affect soil salinity in the coastal districts of Surat, Bharuch, and Valsad.

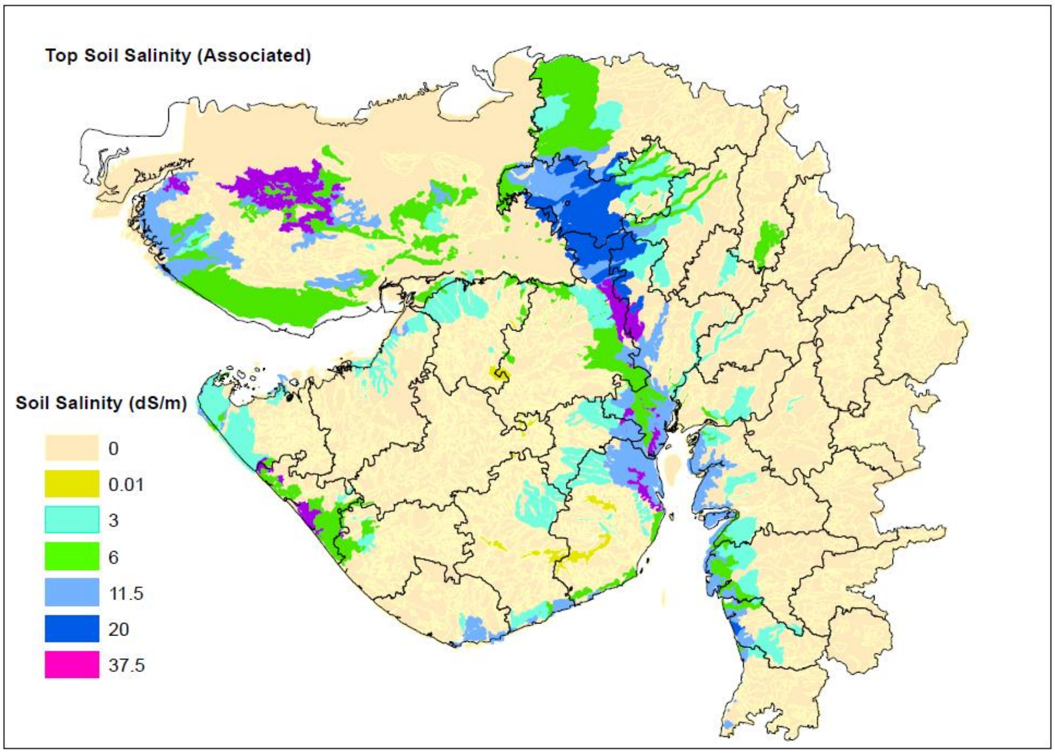


Figure 3.7: Soil salinity map of Gujarat

IV. Soil Depth

Soil depth plays a key role in crop yield of annual crops, as well as perennials, plant growth and yield. The effective depth of a soil for plant growth is the vertical distance in the soil from the surface to a layer that essentially stops downward growth of the roots of plants. The barrier layer may be rock, sand, gravel, heavy clay, or a cemented layer. Deep soils may contain more nutrients and plant water than surface soils with similar textures. Soil depth and nutrient and water capacity often determine the yield of a crop, particularly annual crops are grown with little or no irrigation. Plants growing on shallow soils also have less mechanical support than those growing on deep soils. Trees growing on shallow soils are more susceptible to wind blowing than those growing on deep soils. The depth of the soil that has deep to very deep is the predominant soil in the north and the south of Gujarat with some exception in an eastern region of the north and south of Gujarat. In Kutch, deep soils are found in the coastal region. In rain-fed agriculture, deep to very deep soil plays an important role, as it has better moisture storage capacity. This type of soil supports medium to deep root crops. Long-term crops favor this soil. The surface soil is confined in the eastern north and south of Gujarat, the central region of Saurashtra, where it is the predominant soil and the eastern region of Kutch. Cultures with a shallow root system and short-term harvest time are favored in this soil. Some forage crops can be grown on shallow soils because their root depth is shallow. Using the spatial data generated it was found that most of the soils falling under this watershed area have a maximum depth of around 54 cm. Such soils cover nearly 250 km^2 of the watershed. Another about 271 km^2 is under soils of 25-50 cm. About 612 km^2 is under the soil of depth under 60 cm. About 108 km^2 is under soils of depth less than 10 cm. Such shallow soils are mostly in hilly and stony areas.

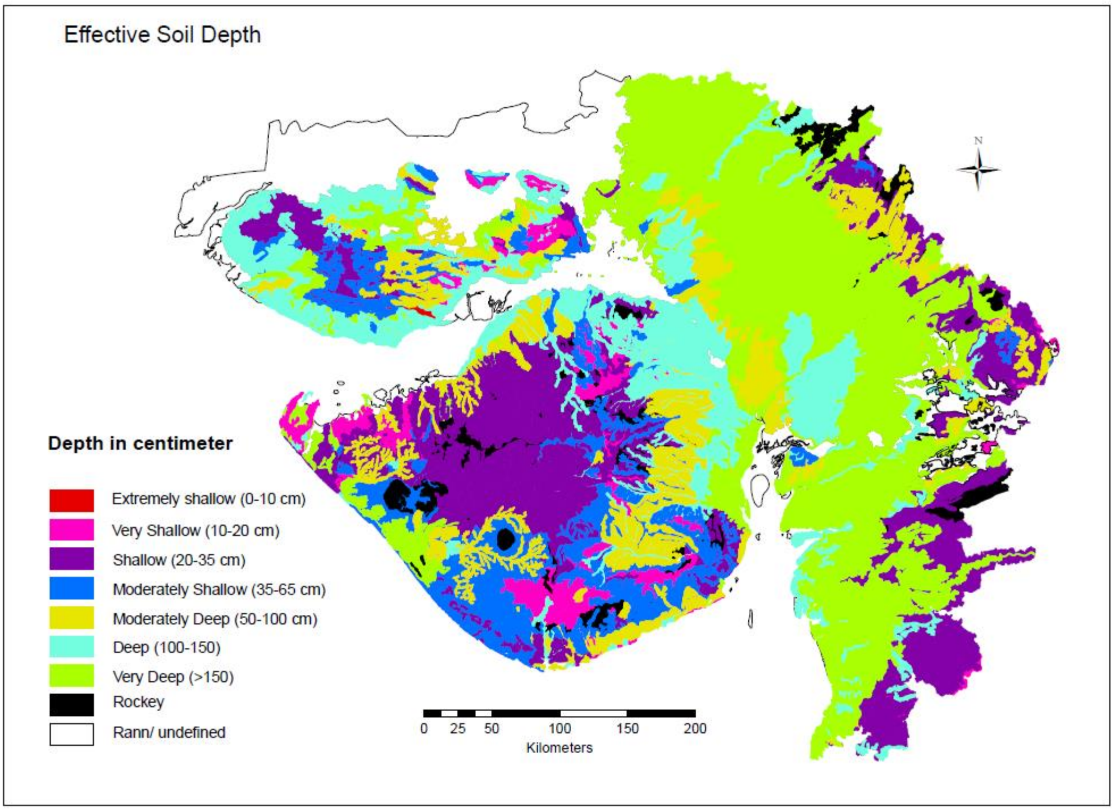


Figure 3.8: Soil depth map of Gujarat

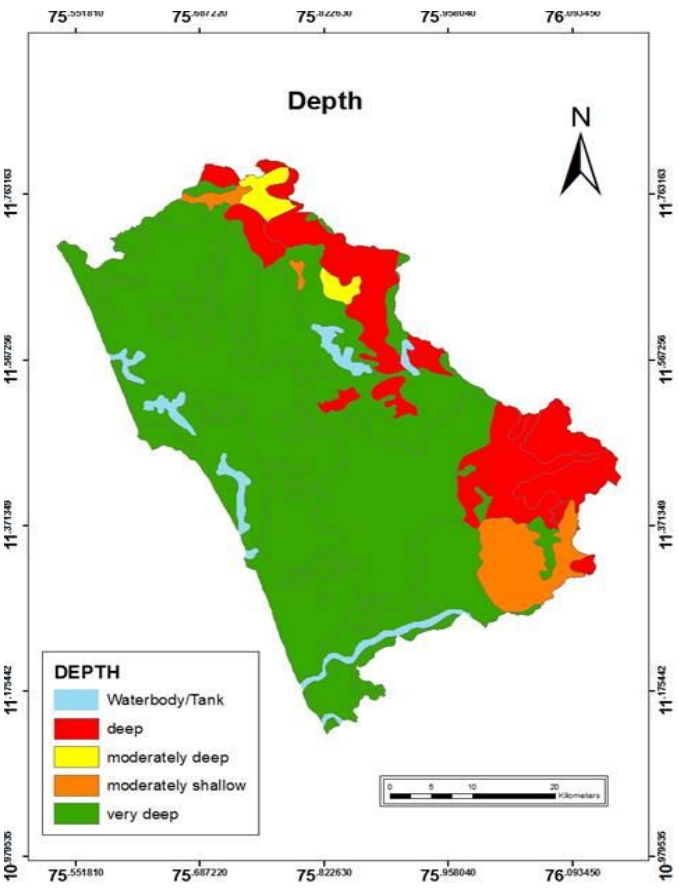


Figure 3.9: Soil depth map of Kozhikode district

Using the spatial data generated it was found that most of the soils falling under this watershed area have a maximum depth of around 54 cm. Such soils cover nearly 250 km^2 of the watershed. Another about 271 km^2 is under soils of 25-50 cm. About 612 km^2 is under the soil of depth under 60 cm. About 108 km^2 is under soils of depth less than 10 cm. Such shallow soils are mostly in hilly and stony areas.

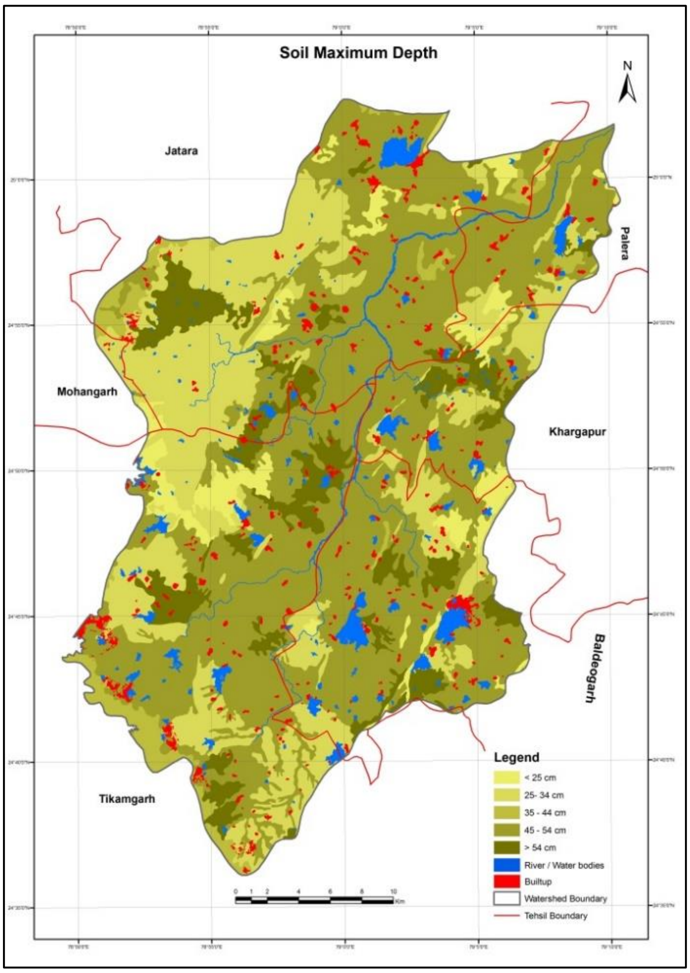


Figure 3.10: Soil depth map of the Ur River Watershed

V. Soil pH

The soil pH is a measure of soil acidity, neutrality or basicity. Gujarat soil pH values range from 6 to 10. Both extremes pose some limitations to crop production. The soil pH release substances extremes of soils that can be toxic to plants. Acidic soils can dissolve toxic amounts of metals such as aluminum and manganese. Alkaline soils can accumulate sodium salts and carbonates in toxic concentrations that can alter the soil structure, making it difficult to grow the root of the plant. Stunted root systems have difficulties while absorbing adequate water and nutrients. Toxic metals in acid or subsoil soils are responsible for the depletion of nutrients. Clay pans also prevent root growth. Slightly acid soils (pH 6.5) are considered more favorable for total nutrient absorption. Such soils are also optimal for nitrogen fixing legumes and soil nitrogen fixing bacteria. Some plants adapt to acidic or basic soils due to the natural selection of species under these conditions. Potatoes grow well on soils with pH < 5.5, while cotton, pea, and many herbs grow well on alkaline soils (> 7.5 pH). The soil pH also affects the soil in other ways. For example, the microbial activity of the soil; In particular nitrogen-fixing bacteria can be reduced in acid soils. Sodium soil (> 8.5 pH) is mainly limited to the coastal region of Kutch and Kutch central, north and eastern part of northern Gujarat, a part of the central and eastern part of central Gujarat, eastern and western parts of southern Gujarat And central Saurashtra. Acid soils are found in southern Gujarat, the central part of the Kutch region, and western part of central Gujarat. The soil with pH between 7 and 8 is predominant in Gujarat.

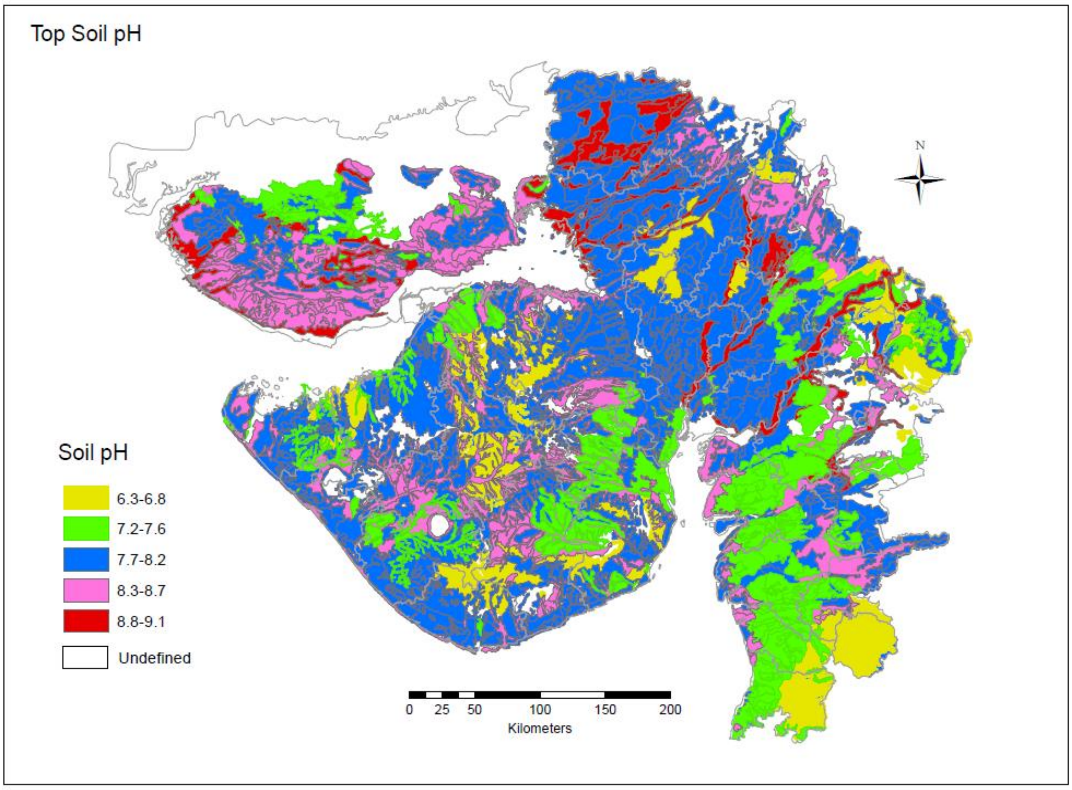


Figure 3.11: Soil pH map of Gujarat

Soils of this humid tropical district are naturally acidic in reaction due to the intense leaching conditions and the consequent loss of basic cations. The primary cause for the development of strong acid soils in the district is management practices by the farmers such as the application of heavy input of acidic fertilizers without regular application of lime to neutralize the acidity generated apart from the climatic conditions. Soil acidification has assumed serious proportion in the district with more than 95% of soil samples tested showed acidic in reaction, out of which more than 50% falls under the class of very strong to extremely acidic in reaction pH (< 5.5). Application of liming materials based on soil test results are essential to improve the crop productivity and in the absence blanket recommendation of 600 kg lime per hectare is recommended.

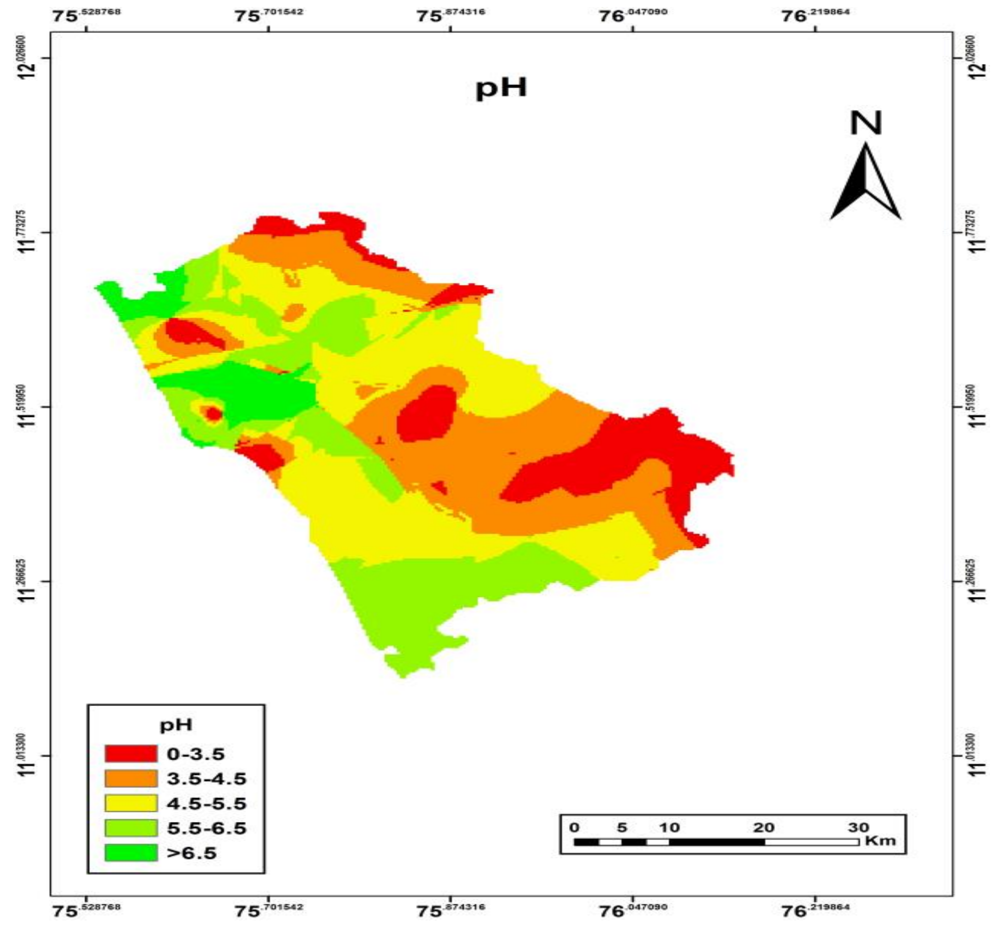


Figure 3.12: Soil pH map of Kozhikode district

The soil pH is a measure of the alkalinity or acidity of the soil. The soil pH is measured on a logarithmic scale from 0 (strongest acid) to 14 (strongest alkali or base), neutral is 7, slightly acid is considered to be 5.2 to 6.0, moderately acid 5.6 to 6.0, strongly acid 5.1 to 5.5, very strongly acid 4.5 to 5.0, and extremely acid below 4.5. Plants need a proper balance of macro and micronutrients in the soil and the soil pH has an important influence on the availability of nutrients and on the growth of different kinds of plants.

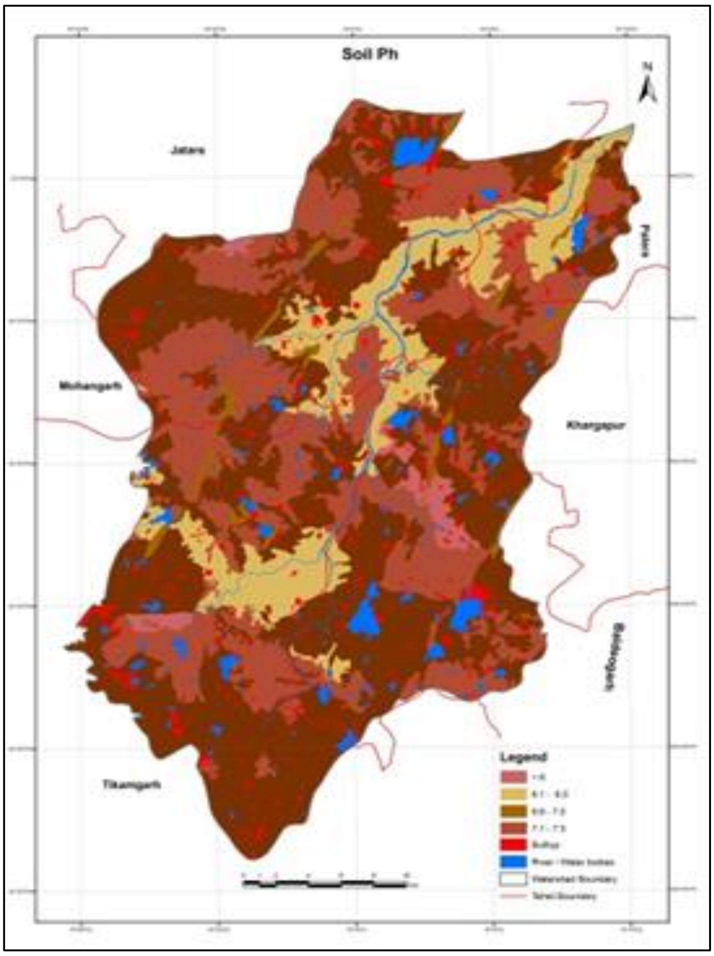


Figure 3.13: Soil pH map of the Ur River Watershed

VI. Soil Erosion

Soil erosion caused by water and the wind is a major problem in Gujarat. There are slight to moderate soil erosion occurs in Saurashtra, Kutch, southern Gujarat, central Gujarat, and northern Gujarat. Severe soil erosion confined in the eastern part of south, north, and central Gujarat and in some central region in Saurashtra. These areas suffer from severe erosion because the terrain is undulating and the soil is loose, the situation further worsened by rainwater which loosened the soil and it gets washed away because of sloppy terrain.

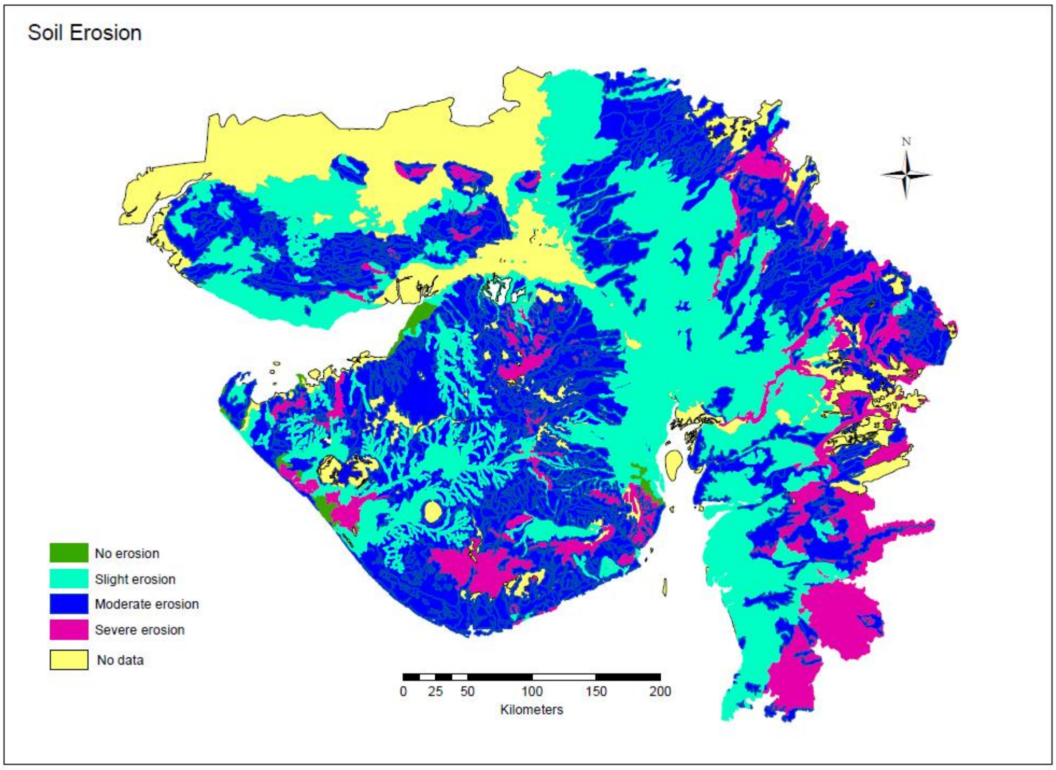


Figure 3.14: Soil erosion map of Gujarat

Soil erosion is the process of detachment, transportation, and deposition of soil particles from the land surface. Soil erosion is one of the most serious environmental problems in the world today and with decreased soil fertility causes the destruction of our natural ecosystems like pastures, forests and agricultural ecosystems. The large-scale erosion of fine-textured top soil and organic matter from the majority of the areas due to high rainfall and undulating topography has given rise to soils consisting of large particles and gravels with low water holding capacity. The first predominant cause of soil degradation in these high rainfall zone regions undoubtedly is water erosion. The process of erosion sweeps away the topsoil along with organic matter and exposes the sub-surface horizons. Erosion status of soils of Kozhikode revealed that majority of the area comes under severely eroded and moderately eroded, and the only little area comes under permanent vegetation is well protected. Besides, on an average 15-18 tons/ha of top fertile soil is eroded in Kozhikode based on our field experiment ultimately resulting in low fertility status besides having other implications like low crop productivity, ground water recharge, etc. (Surendran et al. 2013). The second major indirect cause of degradation is the loss of organic matter by virtue of temperature mediated rapid decomposition of organic matter and leading to loss of rapid soil fertility. Consequences of depletion of organic matter are poor soil physical health, loss of favorable biology and occurrence of multiple nutrient deficiencies.

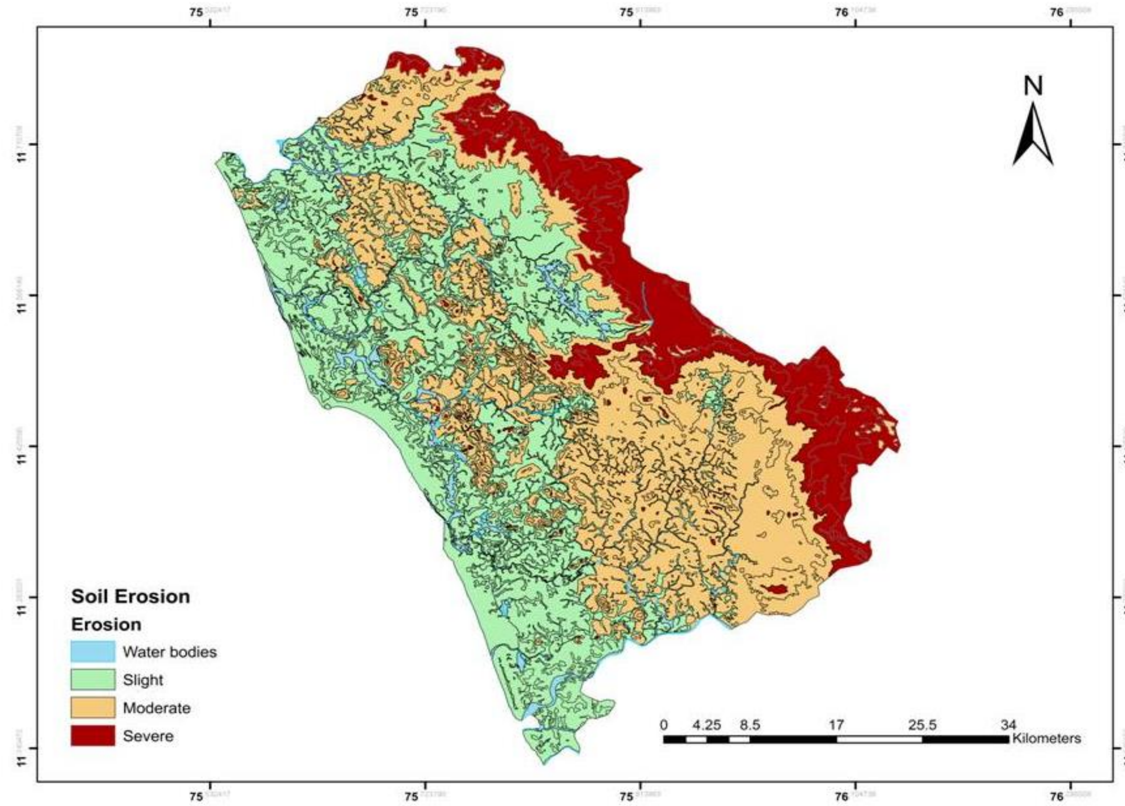


Figure 3.15: Soil erosion map of Kozhikode district

VII. Drainage

Drainage refers to the rapidity and extent, that water is discharged from a soil by runoff from the surface, the flow of groundwater through the soil. Drainage also refers to the state of soil drainage, the frequency, and duration with which the soil is flooded. Most of the soils in Gujarat are well drained. Soil drainage at extreme levels creates problems for crops. Excessively drained soils do not provide most crops with adequate water and nutrients, and soil structure limits root growth. A little too much to excessively is found in the eastern part of Kutch, the north and southern parts of north Gujarat, the coast, and the central parts of Saurashtra. The poor drainage system to very poor borders the eastern coastal part of southern Gujarat: covering districts of Navsari, Surat, Bharuch, Kutch central part a coastal part of Saurashtra. Water and nutrient availability is also limited in poorly drained soils because oxygen deficiency limits the ability of the roots to drink adequate water and nutrients. Decomposition occurs when partially decomposed organic matter accumulates, clogging the soil pores and blocking root growth and drainage of water through the soil. Decomposition forms toxic substances: reduction of nitrogen, sulfur, metals, and organic fermentation products. In addition, it produces methane; that is a greenhouse gas.

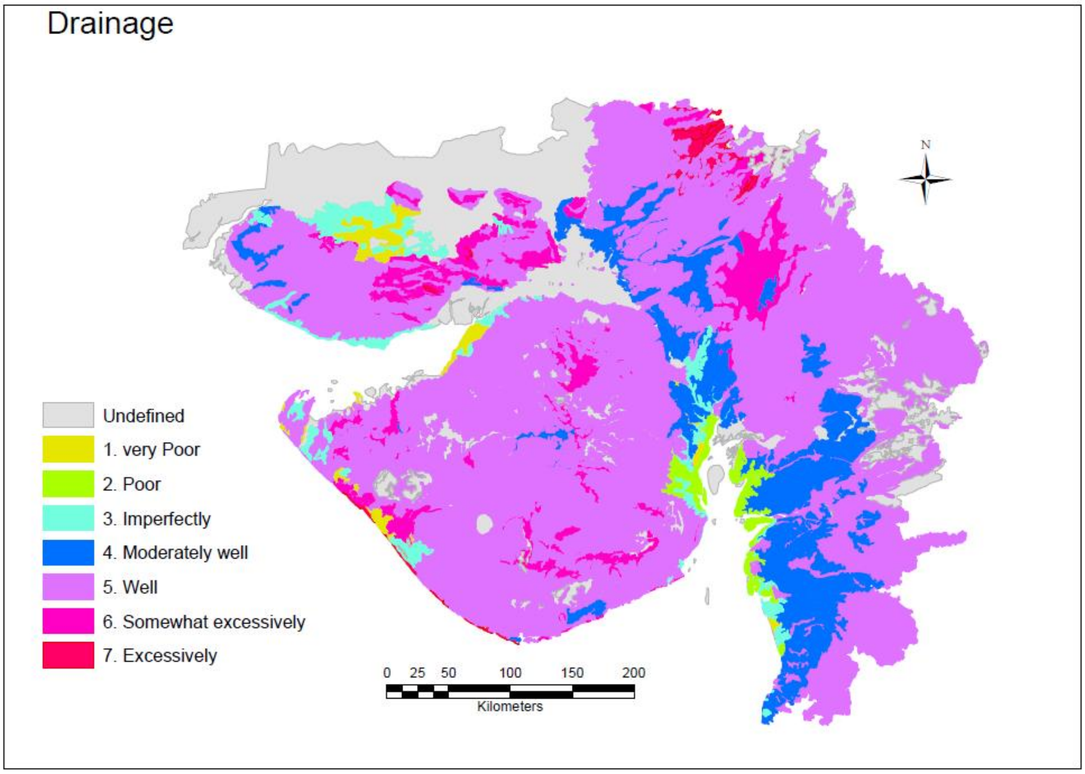


Figure 3.16: Soil drainage map of Gujarat

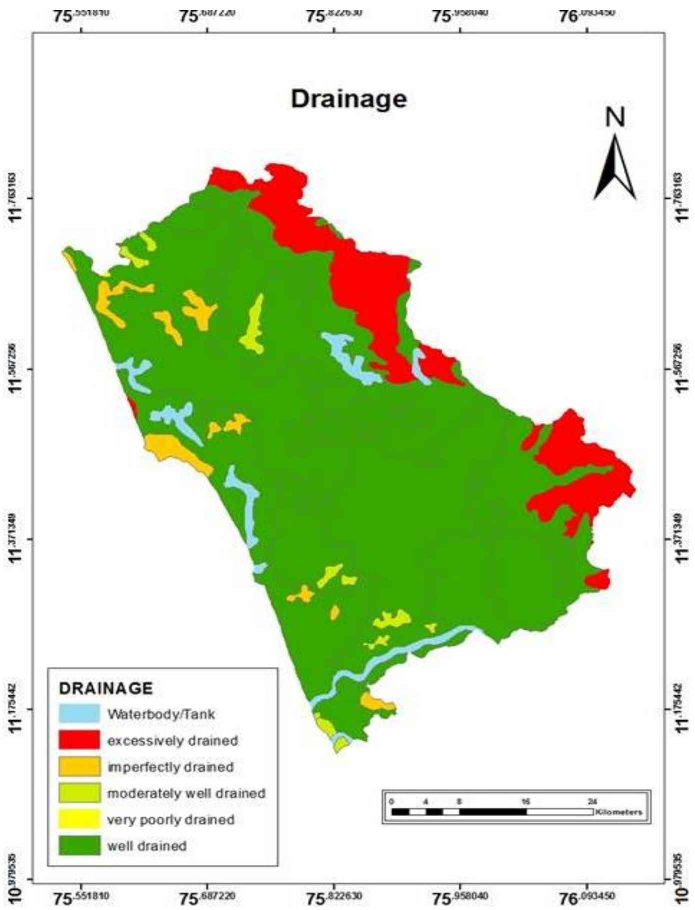


Figure 3.17: Soil drainage map of Kozhikode district

The Ur River watershed has dendritic drainage pattern. The morphometric analysis of the watershed showed fifth as the highest stream order. The stream order demonstrates the connectivity and discharge of the stream segments arising from the basin. Moreover, the Ur River watershed has low drainage density of 0.564/Km, indicating coarse drainage network of the watershed. Drainage density is attributed to the permeability of the sub-surface material, type of vegetation and mountainous relief. Drainage density is the total length of the streams divided by the total area of the basin. It is the measure of closeness of channels. High drainage density is also an indication of finer drainage texture, thus the water travels down faster in the terrain.

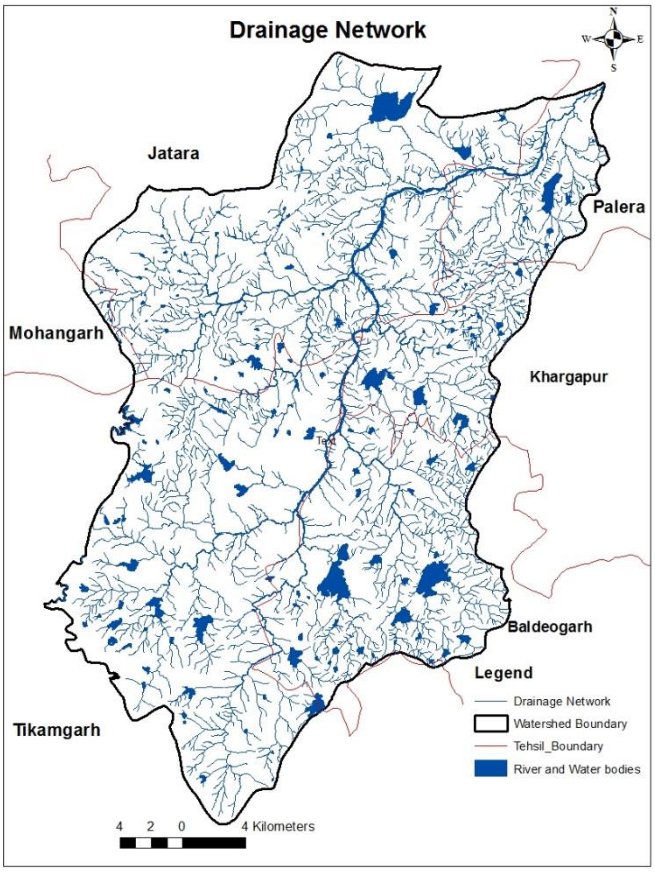


Figure 3.18: Drainage network map of the Ur River Watershed

3.2.2 Spatial Patterns of Land

I. Topography and Elevation

Topography is a non-vital factor that refers to the "lay of the land". It includes the physical characteristics of the land such as elevation of land, slope, terrain (flat, rolling, mountainous, etc.), ridges and bodies of water. As altitude increases, the temperature drops. With this elevation and temperature, they are inversely proportional. In higher-altitude crops, a longer growth cycle is required. Therefore, potatoes and wheat can be grown at 2,500 to 3,800 meters above sea level (masl). Similarly, maize can be grown below 2,500 masl. The altitude or elevation of the earth with respect to the level of the sea surface influences the growth and development of the plant mainly through the effect of the temperature. The relation of this abiotic factor to temperature is the distance between the equator and the Arctic poles. The temperature decreases by 1˚C for every 100 meters of altitude in dry air. This abiotic factor is an important consideration in the selection of crops or sites for a more productive crop. Coconut prefers an elevation not exceeding 600 masl (PCARRD 1982). For a better quality, the tea is cultivated better than 1000 masl while the rubber does not require more than 500 masl because at higher elevation the latex flow is restricted (Abellanosa and Pava 1987). The seasonality of ripening of various fruit crops, e.g. Durian, is modified when they are planted in different elevations. The effect of the elevation of the earth on the growth and development of the plants is evident when exploring a high mountain. The dominance of certain types of plants varies with elevation. With the change in altitude from sea level up to 16,000 feet from the foot to the top of a mountain in the Peruvian Andes or New Guinea, temperatures change from tropical to subtropical, temperate and subarctic to arctic. Likewise, the influence of this abiotic factor on the growth and distribution of plants is appreciated. There is a change of tropical vegetation in the coastal base for the oak forest, then conifers, and finally a tundra scene with resistant grasses, mosses, and dwarf shrubs. At the top of the Arctic, only occasional lichens are found on exposed rocks. In the tropics, the wood line above which no more tree grows can be found between 3,962 to 4,267 masl.

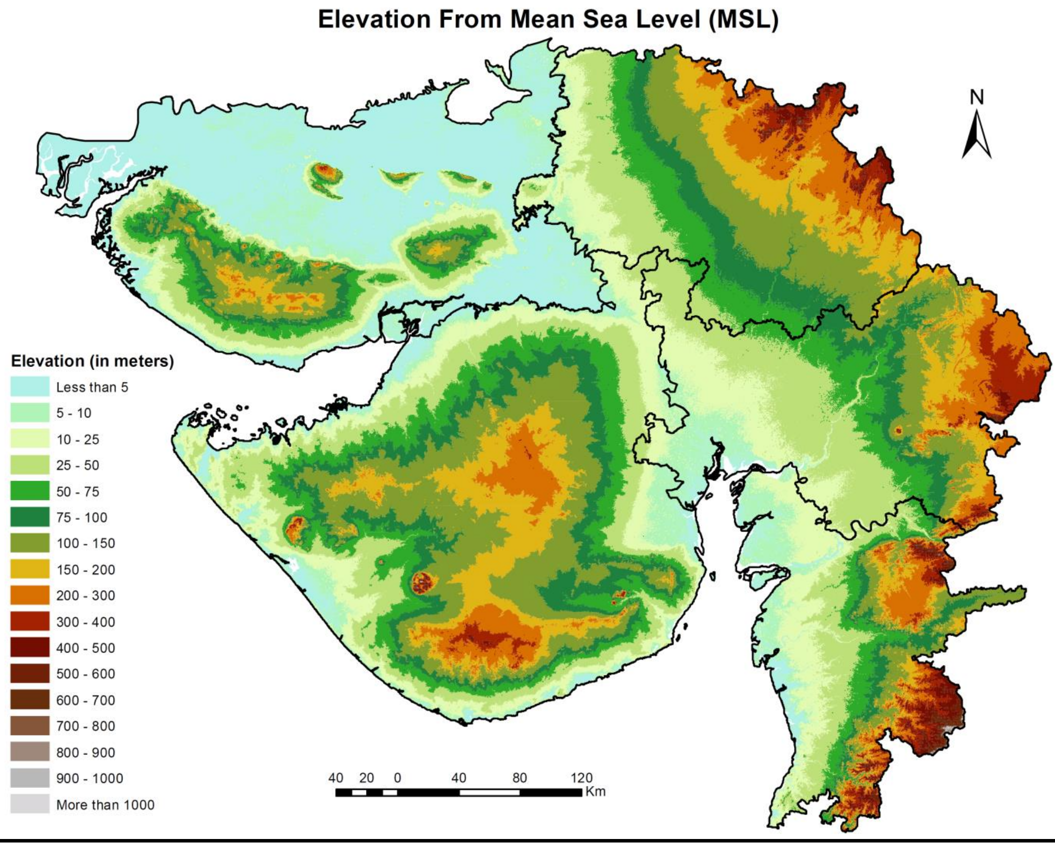


Figure 3.19: Elevation map of Gujarat

Topographically the Kozhikode district has three distinct regions *viz*., coastal lands, midlands and hilly highlands of Western Ghats. The coastal land constitutes about 12.4% of the district, midlands 49.5% and high lands about 32% area of the district.

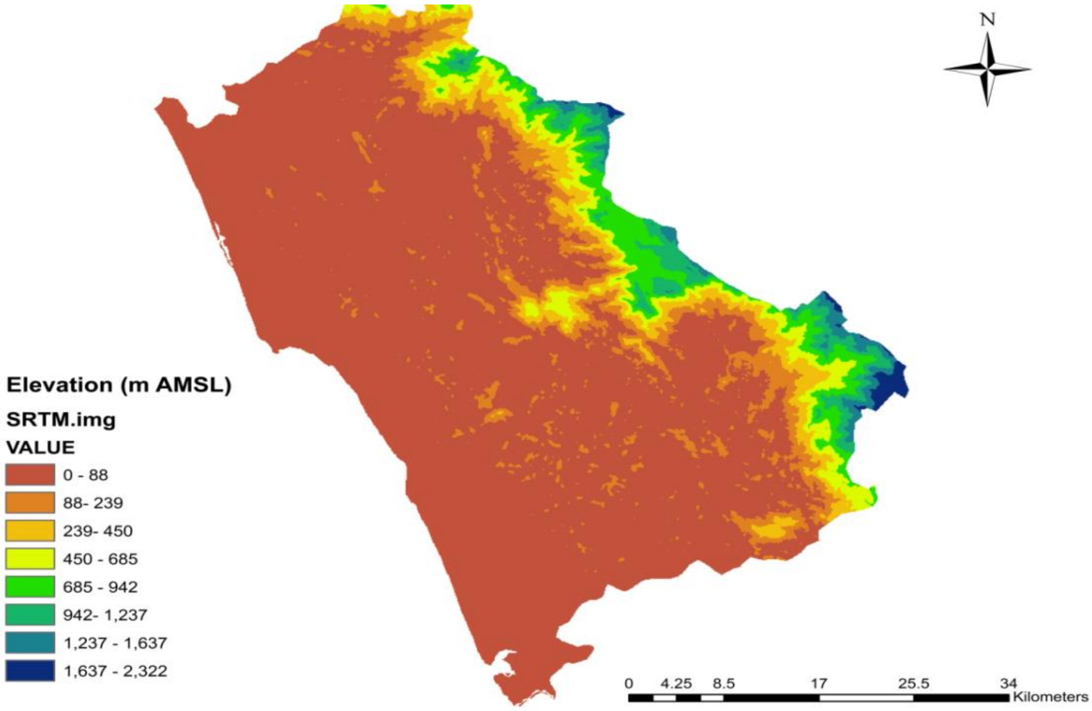


Figure 3.20: Elevation map of Kozhikode district

Geographically, the Ur River watershed forms nearly the center of the Bundelkhand region that lies between the Vindhyan plateau in the south and the great Ganga-Yamuna plains in the north. Elevation of the area lies between the 200 to 400 meters. The highest peak in the southwest rises to 403 meters. This is situated near in the southern part of Tikamgarh tehsil. But there are several other spots in the western part of this area, with an elevation of around 380 to 400 meters. The average elevation above sea level of the south western parts is around 450 meters; it gently drops to 194 in north-east.

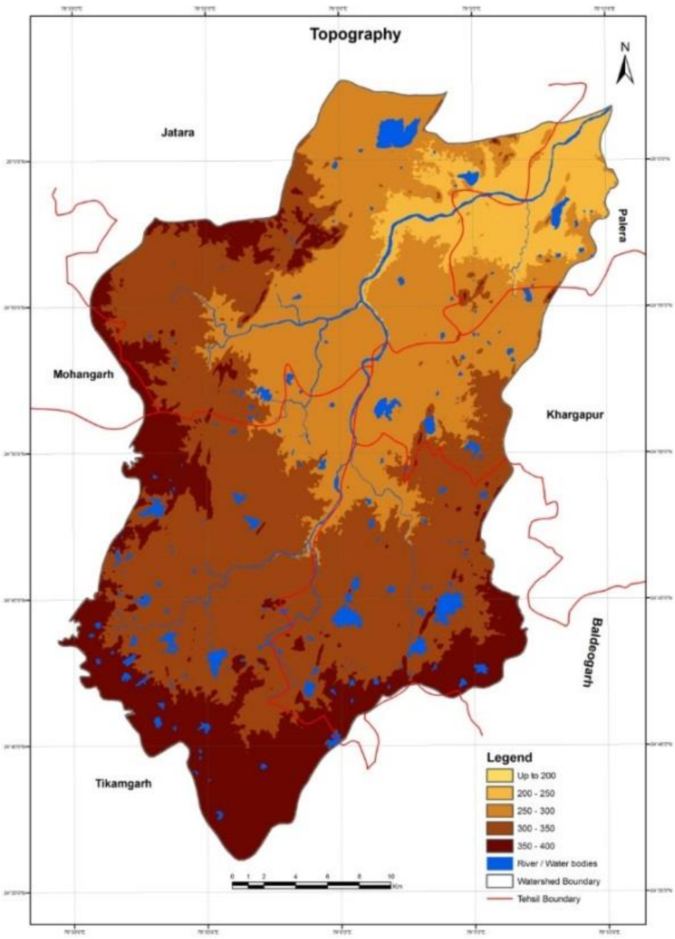


Figure 3.21: Topography map of the Ur River Watershed

II. Slope

The slope or slope of a land is the percentage change in its elevation over a certain distance. It is measured by dividing the vertical distance between the foot and the top of the earth by the horizontal distance between those points, multiplied by 100. An elevation angle of 45 degrees is equivalent to 100% slope. The inclination of a slope affects the growth of the plant through the differential incidence of solar radiation, wind speed, and soil type. A steep slope is susceptible to rapid surface runoff and soil erosion that causes soil degradation. Areas with a slope less than 5% can be used for agricultural purposes and as per the data, it is 92.3% which is 175,153 km^2 out of the total area of 189,774.92 km^2.

The slope is the principal factor of the superficial water flow/ run off since it determines the gravity effect on the water movement. It influences surface and subsurface flow of rain water causing run off, soil erosion and effective in recharge to the groundwater reservoir. Based on the percentage of the slope the entire Kozhikode district area is classified into 8-categories. Distributions (%) of eight slope gradient classes are 0-0.5%, 0.5-2%, 2-5%, 5-8%, 8-16%, 16-30%, 30-45%, and > 45%.

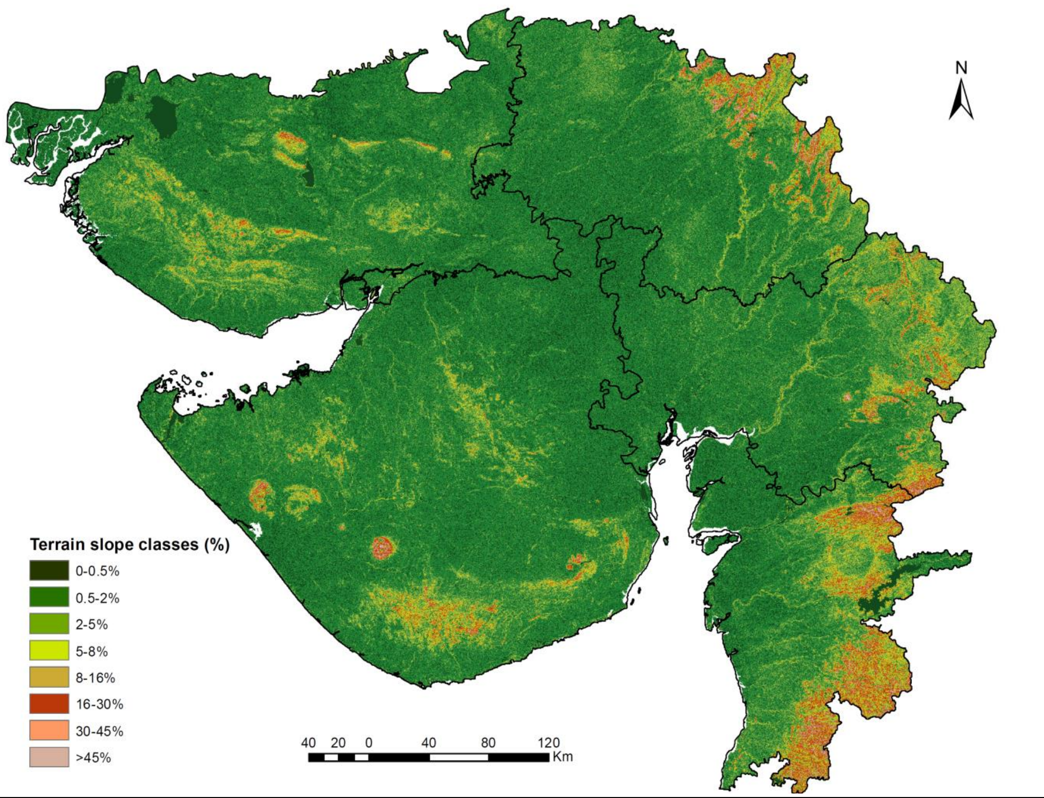


Figure 3.22: Slope map of Gujarat

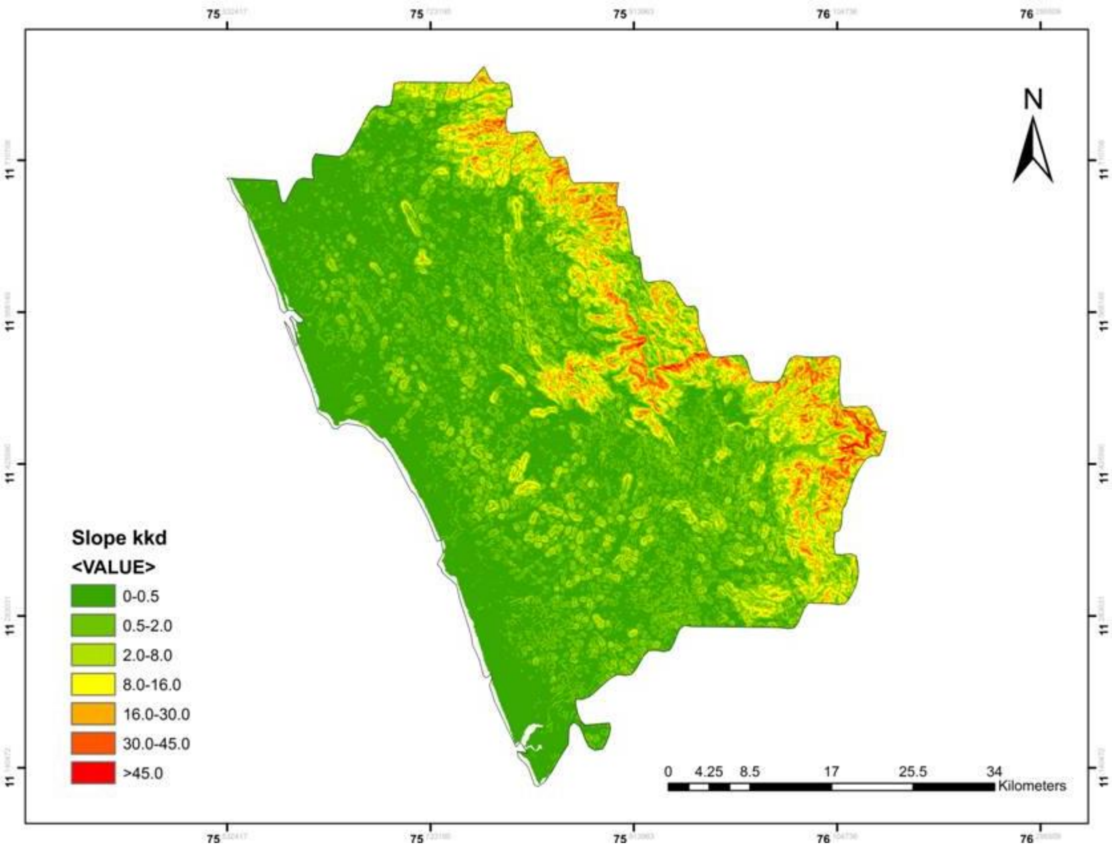


Figure 3.23: Slope map of Kozhikode district

The slope of the Ur River watershed lies between 3 and 35 %. Therefore, Slope shows a large plain surface which is spread with local patches of a fairly sharp gradient. The sloping downwards from the elevated southwest to the lower northeast is very gentle. In general, the gradient remains below 3% throughout in this watershed. The long continuous lines of the high gradient in the map are mainly along the linear ridges formed by the Quartz Reefs. In the slope map, such ridges aligned in the northeast-southwest direction are seen to be interspersed throughout in this area and several of them run along long distance. The slope of these ridges is fairly steep, often rising to the range of 15-35 %. Patches of the steeper slope are, however, extremely rare. Smaller but more dispersed patches of the high gradient are also seen, where the Inselbergs rise high above the surrounding pedi-plains. The widespread patches of a relatively less steep gradient in the map mostly indicate Inselbergs and Pediment Inselberg complexes. Denudational hills in several parts of this area are also indicated by similar patches of high gradient.

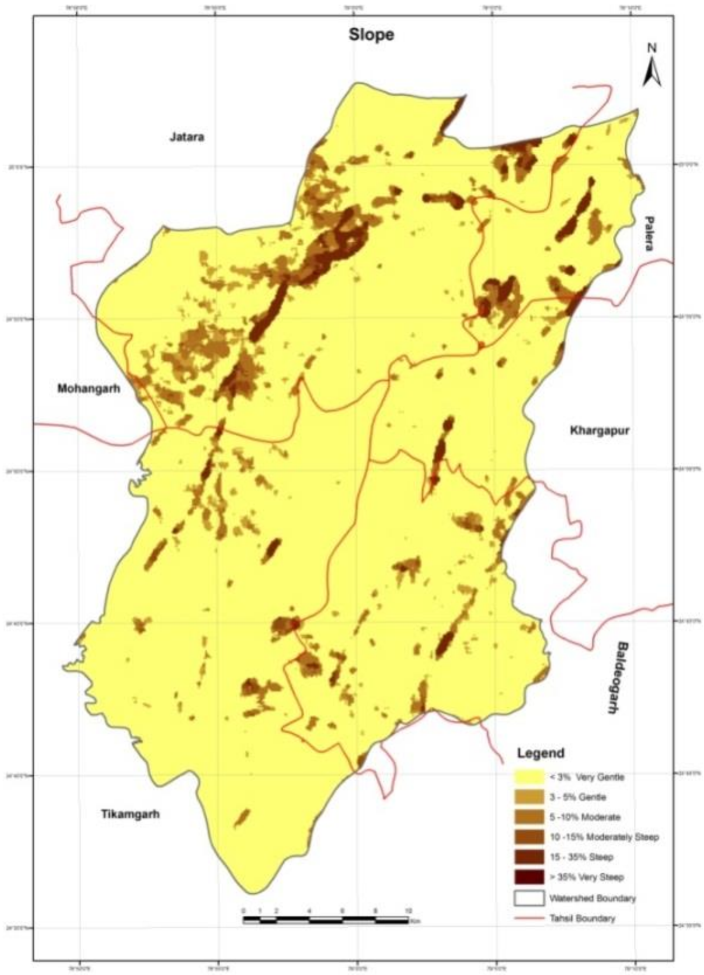


Figure 3.24: Slope map of the Ur River Watershed

III. Land Use Land Cover (LULC)

Land use is the form and extent to which land is put to use. It can also be referred to as the human use of land. Land use is the modification of the natural environment in settlements, roads, rail networks, other infrastructures, agriculture, forests, wetlands, wasteland, etc. It has also been defined as the arrangements, activities, and inputs that people perform in a certain type of terrestrial coverage to produce, change or maintain (Gregorio and Jansen 1998). To maintain the balance between the environment and development planners must have knowledge about the existing land use and trends over the years. People discuss how the earth has changed over time. Sometimes there are conflicts over land use. Therefore, there is a need for proper land assessment and classification. Since several land categories are within the scope of different departments, there are inconsistencies in land use classes. There is a need to have a standard land use classification, which can be applied to the entire state. The classification of land use should be detailed and each kind of land needs to be defined to reduce the darkness. In addition, many scholars have highlighted the need for a systematic database to assess changes in land use. The Gujarat Land Use Notification Area is 196,024 km^2, which includes urban areas, agriculture, forests, wastelands, water, and wetlands. Agriculture is dominant among all categories of land use, which is 60.4% of the total area of Gujarat with an area of 118,440 km^2.

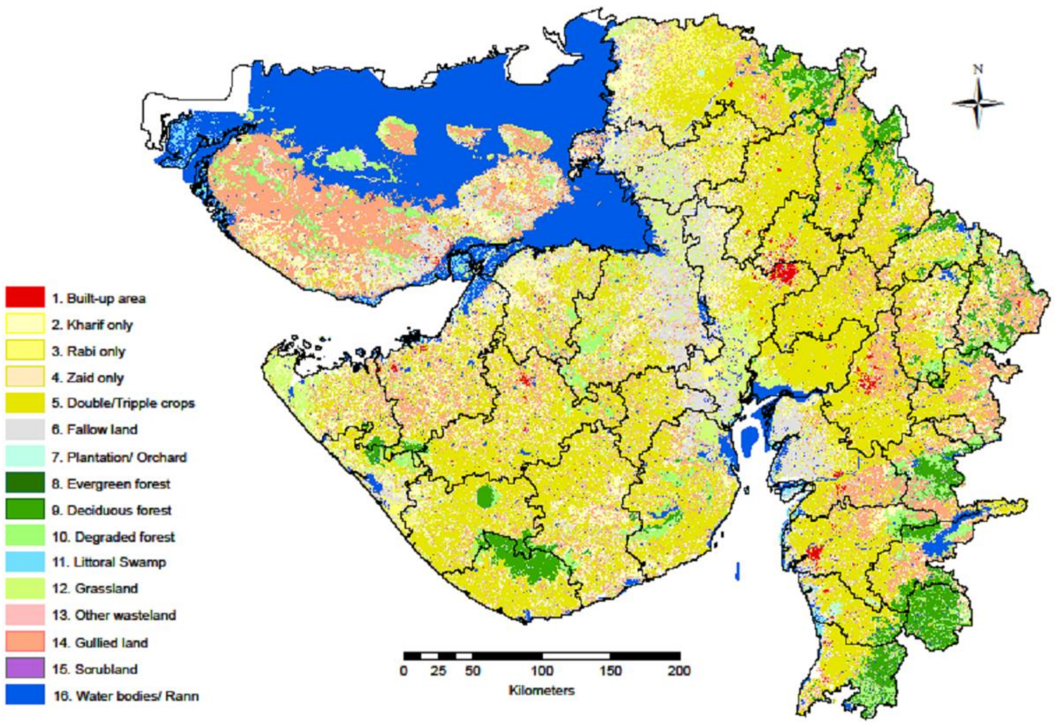


Figure 3.25: Land use land cover (LULC) map of Gujarat for 2007–2008

According to the GIS data base used in this study, Gujarat has a total land surface area of 196,024 km^2. The land under agriculture is 118,434 km^2 or 60% of the total area of the state. Around 6.2% is occupied by built-up areas. The remaining land consists of forests (13%), wastelands (13.2%), wetlands (3%), and water (4.3%). For use in the AEZ Gujarat, three available GIS layers were combined, containing respectively information on (i) major land use/cover, (ii) irrigated areas, and (iii) inland water bodies. The resulting six land use/land cover categories, used for land accounting and to characterize each 3 arc second grid-cell, are: (1) irrigated cultivated land; (2) rain-fed cultivated land; (3) forest land; (4) scrub and other vegetated land; (5) settlements; and (6) water bodies.

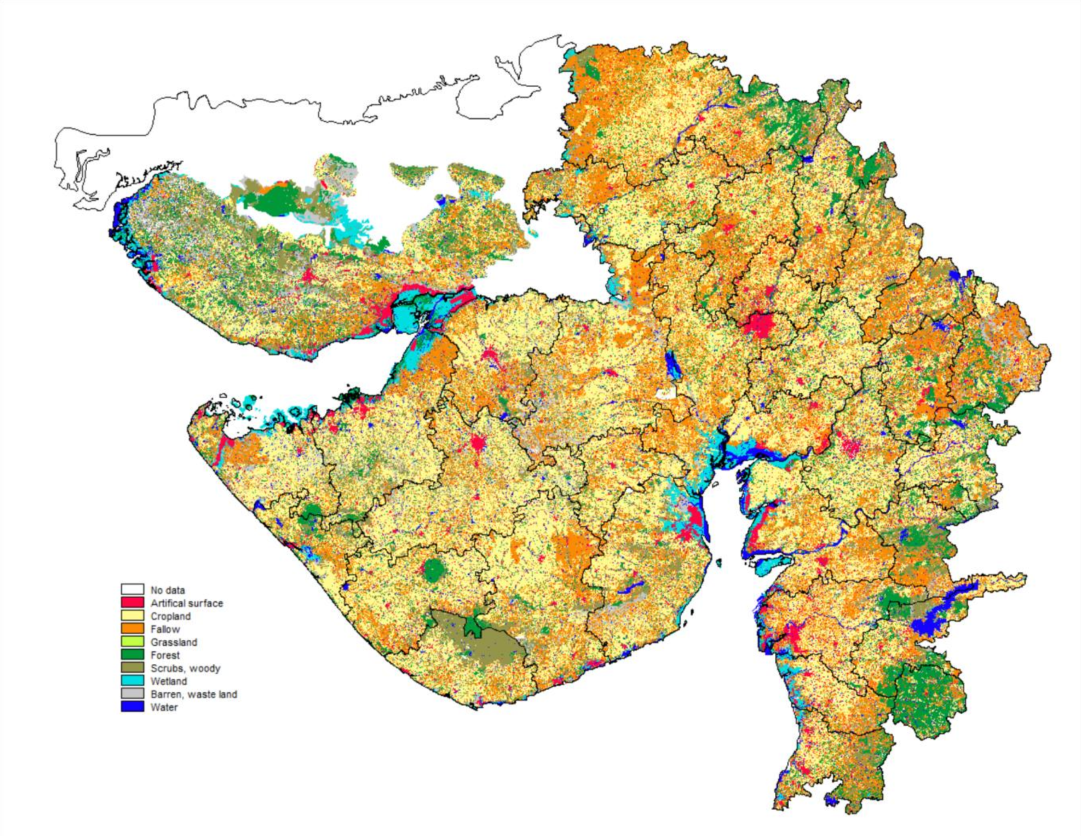


Figure 3.26: Land use land cover (LULC) map of Gujarat for 2011–2012

Land use describes how a parcel of land is used for agriculture, settlements or industry, whereas, land cover refers to the material such as vegetation, rocks or water bodies, which are present on the surface. The total geographical area of the Kozhikode district is 234,641 hectares in which the net area sown is 155,677 hectares.

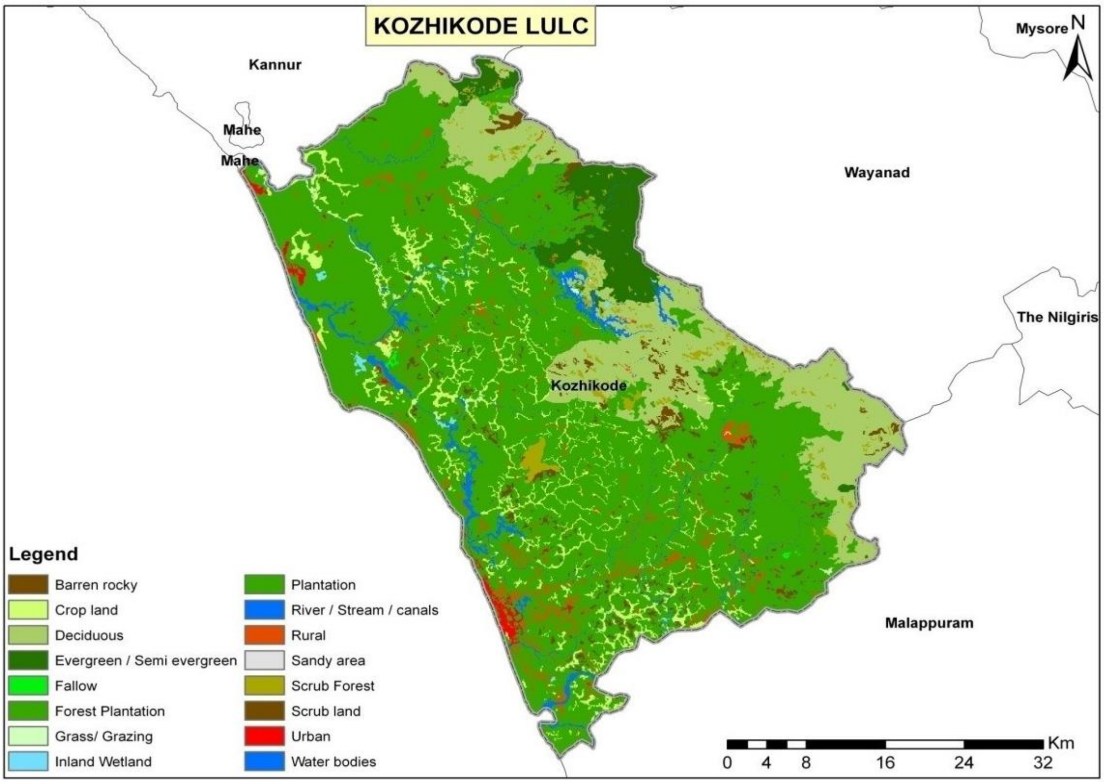


Figure 3.27: Land use land cover (LULC) map of Kozhikode district

The LULC map for Tikamgarh district has been prepared through LISS-IV Satellite imagery having a 5.8-meter resolution. Cultivation, forest, Rabi crop, Kharif crop and land use/land cover change detection map were also prepared using this technique. The land use analysis indicates that the forests constitute 35.05% of the area (347.01 km^2), while agricultural lands constitute 49.25% (487.64 km^2) and habitation is about 1.66% covering 16.45 km^2 only. The rest of the area is barren rocky (7.61%), water bodies (3.92%). Under the forest category, maximum area is covered by scrub forest with 16.79% of the total geographical area, dense forest (4.46%) and land with or without scrub (13.80%).

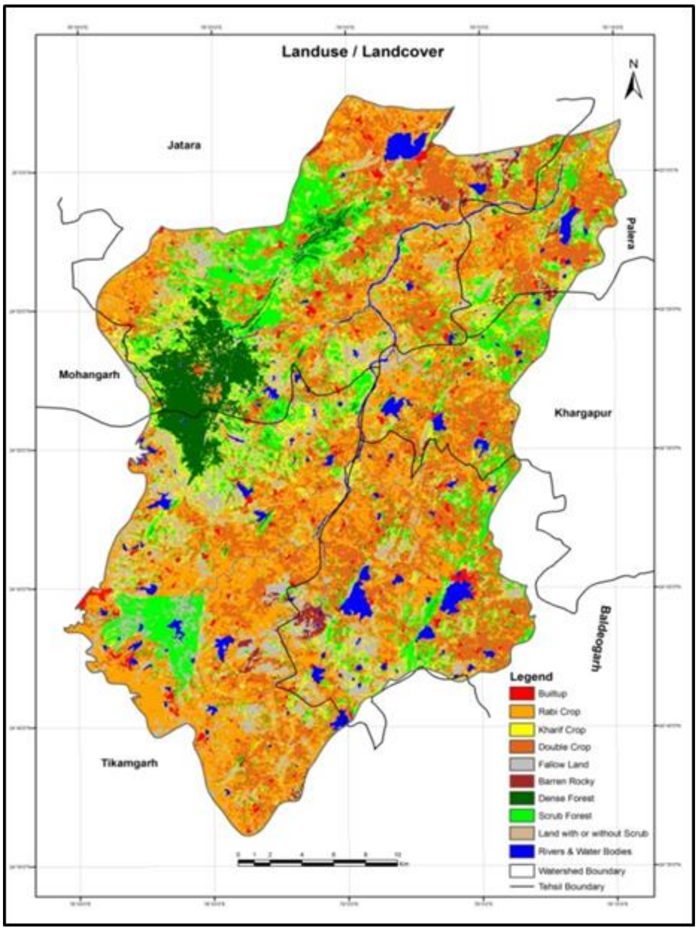


Figure 3.28: Land use land cover (LULC) map of the Ur River Watershed

3.2.3 Spatial Patterns of Forest

The forest cover includes all lands with a tree crown of more than 10%. The forest and tree cover of the state according to the evaluation in 2013 is 24,317 km^2, which is equivalent to 12.41% of the geographical area. The table below shows the distribution of forests and tree cover in Gujarat. However, according to data provided by the Directorate of Economics and Statistics, the forest area in Gujarat is 19,130 km^2. This study, in order to analyse the regional variations of forests and tree cover, we used the data available in the reports of Forest Survey of India (FSI). The variation in the forest coverage data of different agencies is due to the different scale and resolution of the surveys adopted. The state's forest cover in Gujarat has shown a general increase since 1991 when forest cover was 11,907 km^2 and increased to a maximum of 15,152 km^2 in 2001. In 2011, the total forest area of Gujarat was estimated at 14,619 km^2. (FSI 2011). This increase is due to management interventions such as regeneration and departmental plantations. The Forest Survey of India (FSI 2011) has classified forest cover under very dense forests with 70% and above canopy cover, moderate dense forest with 40-70 % canopy cover and open canopy cover forests between 10 and 40 %.

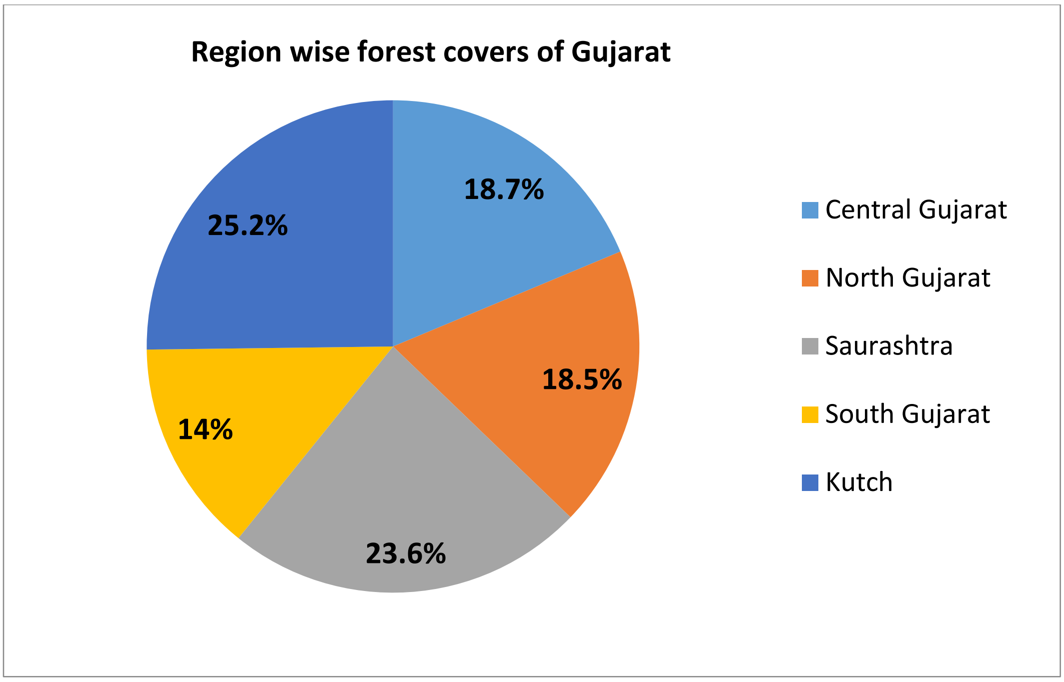


Figure 3.29: Region wise forest covers to total forest area of Gujarat

The tree cover of Gujarat outside the forest area is about 10,459 km^2, representing 5.3% of the geographical area compared to only 2.8% in India. The tree outside the forest area is the second highest among the states of India. For forest resources to be valuable and productive in terms of providing ecosystem services, it is essential that the density of forest cover increases. The wise forest covered Gujarat region is given in lower numbers. Kutch has the highest forest cover in the entire Gujarat region, accounting for 25.2% of the total forest, followed by Saurashtra (23.6%), central Gujarat (18.7%), north Gujarat (18.5%), and south Gujarat (14%). Kutch has 26.7% of its area under forest cover, the highest among the entire region followed by south Gujarat (21.4%), north Gujarat (13.1%), central Gujarat (10.3%), and Saurashtra (8.1%). Kutch has 6,390 km^2 of forest resources, followed by Saurashtra (5964 km^2), central Gujarat (4730 km^2), north Gujarat (4,682 km^2), and south Gujarat (3548 km^2).

I. Mangroves

The mangroves are salt tolerant plant communities rich in biodiversity–both terrestrial and aquatic species. They provide a number of ecological services and play a key role in protecting coastal areas from erosion and rise in sea level and act as a shield against cyclones, ecological disasters and as protector of shorelines. They are also beneficial for land accretion as they trap fine debris particles. The mangroves create a buffer zone between the land and sea. It harbors a variety of life forms like invertebrates, fish, amphibians, reptiles, birds and even mammals like tigers. Mangroves also provide the main source of income generation for shoreline communities like fisher folk and a good source of timber, fuel, and fodder. It also acts as a potential source for recreation and tourism. The highest mangrove cover in Gujarat is found in Kutch district, which possesses an area of 314 km^2 followed by Jamnagar (218 km^2) and Bharuch (47 km^2). The mangroves in various districts are under three main categories: very dense (canopy density of more than 70%), moderately dense (canopy density between 40 to

70%), and open mangrove (canopy density is between 10 to 40 %). Mangroves, as said earlier, provide a variety of ecological services. There is, however, a lack of dense mangrove cover with most mangroves in the open forest category hence they provide lower ecosystem services. Efforts need to be scaled up to ensure a significant increase in dense mangrove cover for the ecosystem to be productive of natural resources and protect the coastal communities and infrastructure against mighty cyclones.

II. Waste Land

Degraded land is one which can be brought under vegetative cover with reasonable effort and which is currently under-utilised and land which is deteriorating for lack of appropriate water and soil management or on account of natural causes (Department of Land Resources, MoRD n.d.). According to the National Wasteland Atlas, wastelands have been classified as the following: 1) Gullied and/or ravinous land – medium; 2) Gullied and/or ravinous land-Deep; 3) Land with Dense Scrub; 4) Land with Open Scrub; 5) Waterlogged and Marshy land-Permanent; 6) Waterlogged and Marshy land-Seasonal; 7) Land affected by salinity/ alkalinity-Moderate; 8) Underutilised/ degraded notified forest land-Scrub dominated; 9) Underutilised/ degraded notified forest land-Agriculture; 10) Degraded pastures/grazing land; 11) Degraded land under plantation crops; 12) Sands-Coastal; 13) Mining wastelands; and 14) Barren rocky area. The classification made by the National Wasteland Atlas cannot be compared to two time periods because of non-uniform classification schemes. Saurashtra has an area of 11,758 km^2 wasteland, which is 45% of its geographical area and highest among the entire region followed by Kutch (5,156 km^2), central Gujarat (4,537 km^2), north Gujarat (3,124 km^2), and south Gujarat (1,254 km^2). In Saurashtra, the Surendranagar district accounts for the largest wasteland area extending up to 2,806 km^2 in the region and second largest in the state after Kutch. In north Gujarat, most of the wastelands are concentrated in the Banaskantha (930 km^2) and Aravali (628 km^2) districts. Narmada (704 km^2) and Dahod (720 km^2) are the major district holding wasteland in central Gujarat. Most of the wastelands are concentrated in Surat (341 km^2) and Valsad (314 km^2) district in south Gujarat.

The Ur River watershed has about 4598.62 hectares of lands as culturable wasteland area. Figure 3.31 represents the sub-watershed wise percentage distribution of wasteland area. SW5 falling in Jatara has the maximum wasteland area of about 1,006 hectares followed by SW8, SW1, SW6, SW7, SW3, SW2, and SW4 which has the least wasteland area of about 180 hectares.

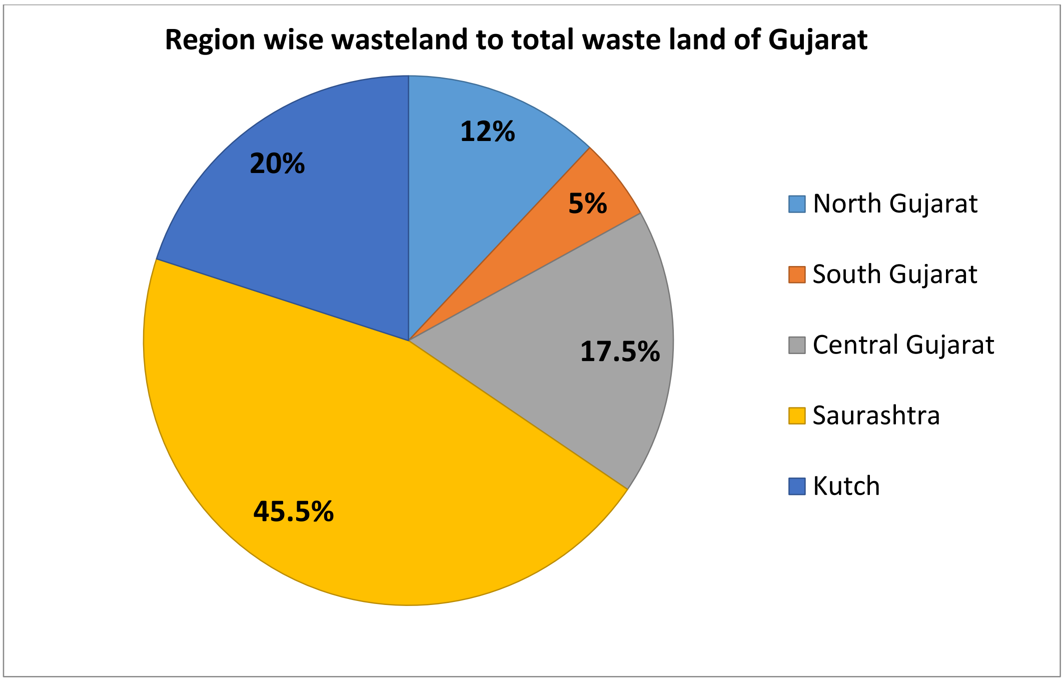


Figure 3.30: Region wise waste land distributions in Gujarat

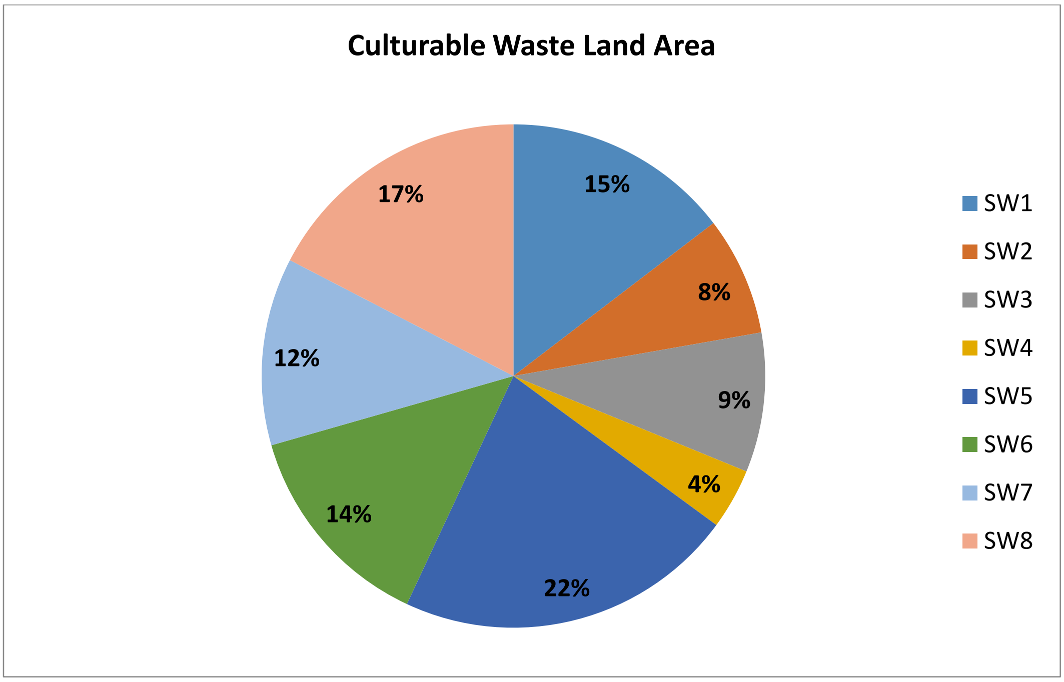


Figure 3.31: Percentage distribution of culturable waste land area in the Ur River Watershed

III. Wetlands

Wetlands are areas in which water is the key factor regarding controlling the environment and allied flora and fauna. They occur where the water table is at or near the surface of the land. They are among the world's most productive environments in terms of aquatic biodiversity. Many plant and animal species depend on wetlands for their survival. Wetlands have been described as "the kidneys of the landscape", because of the functions they perform during hydrological and chemical cycles and as "biological supermarkets" because of the extensive food webs and rich biodiversity they support (Mitsch and Gosselink 1993). Kutch holds the largest share of wetland (35.5%) followed by Saurashtra at 28.5%, central Gujarat at 26.2%, south Gujarat at 6.3%, and north Gujarat at 3.5%. Below figure gives the distribution of different types of wetlands in Gujarat.

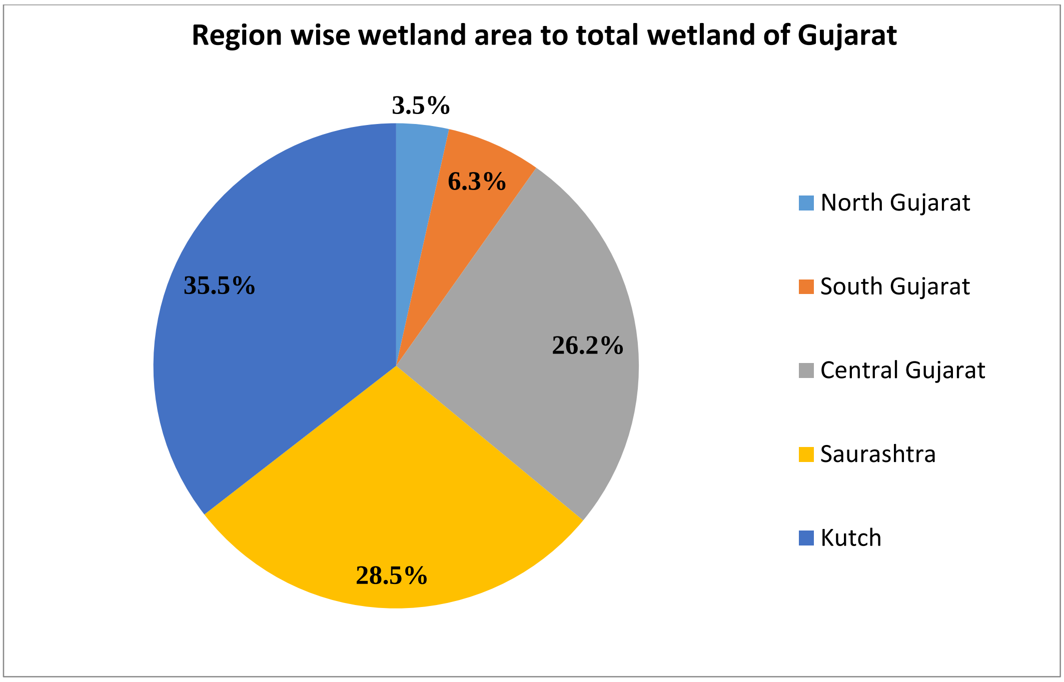


Figure 3.32: Region wise distribution of wetland in Gujarat

The wetland area estimated in Kozhikode district is 7690 hectares which include 117 small wetlands (< 2.25 ha). The major wetland types are River/ Stream, Reservoirs/ Barrages, and tanks/ ponds. Analysis of wetland status in terms of open water and aquatic vegetation shows that around 91 and 90 percent of wetland area is under open water category during post-monsoon and pre-monsoon respectively. Aquatic vegetation (floating/emergent) occupies around 5 and 3 percent of wetland area during post and pre-monsoon respectively. Qualitative turbidity analysis of the open water showed that low and moderate turbidity prevail.

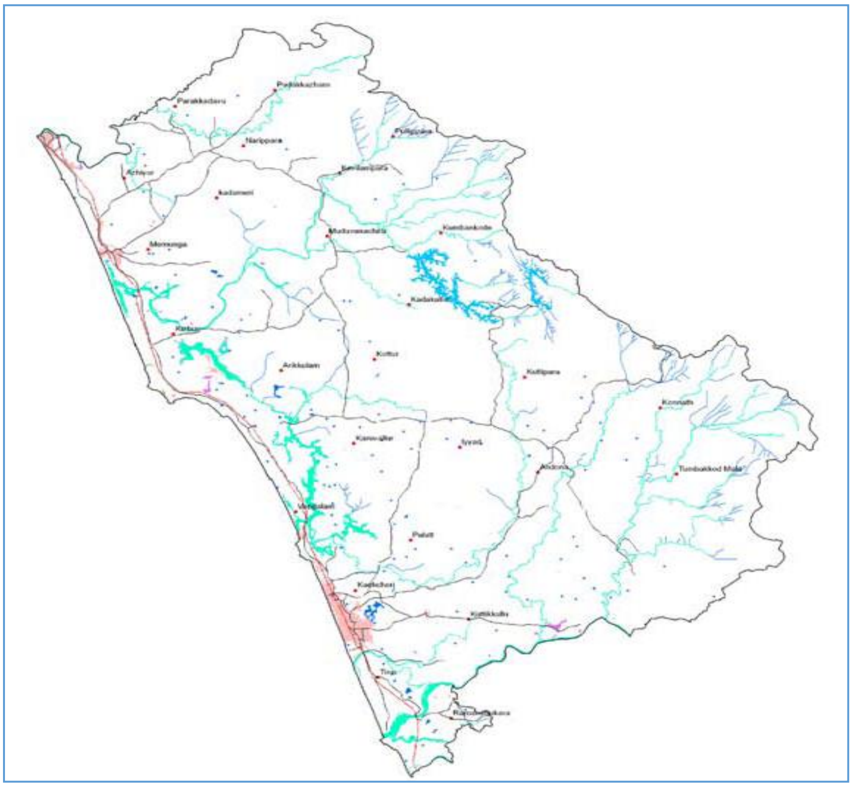


Figure 3.33: Wetland map of Kozhikode district

3.2.4 Spatial Patterns of Water

Water that is central to human life is obvious that the change in the state of water has implications for human existence. It was along the banks of major river systems where human civilizations flourished. Many civilizations have disappeared because of water shortages (droughts) or floods. In a sense, the consumptive use of water and the management of floods and droughts have existed since time immemorial. Modern development and lifestyles have the potential to change the pattern not only of water use, but also of the very nature of water, which is often due to demographic change, urbanization, industrialization, and water pollution.

Fresh water resources, rivers, and water bodies

Gujarat's water resources are characterized by colossal regional variation in the context of wealth and scarcity. The state's water resources are concentrated mainly in its southern and central regions. Coastal wetlands are mainly concentrated around the Gulf of Khambat, the Gulf of Kutch and the two *Ranns*. The Saurashtra, Kutch and northern Gujarat regions have limited surface and groundwater resources. Gujarat experiences an irregular distribution of precipitation ranging from 400 to 2000 mm. Seventy-one percent of its total area is deficient in water. Only 29% of the south and the centre of Gujarat have leftover water. The inadequacy of surface water has led to massive overexploitation of groundwater, which has been a source of concern for a long time. While much of Saurashtra and South Gujarat is safe, most of the northern region of Gujarat and parts of South Kutch are considered over-exploited; the northern Talukas of north Gujarat and some southern regions of Kutch are categorized as critical. Gujarat has a total of 50.1 billion cubic meters of water including surface water, groundwater and storage capacity of reservoirs (excluding *Sardar Sarovar*). Surface water resources contribute 38.1 billion cubic meters while groundwater resources contribute 12 billion cubic meters.

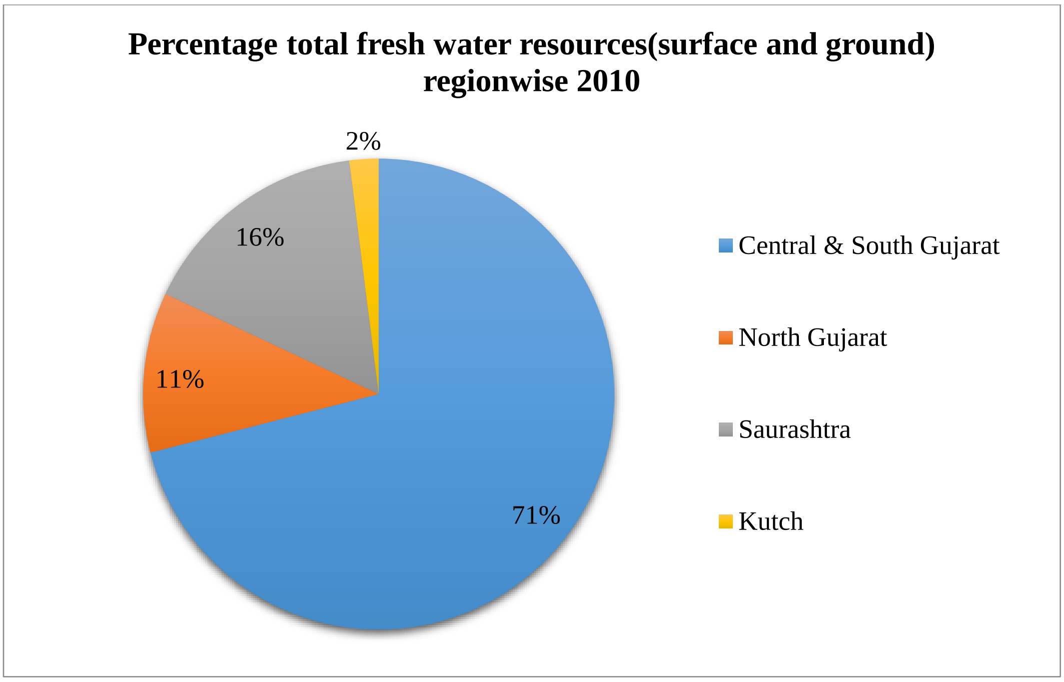


Figure 3.34: Total fresh water in different regions of Gujarat

Water resources in Gujarat are characterized by large regional variations in terms of their wealth and scarcity. The state's water resources are concentrated mainly in the southern and central parts of the state. Saurashtra, Kutch and the northern regions of Gujarat have limited surface and groundwater resources. Geological and geo-hydrological situations such as rocky terrain, deserts and a 1600 km long coastline and water quality problems have added to the complexities of the Gujarat water sector. The following table represents the detail of the water resources in Gujarat. The surface and underground water resources have dynamic and static facets with implications for the availability and quality of water in the state. Measuring the dynamic nature of water in terms of flows has been significant for most development needs. Static nature such as the length and area of water bodies has been vital for actions such as fishing, navigation, watershed development, etc. This chapter tries to cover all these aspects of water resources in Gujarat. It is known that Gujarat experiences irregular rains that vary regionally from 400 to 2000 mm over 196,024 km^2 of the total geographic area. Seventy-one percent of its total area is deficient in water. Twenty-nine percent of the southern and central Gujarat areas have leftover water, which needs to be diverted to the sparse northern regions of Gujarat, Saurashtra, and Kutch. While surface water availability is only two per cent of the country's total water availability, the population is five per cent of the country's total population. Due to insufficient surface water, there is massive over-exploitation of groundwater.

River and water bodies map for Tikamgarh district was prepared by LISS-IV satellite imagery, using digitization process with the help of ArcGIS. River and water bodies' names were taken from Survey of India (SoI) Toposheet. On this map, dotted area shows a large number of tanks. Water bodies are either natural or man-made. They appeared dark blue/ black in colour having linear to an irregular shape and are easily identifiable on the satellite image. The water bodies/ Rivers cover an area 38.80 km^2 which is 3.92% of the total geographical area of the Ur River watershed. The Ur River rises in the hills of Tikamgarh near the western boundary of the district and flows northeast through Jatara and Palera to meet Dhasan just outside the eastern boundary of the district.

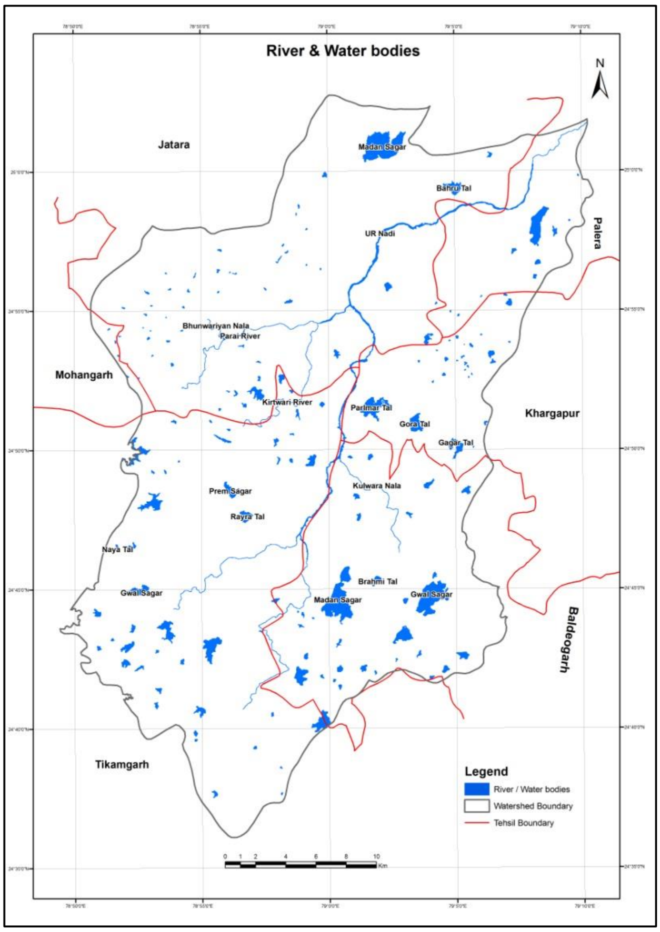


Figure 3.35: River and water bodies map of the Ur River Watershed

I. Surface Water

This section broadly covers the discussion on various facets of surface water resources of Gujarat. Mainly it covers the rainfall, surface water availability and water bodies, river basin potentials, etc.

a) ***Rainfall:*** Many parts of the state are extremely susceptible to drought conditions due to the erratic rainfall pattern in Gujarat. Saurashtra has a limited number of water bodies with rainfall normally ranging between 400 and 800 mm. The average annual rainfall is about 775.0 mm with a standard deviation of 75.1 mm. Gujarat mainland, comprising south, central, and north Gujarat, evinces maximum water concentration owing to rainfall ranging normally between 800 to 2000 mm. The rainfall trend for monsoon season in five regions of Gujarat is presented in figures for the last two decades. These figures suggest that the rainfall in Gujarat has been reasonably high during the decade of 2001–2010 compared to the years during 1991–2000. Most parts of the state including the drier regions of Kutch, north Gujarat, and Saurashtra have benefitted from this.

b) ***Area under surface water bodies:*** The surface water bodies of Gujarat constitute major and minor rivers, canals, reservoirs, tanks, lakes, *talavs* (ponds), and brackish water bodies. The trend has remained the same throughout this period with south and central Gujarat covered by the largest area under water bodies followed by Saurashtra, north Gujarat, and Kutch. A similar trend has been seen for fresh water availability in the four regions of Gujarat. South and central Gujarat have maximum availability at 71% while Kutch has the minimum availability at two percent. In Kutch district, no data was available for the Ranns. The remaining parts of Kutch and the districts of Banaskantha, Mehsana, Ahmedabad, Bhavnagar, Amreli, Junagadh, and The Dangs are covered by water bodies in the range of 0 to 2 % of their total area. On the other hand, districts which have 2 to 4 % of their area under water bodies are Patan, Surendranagar, Rajkot, Jamnagar, Gandhinagar, Sabarkantha, Kheda, Anand, Vadodara, Dahod, Bharuch, Surat, Navsari, and Valsad. Only three districts of Panchmahals, Narmada, and Porbandar have 4 to 6 % of their geographical area under water bodies of various types. The Tapi district has the highest area under water bodies falling in the range of 8 to 10 %.

c) ***River basin potential:*** The river systems of Gujarat may be divided according to the state's regions. Broadly speaking, there are three major groups of rivers flowing in different directions. Narmada, Sabarmati and Mahi are the major rivers of central and north Gujarat while the rivers Mithi, Khari, Bhadar, Shetrunji, and Bhogavo flow in the Saurashtra region. South Gujarat's major river systems are formed by Narmada, Tapi, Purna, Ambika, Auranga, and Damanganga. Three rivers are perennial, namely, Narmada, Tapi, and Mahi. The natural run off from these rivers has created a huge water potential in the state, yet the inconsistent distribution of the resources coupled with topographic factors has led to only partial utilisation of this potential. To combat this drawback, the state has come up with several major and minor projects, adding to the surface storage capacity of these rivers.

d) ***Surface water distribution:*** A total of 50,100 million cubic metres (MCM) of water including surface water, ground water and storage capacity of reservoirs (excluding *Sardar Sarovar*) along with surface water resources, contributes to 38100 million cubic metres of water. Below figure represents the regional distribution of surface water resources in Gujarat. Central and south Gujarat have maximum surface water availability of 31,750 million cubic metres followed by Saurashtra, north Gujarat, and Kutch with 3600, 2100, and 650 million cubic metres respectively (NWRWS 2010).

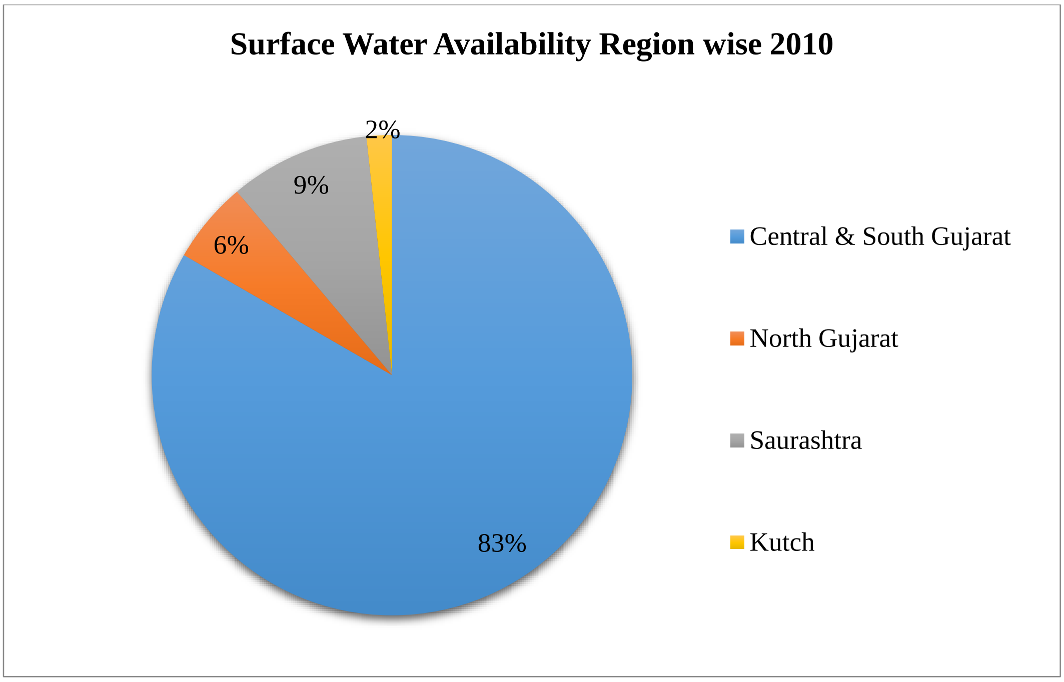


Figure 3.36: Region wise surface water availability in Gujarat

The Kozhikode district is drained by six rivers of which one is of medium nature and all others are minor ones namely Chaliyar, Kuttiyadi, Mahe, Kadalundi, Kallayi, and Korapuzha. The Chaliyar River is a medium river and originates at a height of 2066 masl in Ilambalari hills of Western Ghats of Gudallur district, Tamil Nadu. The Chaliyar drains into Beypore estuary. It is a sixth order stream with a length of 169 km. At its upper reaches, it is formed by Punnurpuzha, Pandiyur, Karimpuzha, Cherupuzha, Kanhirampuzha, Kurumbanpuzha, Vathatpurampuzha, and Iruvantipuzha. At its lower reaches near Cheruvannur, it is flowing as a broad river developing inlets. The utilizable surface flow in Kozhikode district as per CWRDM report is 1363 million cubic meters.

72.14 million cubic meters (MCM) of surface water is available in the entire Ur River watershed. Figure 3.37 represents the sub-watershed wise percentage distribution of surface water availability. SW1 has the maximum surface water availability of 16.96 MCM followed by SW2 (13.56 MCM), SW3 (10.96 MCM), SW7 (10.73 MCM), SW6 (9.26 MCM), SW8 (6.85 MCM), SW5 (2.28 MCM) and SW4 which has the least with 1.54 MCM. This can be attributed to fact that SW4 covers a smaller area and do not have large water bodies with respect to other sub-watersheds.

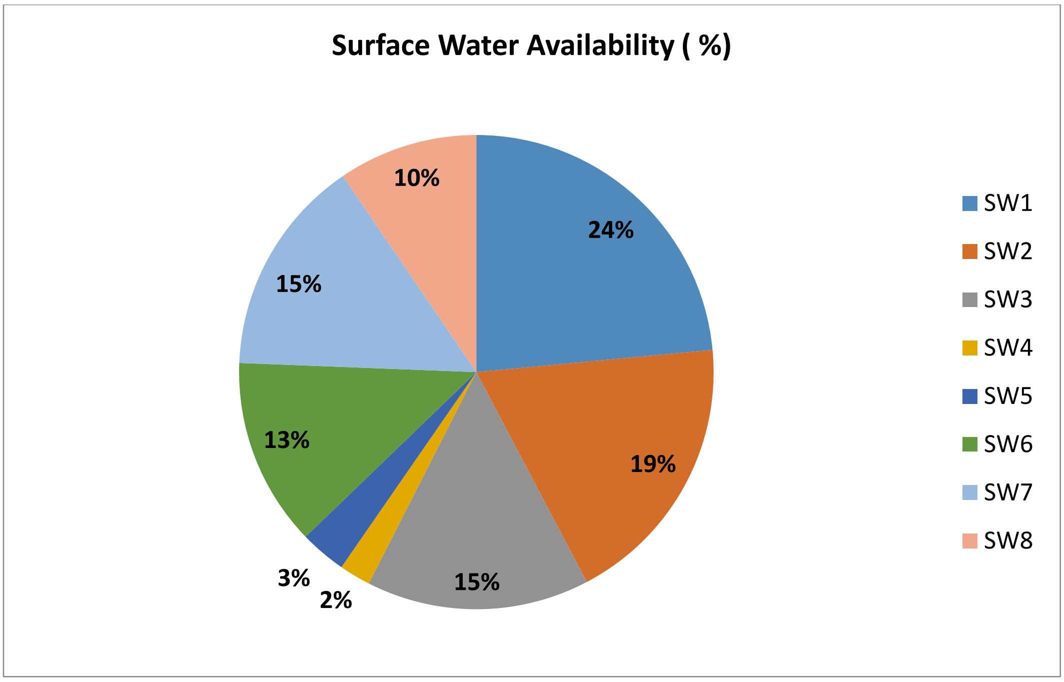


Figure 3.37: Percentage distribution of surface water availability in the Ur River Watershed

II. Groundwater

The diverse terrain conditions have given rise to different groundwater situations in the State. The rock formations ranging in age from Archaean to recent include gneisses, schists, phyllites, intrusive, medium to coarse grained sandstones, basalts and recent alluvium. The high relief area in the eastern and north eastern part occupied by Archaean and Deccan Trap have steep gradient allowing high run-off and therefore have little groundwater potential. The yield of wells in these formations ranges from 5 to 10 $m^3.h^{-1}$. The yield in sandstones varies from 50 to 170 $m^3.h^{-1}$. The yield of wells tapping Quaternary alluvium in Cambay basin ranges between 75-150 $m^3.h^{-1}$. There are five major aquifers in alluvial sediments out of which the top one has dried up due to over exploitation. The regional percentage distribution of 12000 million cubic meters of groundwater resources in Gujarat has been shown in the below figure. The pattern for groundwater availability is not the same as for surface water. Saurashtra has a maximum groundwater availability of 4300 million cubic meters followed by south Gujarat, central Gujarat, north Gujarat, and Kutch with 3950, 3300, and 450 million cubic meters respectively (NWRWS 2010).

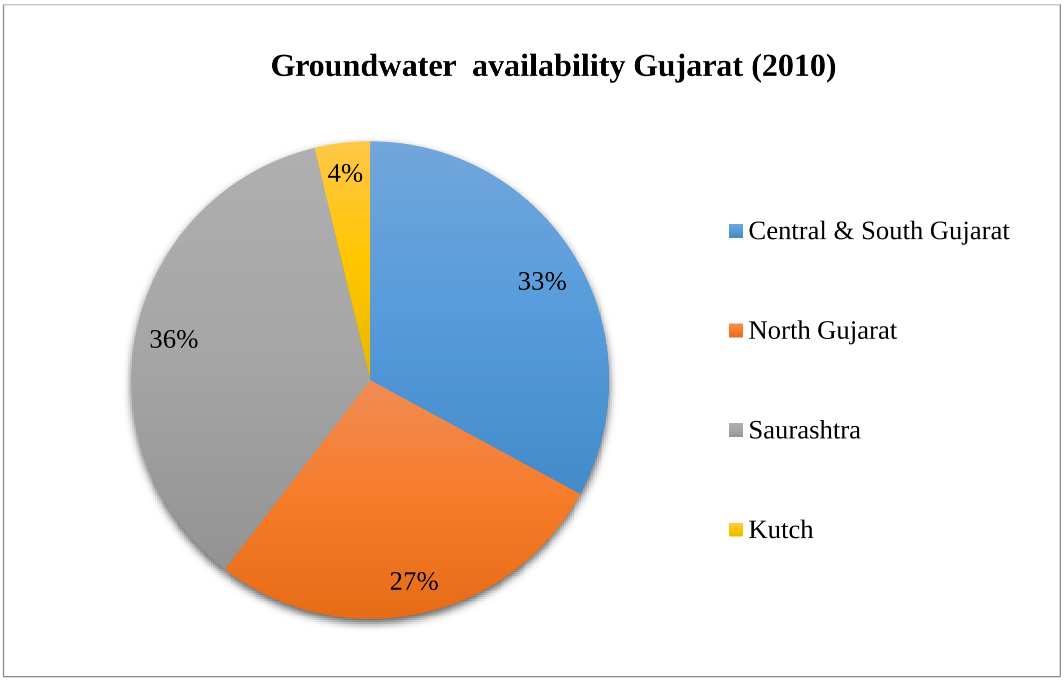
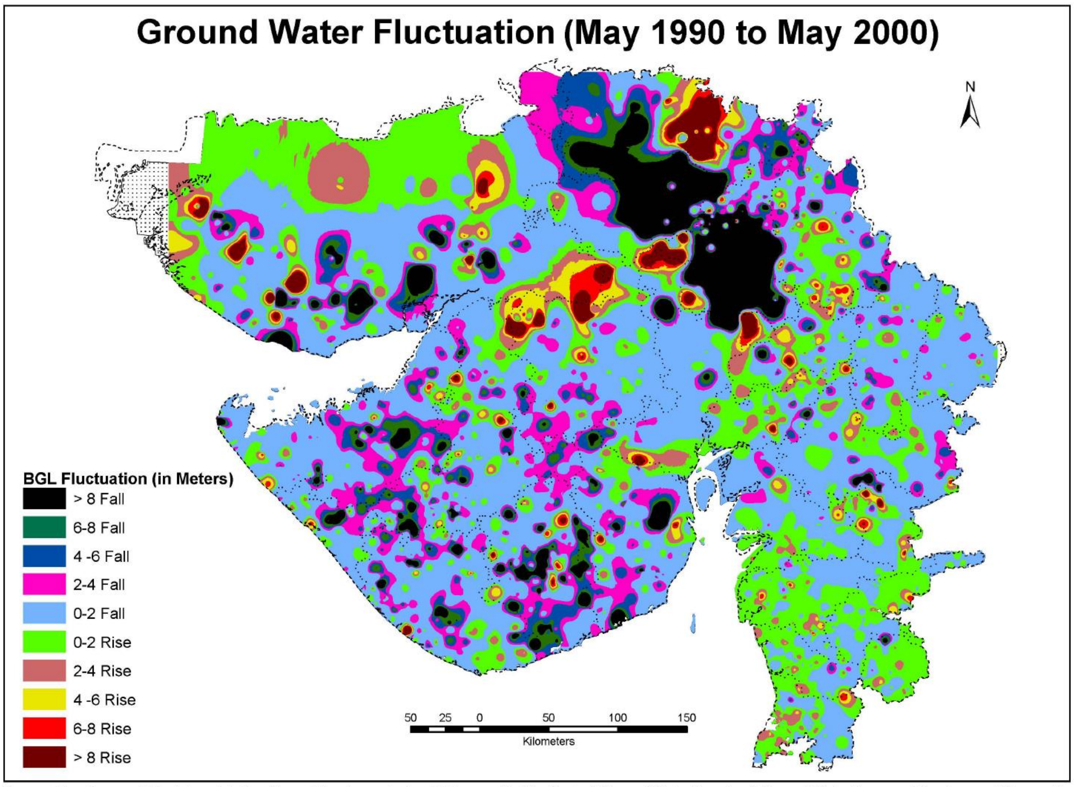


Figure 3.38: Groundwater availability in Gujarat

Groundwater fluctuation over the last two decades

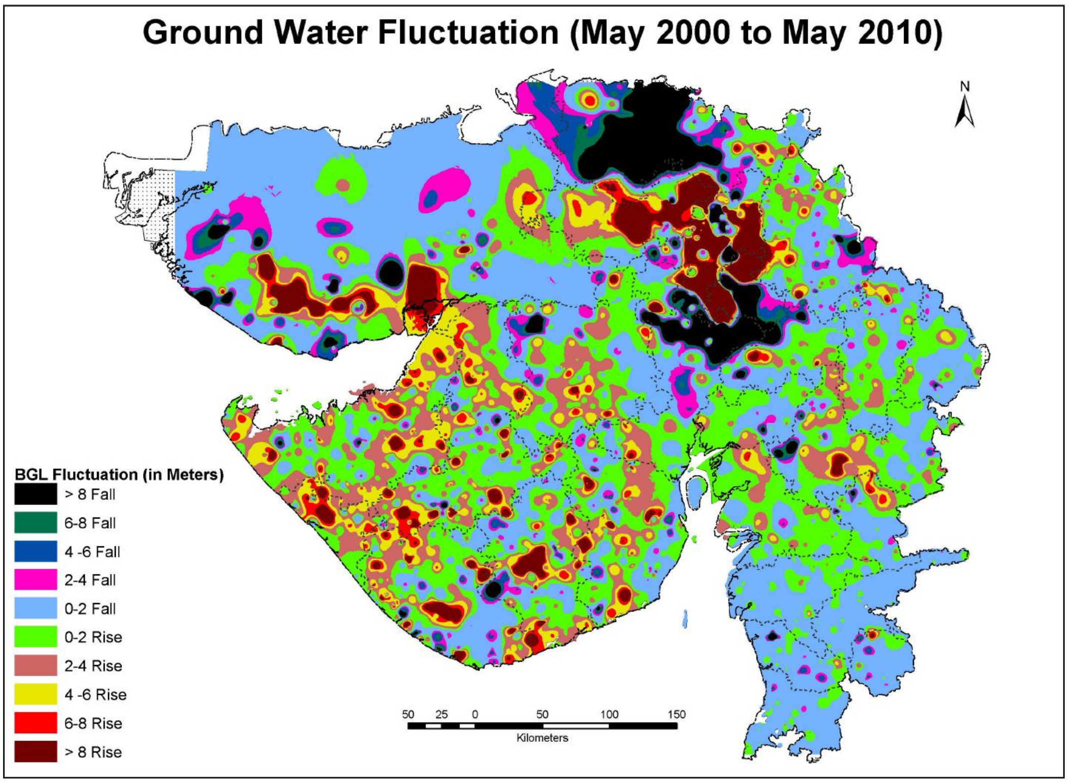
The groundwater table fell between May 1990 and May 2000 by 2 to 4 meters across the state of Gujarat, except in some parts of south Gujarat and the *Rann* of Kutch. 1 meter rise/fall is not taken into consideration. In north Gujarat, about 34% of area experiences more than 6 meters fall of ground water during 1990–2010. The period under discussion witnessed a general trend of decline of 0 to 2 meters fall as well as a rise of 0 to 2 meters in the water table across the state. However, the extreme situation of the earlier period still continues to haunt the region of north Gujarat. During the corresponding period, the Saurashtra region, in general, experienced a rise in its water table by 0 to 4 meters. This fact may be attributed to good rainfall in the last decade as well as to initiatives like augmentation of surface water and ground water recharge through the construction of recharge structures like check dams on a large scale. Although, there is a rise in ground water levels most part of the state, north Gujarat, and Kutch have seen an overall fall even during the decade of 2000–2010.

Source: Based on the spatially interpolated surface of data provided by Central Ground Water Board (CGWB) and Ground Water Resource Development Corporation (GWRDC). The pre-monsoon and post-monsoon wise average groundwater level influencing monitoring station are given in below figures. The average groundwater table in post and pre monsoon has been computed.



Source: Based on spatially interpolated surface of the pizometer level data provided by Central Ground Water Board and Ground Water Resource Development Corporation

Figure 3.39: Groundwater dynamics of Gujarat (May 1990 to May 2000)



Source: Based on spatially interpolated surface of the pizometer level data provided by Central Ground Water Board and Ground Water Resource Development Corporation

Figure 3.40: Groundwater dynamics of Gujarat (May 2000 to May 2010)

A study of fluctuation in groundwater level in Kozhikode district over the past decade (2002–2011) in the pre-monsoon has indicated that the groundwater level has shown a declining trend in parts of south/ south-eastern parts of the district, whereas, it shows rising trend in the northern parts of the district. The district has recorded a maximum fall in groundwater level 2.56 meters at Kozhikode (decadal mean 2002–2011 Vs 2012 April) and a maximum rise of 0.72 meters at Ramanattukara. The rise in groundwater level is less than 1 meter. The long term trend of pre-monsoon groundwater level for the last 10 years (2002–2011) indicates a falling trend in areas at Kozhikode, Balussery, Quilandy, etc. The rising trend is seen at Beypore, Thamarasseri, Mukkali, and Kakkayam, etc. Since the trend of groundwater level during the pre-monsoon indicates development, it can be seen that this is of insignificant nature and does not cause any concern. The analysis of the post-monsoon trend of groundwater level also does not show any trend which needs caution. Some areas showing declining trends include Kozhikode, Balussery, Chemencheri, etc. but around 33% of the locations of GWMWs experienced rising trend.

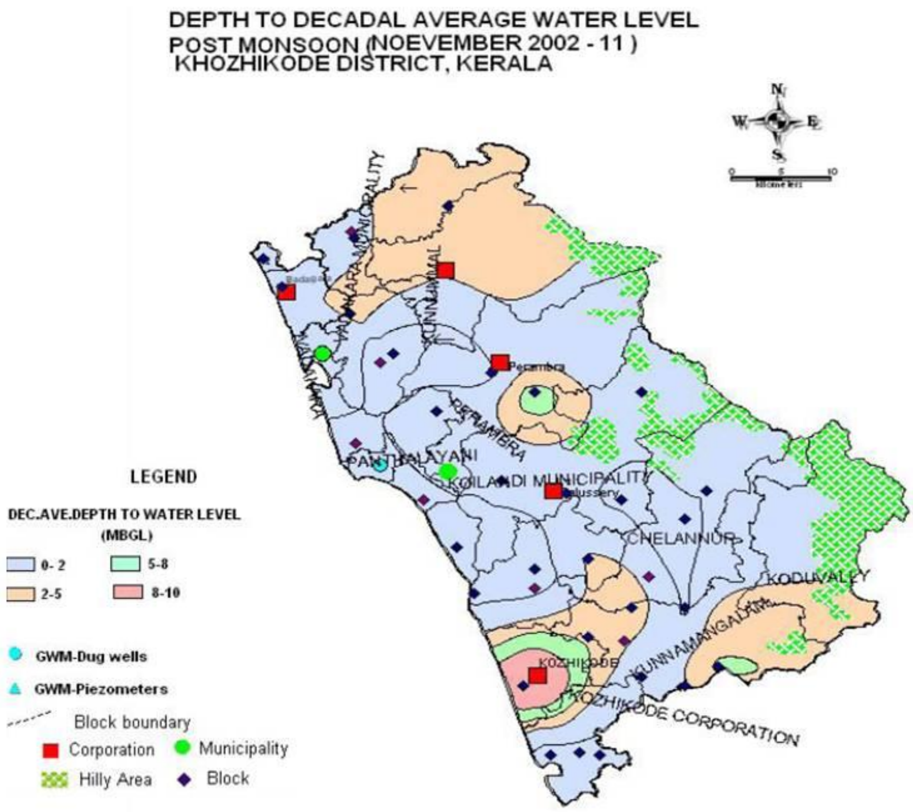


Figure 3.41: Groundwater dynamics of Kozhikode district

The long-term pre-monsoon and post-monsoon period wise average groundwater level series (normal) at each of the stations have been obtained by taking the average daily groundwater level value spanning 1995 to 2005. The pre-monsoon and post-monsoon wise average groundwater level influencing monitoring station are given Figure 3.42. The average groundwater table in post and pre-monsoon has been computed. The monitoring stations at Tikamgarh, Jatara, Baldeogarh, and Palera influence the rainfall pattern in the watershed and fluctuation of the groundwater table. It can be observed that the groundwater table of 2005 to 2006 (both pre and post-monsoon) have maximum influence and 1995 to 1996 (both pre and post-monsoon) has minimal influence on the rainfall pattern in the watershed. The graphical representation of groundwater level also indicates an increasing trend of groundwater table in the Ur River watershed.

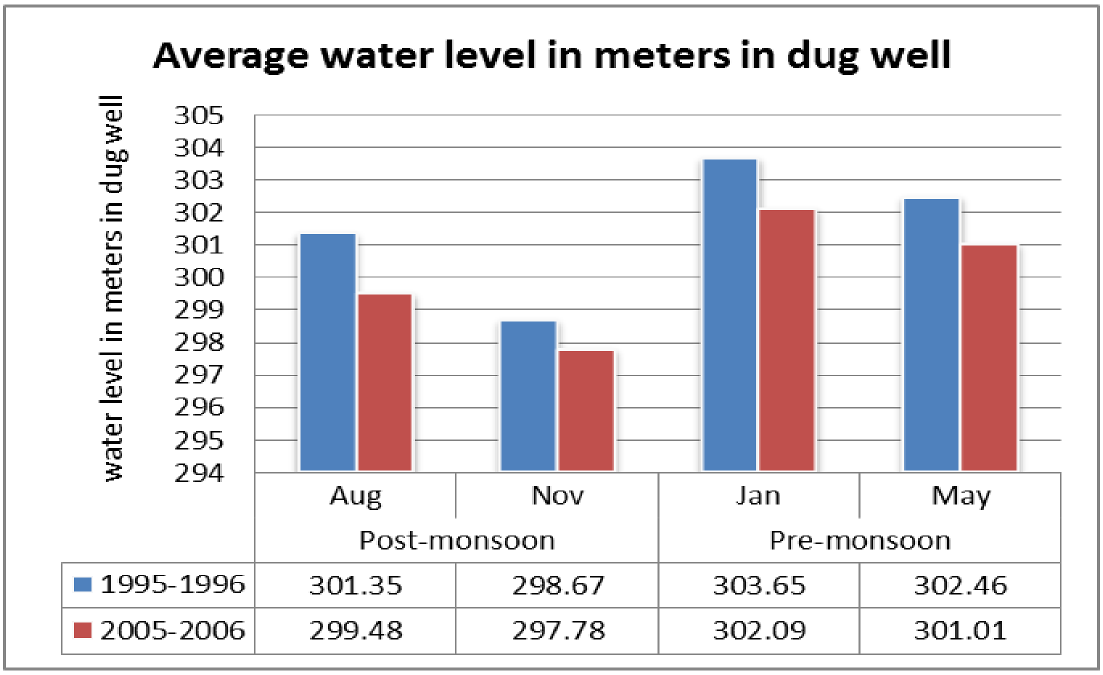


Figure 3.42: Groundwater fluctuations between 1995–2005 in Tikamgarh district

The change in groundwater storage includes a difference between the ground water storages at the start and end of the particular season. The change in groundwater storage has been evaluated by considering the difference between the groundwater levels at the start and end of the season and specific yield for the various types of formations in the watershed. The change in groundwater storage in the monsoon season has been considered by taking the difference in groundwater level between monsoon season groundwater level and preceding non-monsoon season groundwater level and multiplying with the specific yield and area of the watershed. Similarly, the groundwater storage in the non-monsoon season has been considered by taking the difference in groundwater level between monsoon season groundwater level and following year pre-monsoon groundwater level and multiplying it with the specific yield and area of the watershed.

Chapter 4: Crop Suitability and Agro-Ecologically Attainable Yield

4.1 Agro-Climatic Analysis

4.1.1 Potential Evapotranspiration of Reference Soil (mm)

Table 4.1 shows potential evapotranspiration of reference soil (ET0) for the reference climate (1981–2010) and projections for potential evapotranspiration of reference soil for different RCPs (2.6, 4.5, 6.0, and 8.5) during the periods 2050s (2041–2070) and 2080s (2071–2100) for the State of Gujarat, and Kozhikode and Tikamgarh districts. The potential evapotranspiration of reference soil for the reference climate in Gujarat is 1949 mm. The projection using different RCPs for period 2050s shows that change in potential evapotranspiration of reference soil in entire Gujarat may vary from 19 to 39 mm, and projection for period 2080s may vary from 19 to 117 mm. The potential evapotranspiration of reference soil for the reference climate in Kozhikode district is 1553 mm. The projection using different RCPs for period 2050s shows that change in potential evapotranspiration of reference soil in Kozhikode district may vary from 50 to 76 mm, and projection for period 2080s may vary from 61 to 136 mm. The potential evapotranspiration of reference soil for the reference climate in Tikamgarh district is 1782 mm. The projection using different RCPs for period 2050s shows that change in potential evapotranspiration of reference soil in Tikamgarh district may vary from -35 to 29 mm, and projection for period 2080s may vary from -32 to 108 mm.

Table 4.1: Annual potential evapotranspiration of reference soil (ET0) for reference climate (1981–2010) and ET0 projections for future climate scenarios during 2050s (2041–2070) and 2080s (2071–2100) for the study areas

Study areas	**ET0 (mm) during reference climate* (1981–2010)**	****E-Mean of ET0 projections during 2050s (mm)**				****E-Mean of ET0 projections during 2080s (mm)**			
		RCP 2.6	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**	**RCP 2.6**	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**
Gujarat	1949	1968	1968	1988	1988	1968	1988	2066	2066
Kozhikode	1553	1603	1604	1619	1629	1614	1626	1659	1689
Tikamgarh	1782	1776	1747	1797	1811	1780	1750	1845	1890

*Reference climate (CRUTS32: 1981–2010); **E-Mean: Ensemble mean-ESM2M of all five models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) are taken into consideration to avoid extreme variations in the result.

4.1.2 Reference Evapotranspiration Deficit (mm)

Table 4.2 shows reference evapotranspiration deficit (WDE) for the reference climate (1981–2010) and projections for actual evapotranspiration for different RCPs (2.6, 4.5, 6.0, and 8.5) during the periods 2050s (2041–2070) and 2080s (2071–2100) for the State of Gujarat, and Kozhikode and Tikamgarh districts. In the current climatic condition in Gujarat, reference evapotranspiration deficit is 1364 mm. The projection using different RCPs for period 2050s shows that change in reference evapotranspiration deficit in entire Gujarat may vary from 27 to 41 mm, and projection for period 2080s may vary from 27 to 95 mm. The reference evapotranspiration deficit in Kozhikode district for the reference period is 514 mm. The projection using different RCPs for period 2050s shows that change in reference evapotranspiration deficit in Kozhikode district may vary from 43 to 83 mm, and projection for period 2080s may vary from 38 to 88 mm. The reference evapotranspiration deficit in Tikamgarh district for the reference period is 1160 mm. The projection using different RCPs for period 2050s shows that change in reference evapotranspiration deficit in Tikamgarh district may vary from -23 to 24 mm, and projection for period 2080s may vary from -39 to 101 mm.

Table 4.2: Annual reference evapotranspiration deficit (WDE) for reference climate (1981–2010) and projections for future climate scenarios during 2050s (2041–2070) and 2080s (2071–2100) for the study areas

Study areas	**WDE (mm) during reference climate* (1981–2010)**	**E-Mean of WDE projections during 2050s (mm)**				**E-Mean of WDE projections during 2080s (mm)**			
		RCP 2.6	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**	**RCP 2.6**	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**
Gujarat	1364	1391	1391	1405	1391	1391	1405	1459	1459
Kozhikode	514	557	560	597	575	575	552	602	597
Tikamgarh	1160	1181	1137	1184	1184	1159	1121	1224	1261

*Reference climate (CRUTS32: 1981–2010); **E-Mean: Ensemble mean-ESM2M of all five models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) are taken into consideration to avoid extreme variations in the result.

4.1.3 Annual Actual Evapotranspiration (mm)

Table 4.3 shows annual actual evapotranspiration (ETA) for the reference climate (1981–2010) and projections for actual evapotranspiration for different RCPs (2.6, 4.5, 6.0, and 8.5) during the periods 2050s (2041–2070) and 2080s (2071–2100) for the State of Gujarat, and Kozhikode and Tikamgarh districts. The annual actual evapotranspiration for the reference climate in Gujarat is 586 mm. The projection using different RCPs for period 2050s shows that change in annual actual evapotranspiration in entire Gujarat may vary from -17 to 6 mm, and projection for period 2080s may vary from -6 to 12 mm. The annual actual evapotranspiration in Kozhikode district for the reference period is 1039 mm. The projection using different RCPs for period 2050s shows that change in annual actual evapotranspiration in Kozhikode district may vary from -18 to 15 mm, and projection for period 2080s may vary from 0 to 53 mm. The annual actual evapotranspiration in Tikamgarh district for the reference period is 621 mm. The projection using different RCPs for period 2050s shows that change in annual actual evapotranspiration in Tikamgarh district may vary from -26 to 5 mm, and projection for period 2080s may vary from 0 to 8 mm.

Table 4.3: Annual actual evapotranspiration (ETA) of reference soil and reference crop (mm) for reference climate (1981–2010) and projections for future climate scenarios during 2050s (2041–2070) and 2080s (2071–2100) for the study areas

Study areas	ETA (mm) during reference climate* (1981–2010)	**E-Mean of ETA projections during 2050s (mm)				**E-Mean of ETA projections during 2080s (mm)			
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Gujarat	586	569	580	586	592	580	586	598	598
Kozhikode	1039	1045	1043	1021	1054	1039	1073	1057	1092
Tikamgarh	621	595	609	613	626	621	628	621	629

*Reference climate (CRUTS32: 1981–2010); **E-Mean: Ensemble mean-ESM2M of all five models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) are taken into consideration to avoid extreme variations in the result.

4.1.4 Total Number of Growing Period Days (LGD)

Table 4.4 shows total number of growing period days (LGD) for the reference climate (1981–2010) and projections for total number of growing period days for different RCPs (2.6, 4.5, 6.0, and 8.5) during the periods 2050s (2041–2070) and 2080s (2071–2100) for the State of Gujarat, and Kozhikode and Tikamgarh districts. Total number of growing period for the reference climate for the entire Gujarat is 108 days. The projection using different RCPs for period 2050s shows that total number of growing period in entire Gujarat may vary from 105 to 111 days, and projection for period 2080s may vary from 107 to 109 days. Total number of growing period for the reference climate for the Kozhikode district is districts 265 days. The projection using different RCPs for period 2050s shows that total number of growing period in the Kozhikode district may vary from 250 to 257 days, and projection for period 2080s may vary from 250 to 259 days. Total number of growing period for the reference climate for the Tikamgarh district is districts 131 days. The projection using different RCPs for period 2050s shows that total number of growing period in the Tikamgarh district may vary from 129 to 133 days, and projection for period 2080s may vary from 128 to 136 days.

Table 4.4: total number of growing period days (LGD) for reference climate (1981–2010) and LGD projections for future climate scenarios during 2050s (2041–2070) and 2080s (2071–2100) for the study areas

Study areas	LGD (days) during reference climate* (1981–2010)	**E-Mean of LGD projections during 2050s (days)				**E-Mean of LGD projections during 2080s (days)			
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Gujarat	108	108	107	105	111	107	109	107	108
Kozhikode	265	255	257	250	257	253	259	250	258
Tikamgarh	131	129	130	130	133	130	136	128	128

*Reference climate (CRUTS32: 1981–2010); **E-Mean: Ensemble mean-ESM2M of all five models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) are taken into consideration to avoid extreme variations in the result.

4.2 Biomass and Yield Calculation

The main purpose of the AEZ Module II is the calculation of agro-climatically attainable biomass and yield for specific land utilization types (LUTs) under various input/management levels for rain-fed and irrigated conditions.

Module II consists of two steps:

i. Calculation of crop biomass and yield potentials considering only prevailing radiation and temperature conditions; and
ii. Computation of yield losses due to water stress during the crop growth cycle. The estimation is based on rain-fed crop water balances for different levels of soil water holding capacity.

Yield estimation for irrigation conditions assumes that no crop water deficits will occur during the crop growth cycle. As initial criteria to screen the suitability of grid-cells for the possible presence of individual LUTs, the AEZ assessment tests the match of prevailing conditions with the LUT's parametric requirements. A total of 15 matching are tested for the full range of possible starting dates and resulting in an optimum match, suboptimum match, and not suitable conditions. The "optimum and suboptimum match categories" are considered for further biomass and yield calculations. Calculation procedures of constraint-free biomass and yield (i.e. carbon accumulation is driven mainly by prevailing radiation and temperature regimes in a grid-cell) are based on a robust eco-physiological model (Kassam 1977). The constraint-free crop yields calculated in the AEZ assessment reflect yield potentials with regard to temperature and radiation regimes prevailing in the respective grid-cells. The model requires the following crop characteristics: (a) Length of growth cycle (days from emergence to full maturity); (b) minimum temperature requirements for emergency; (c) maximum rate of photosynthesis; (d) respiration rates for leguminous and non-leguminous crops as functions of temperature; (e) length of yield formation period; (f) leaf area index (LAI) at maximum growth rate; (g) harvest index (Hi); (h) crop adaptability group, and (i) sensitivity of crop growth cycle length to heat provision. The biomass calculation also includes simple procedures to account for different levels of atmospheric CO_2 concentrations. For each crop type and grid-cell, the starting and ending dates of the crop growth cycle are determined optimally to obtain best crop yields, separately for rain-fed and irrigated conditions. This procedure also entails adaptation of crop calendars (smart farmer) in simulations with year-by-year reference climate weather conditions, or under climate distortions applied in accordance with various climate change scenarios.

Land Utilization Types

Differences in crop types and production systems are empirically characterized by the concept of land utilization types (LUTs). An LUT consists of a set of technical specifications for crop production within a given socio-economic setting. Attributes specific to a particular LUT include agronomic information, nature of main produce, water supply type, cultivation practices, utilization of produce, and associated crop residues and by-products. The calculated yield of each crop/ LUT depends on climate, water sources and the assumed intensity of inputs and management. Three generic levels of input/management conditions are defined: low, intermediate, and high input level. Under a low level of inputs (traditional management assumption), the farming system is largely subsistence based. Production is based on the use of traditional cultivation (if improved cultivation is used, they are treated in the same way as local cultivation), labor intensive techniques, and no application of nutrients, no use of chemicals for pest and disease control, and minimum conservation measures. Under a high level of input (advanced management assumption), the farming system is mainly market oriented. Commercial production is the management objective. Production is based on improved or high yielding varieties, fully mechanized with low labor intensity and uses optimum applications of nutrients and chemical pest, disease and weed control measures. This variety in management and input levels is translated into yield differences by assigning different parameters for LUTs depending on the input/management level, e.g. such as harvest index and maximum leaf area index. LUTs are parameterized to reflect environmental and eco-physiological requirements for growth and development of different crop types. Numerical values of crop parameters are varied depending on the assumed input/management level to which LUTs are subjected.

Water Limited Biomass Production and Yields

Under rain-fed conditions, water stress may occur during different stages of the crop development reducing biomass production and the yields achieved. In the AEZ assessment, water requirements for each LUT are calculated and taken into account in the calculation of LUT-specific water balance and actual evapotranspiration in a grid-cell. The total water requirement of a crop without any water stress is assumed to be the crop-specific potential evapotranspiration (ETm). The ETm is calculated in proportion to reference potential evapotranspiration (ET0), as in Module I, multiplied by crop and crop-stage specific parameters 'kc'. The values of kc for different stages of crop development are given as input parameters (FAO 1992a; 1992b; 1992c; 1998). Yield reduction in response to water deficits is calculated as a function of the relationship between actual crop evapotranspiration (ΣETa, mm/day) and maximum crop evapotranspiration (ΣETm, mm/day), both accumulated within and across the four crop stages. The sensitivity of each crop to water stress is expressed by the value of the water stress coefficient (ky, fractional), an LUT-specific parameter which changes with crop development stage. Water limited yield is then calculated as potential yield multiplied by the grid-cell specific water-stress reduction factor (FAO 1992b; 1998).

4.3 Agro-Climatic Constraints

At the stage of computing potential biomass and yields, no account is taken of the climatic–related effects operating through pests and diseases, and workability. Agro-climatic constraints cause direct or indirect losses in the yield and quality of the product. Yields losses in a rain-fed crop due to agro-climatic constraints have been formulated based on principles and procedures originally proposed in FAO (1978–1981a, b) and on experiences in individual countries (e.g. China, Bangladesh, Mozambique, Ghana, Kenya). The relationships between these constraints with general agro-climatic conditions such as moisture stress and excess air humidity are varying by location, between agricultural activities as well as by the use of control measures. The impact of these yield constraints on the basis of prevailing climatic conditions has been approximated. The efficacy of control of these constraints (e.g. pest management) is accounted for the assumed three levels of inputs. Due to the relatively high level of uncertainty, the assessment of agro-climatic constraints has been applied separately in Module III, such that effects are transparent, well separated.

Five different yield constraints (i.e. yield-reducing factors) are taken into account: (a) Long-term limitation to crop performance due to year-to-year rainfall variability; (b) Pests, diseases and weeds damage on plant growth; (c) Pests, diseases and weeds damage on quality of produce; (d) Climatic factors affecting the efficiency of farming operations; and (e) Frost hazards.

4.4 Agro-Edaphic Constraints

Module IV estimates factors for yield reductions caused by constraints due to prevailing soil and terrain-slope conditions. The soil suitability is assessed through crop/ LUT specific evaluations of major soil qualities. Terrain suitability is estimated from terrain-slope and rainfall concentration characteristics. Soil and terrain characteristics are read from 3 arc-second grid-cells in which prevailing soil and terrain combinations have been quantified. Soil units are characterized by the following soil parameters: organic carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry. For this AEZ study, the calculations are crop/ LUT specific and are performed for an assumed high input level and four water supply systems separately, including rain-fed conditions, sprinkler irrigation, gravity irrigation and drip irrigation.

Soil Suitability Assessment Procedures

In the AEZ assessment, edaphic suitability is assessed in terms of several land qualities specifically related to soil properties and conditions as reflected in the soil database and the terrain-slope database. The individual soil profile attributes, soil drainage conditions and prevalence of soil phases that have been related to requirements and tolerances of crops one combined ultimately into land utilization specific soil suitability ratings. First, individual soil qualities are defined and quantified. The below table provides an overview of the seven soil qualities used in the AEZ assessment in relation to relevant soil profile attributes, including soil drainage conditions and soil phase prevalence.

Table 4.5: Soil qualities and soil attributes

Rating	Soil Qualities	Soil quality related soil profile attributes, soil drainage conditions and soil phase characteristics
SQ1	Nutrient availability	Soil texture, soil organic carbon, soil pH, total exchangeable bases
SQ2	Nutrient retention capacity	Soil texture, base saturation, cation exchange capacity of soil and of clay fraction
SQ3	Rooting conditions	Soil textures, coarse fragments, vertic soil properties and soil phases affecting root penetration and soil depth and soil volume
SQ4	Oxygen availability to roots	Soil drainage and soil phases affecting soil drainage
SQ5	Excess salts (salinity and sodicity)	Soil salinity, soil sodicity and soil phases influencing soil salinity and sodicity conditions
SQ6	Toxicity	Calcium carbonate and gypsum
SQ7	Workability (constraining field management)	Soil texture, effective soil depth/volume, and soil phases constraining soil management (soil depth, rock outcrop, stoniness, gravel/concretions and hardpans)

The seven soil qualities (SQ1-7) are estimated from soil characteristics (e.g., organic carbon content, soil pH, texture) read from the soil database. The soil qualities influencing crop performance considered in the assessment include nutrient availability (SQ1); nutrient retention capacity (SQ2); rooting conditions (SQ3); oxygen availability to roots (SQ4); salinity and sodicity (SQ5); toxicities (SQ6); and workability (SQ7). Each of the seven SQ ratings is derived from specific soil characteristics. Soil profile attributes considered for both top-soil (0 to 30 cm) and sub-soil (30 to 100 cm) separately include: soil texture; organic carbon content; pH, cation exchange capacity of soil and clay fraction; base saturation; total exchangeable bases; calcium carbonate contents; gypsum content; sodicity and salinity. In addition prevalence of soil phases, soil drainage characteristics, and of vertic soil properties are also considered.

Soil Suitability

Soil suitability classification procedures, follow a two-step approach:

i. Crop responses to individual soil attribute conditions and relevant soil drainage and phase conditions are combined into soil quality (SQ) ratings

ii. Soil qualities are combined in crop specific, input and management level specific and water supply specific soil suitability ratings

Functional relationships of soil qualities have been formulated to quantify crop/ LUT suitability of soil units. The following guiding principles formed the basis for the way soil qualities were combined with different levels of inputs and management:

- Nutrient availability and nutrient retention capacity are key soil qualities;
- Nutrient availability is of utmost importance for low level input farming; nutrient retention capacity is most important for high level inputs;
- Nutrient availability and nutrient retention capacity are considered of equal importance for intermediate level inputs farming;
- Nutrient availability and nutrient retention capacity are strongly related to rooting depth and soil volume available; and
- Oxygen available to roots, excess salts, toxicity and workability are regarded as equally important soil qualities, and the combination of these four soil qualities is best achieved by multiplication of the most limiting rating with the average of the ratings of the remaining three soil qualities

The results of the soil unit suitability assessment are stored by each soil unit/ slope class/ crop/ input level/ water supply system combination for integration with the results of the agro-climatic suitability assessment (in Module V).

Terrain Suitability

The influence of topography on agricultural land use is manifold. Farming practices are adapted to terrain slope, slope aspect, slope configuration and micro-relief. For instance, steep irregular slopes are not practical for mechanized cultivation, while these slopes might very well be cultivated with adapted machinery and hand tools. Sustainable agricultural production on sloping land is foremost concerned with the prevention of erosion of topsoil and decline of fertility. Usually, this is achieved by combining special crop management and soil conservation measures. Cultivated sloping land may provide inadequate soil protection and without sufficient soil conservation measures, cause a considerable risk of accelerated soil erosion. In the short term, cultivation of slopes might lead to yield reductions due to loss of applied fertilizer and fertile topsoil. In the long term, this will result in losses of land productivity due to truncation of the soil profile and consequently reduction of natural soil fertility and of available soil moisture.

The terrain-slope suitability rating used in the AEZ assessment captures the factors described above which influence production and sustainability. This is achieved through: (i) defining for the various crops permissible slope ranges for cultivation, by setting maximum slope limits; (ii) for slopes within the permissible limits, accounting for likely yield reduction due to loss of fertilizer and topsoil, and (iii) distinguishing among farming practices ranging from manual cultivation to fully mechanized cultivation. Slope ratings are defined by crop group, input level and for the eight slope range classes used in the land resources database.

4.5 Integration of Climatic and Edaphic Evaluation

Module V executed the final step in the AEZ assessment crop suitability and land productivity assessment. It reads the LUT specific results of the agro-climatic evaluation for biomass and yield calculated in Module II/ III for different soil classes and its uses the edaphic ratings produced for each soil/slope combination in Module IV. The inventories of soil resources and terrain-slope conditions are integrated by ranking all soil types in each soil map unit with regard to an occurrence in different slope classes. Considering simultaneously for all grid cells belonging to a particular soil map unit the respective slope class distribution results in an overall consistent distribution of soil-terrain slope combinations by individual soil association map units and 3 arc-sec grid cells. Soil evaluation and slope rules are applied separately for each water supply system. The algorithm in Module V steps through the grid cells of the spatial soil association layer of soil database and determines for each grid cell the respective make-up of land units in terms of soil types and slope classes. Each of these component land units is separately assigned the appropriate suitability and yield values and results are accumulated for all elements. Processing of soil and slope distribution information takes place at 3 arc-second grid cells.

The main purpose of Module V is to compile a grid-cell database for each crop or crop group storing evaluation results that summarize the processed sub-grid information. Computations include the following steps:

i. Reading agro-climatic yields calculated for separate crop water balances of six broad soil AWC classes (from Module II/ III);
ii. Applying the AEZ rules for water-collecting sites (defined as Fluvisols and Gleysols in flat terrain);
iii. Applying reduction factors due to edaphic evaluation for the specific combinations of soil types/slope classes making up a grid-cell; and
iv. Aggregating results over component land units (i.e. soil type/ slope combinations)

The results of crop evaluations in Module V are stored as separate databases each organized by grid cells. Separate files are generated by crop, input level, water supply system, and scenario/ time period. Each database contains information in terms of suitable extents and potential production by suitability classes. Various utility programs have been developed to aggregate and tabulate results by administrative units or to map the contents of Module V crop databases in terms of suitability index and potential grid cell output. Assessing crop suitability is an important component of assessment studies, including changes to crops geographic distribution under climate change in coming decades. On the one hand, it is well known that crops will respond to specific changes in temperature and precipitation at the locations where they are currently grown; on the other, it is also expected that not all crops and cultivars will remain suitable within their current geographical ranges, with tendencies to migrate towards higher latitudes and a push out of production in areas already at the margin of production. Yet most crop modeling platforms available today present fixed grid simulations of crops, i.e. they do not allow for dynamical movements of ideal crop ranges, and thus tend to underestimate likely adaptation responses by farmers. These will doubtlessly attempt to switch where possible to cultivars and crops better adapted to changing conditions. By the same token, those model platforms that have excelled in computing suitability have much less crop modeling detail than available under the proposed platform. Adequate agricultural exploitation of the climatic potentials and maintenance of land productivity largely depend on soil fertility and the management of soils on an ecologically sustained basis. Soil fertility is concerned with the ability of the soil to retain and supply nutrients and water in order to enable crops to maximally utilize the climatic resources of a given location. The fertility of a soil is determined by both its physical and chemical properties. An understanding of these factors and insight in their interrelations is essential for the effective utilization of climate, terrain and crop resources for optimum use and production. From the basic soil requirements of crops, a number of soil characteristics have been established related to crop yield. For most crops, optimal, sub-optimal, marginal, and unsuitable levels of these soil characteristics are known and have been quantified. Beyond critical ranges, crops cannot be expected to yield satisfactorily unless special precautionary management measures are taken. Soil suitability classifications are based on knowledge of crop requirements of prevailing soil conditions, and of applied soil management. In other words, soil suitability procedures quantify to what extent soil conditions match crop requirements under defined input and management circumstances.

4.6 Net Primary Production: Rain-fed Condition (kg/ha)

Table 4.6 shows net primary production in rain-fed condition (NPP-R) for the reference climate (1981–2010) and projections for net primary production in rain-fed condition for different RCPs (2.6, 4.5, 6.0, and 8.5) during the periods 2050s (2041–2070) and 2080s (2071–2100) for the State of Gujarat, and Kozhikode and Tikamgarh districts. The net primary production in rain-fed condition for the reference climate in entire Gujarat is 9799 kg/ha. The projection using different RCPs for period 2050s shows that change in net primary production in rain-fed condition in Gujarat may vary between -392 to 196 kg/ha, and projection for period 2080s may vary between -296 to 196 kg/ha. The net primary production in rain-fed condition for the reference climate in Kozhikode district is 14729 kg/ha. The projection using different RCPs for period 2050s shows that change in net primary production in rain-fed condition in Kozhikode district may vary between -272 to -20 kg/ha, and projection for period 2080s may vary between -36 to 201 kg/ha. The net primary production in rain-fed condition for the reference climate in Tikamgarh district is 11389 kg/ha. The projection using different RCPs for period 2050s shows that change in net primary production in rain-fed condition in Tikamgarh district may vary between -536 to -19 kg/ha, and projection for period 2080s may vary between -99 to 235 kg/ha.

Table 4.6: Rain-fed net primary production (kg/ha) for reference climate (1981–2010) and NPP-R projections for future climate scenarios 2050s (2041–2070) and 2080s (2071–2100)

Study areas	NPP-R (kg/ha) during reference climate* (1981–2010)	**E-Mean of NPP-R projections during 2050s (kg/ha)				**E-Mean of NPP-R projections during 2080s (kg/ha)			
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Gujarat	9799	9407	9701	9603	9995	9701	9995	9995	9505
Kozhikode	14729	14709	14683	14457	14582	14693	14799	14817	14930
Tikamgarh	11389	10853	11246	11185	11370	11398	11624	11290	11327

*Reference climate (CRUTS32: 1981–2010); **E-Mean: Ensemble mean-ESM2M of all five models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) are taken into consideration to avoid extreme variations in the result.

4.7 Climate Change Impacts on Crop Suitability and Attainable Yield

The analysis was carried out for the reference climate (1981–2010) and for the ensemble mean of all five models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) under RCP 4.5 climate scenarios for the period 2050s (2041–2070). Ensemble mean of all five models was considered in order to avoid extreme variations in the result. Results of the analysis for the crops show: (i) suitability index, area (ˣ000 hectares) & percentage, occurrence of very suitable and suitable agricultural land; and (ii) attainable yield (kg/ha), i.e. reference climate and for the ensemble mean of five models under RCP 4.5 climate scenarios for the period 2050s. The AEZ results show that projected climate change affects crop production differently across crops regions.

In Gujarat, the projected areas show a drastic reduction everywhere except Saurashtra, which shows an increase in harvested area of only a couple of thousand square kilometers. The harvested area of mustard, peanut, bajra, castor, pigeon, mango, wheat, and white potato decreases ranging from 63 to 100 %. Mustard, BT cotton, mango, wheat, and white potatoes have never been grown in the rain-fed condition and will be suitable for irrigated conditions only. Sorghum will be promising crop in most parts of Gujarat. Regarding irrigation and production conditions, the substantial a decrease in harvested areas and a decrease of yield are reflected with only sorghum, cotton, BT cotton and maize promising a yield increase between 8 and 32 %. The below tables provide a reference climate overview of harvested and suitable areas, and yield for the top agricultural commodities of the State of Gujarat under rain-fed and irrigated conditions.

Table 4.7: Area harvested (*000 Hectare) and yield (kg/ha) for rain-fed crops in the State of Gujarat:

Crop Type	Rain-fed Crops	------------------------------ VS+S ----------------------------					
		Area (*000 Hectare)			Yield (kg/ha)		
		1981–2010*	2050s**	% Difference	1981–2010*	2050s**	% Difference
Food Grains	Bajra	2277.8	852.1	-62.6	1695.0	1703.3	0.5
	Maize	3162.9	3616.2	14.3	6702.4	6692.2	-0.2
	Rice (rcb)	0.0	12.8		0.0	3216.0	
	Rice (rcw)	0.0	0.0		0.0	0.0	
	Sorghum	6386.0	7026.9	10.0	5844.8	6089.0	4.2
Cash Crops	BT cotton	0.0	0.4		0.0	789.0	
	Cotton	950.3	1198.6	26.1	577.0	615.4	6.7
	Sugarcane	0.0	0.0		0.0	0.0	
	Tobacco	22.0	18.8	-14.5	478.3	884.5	84.9
Pulses	Gram	2277.8	852.1	-62.6	1695.0	1703.3	0.5
	Pigeon pea	1130.8	455.4	-59.7	1982.5	1983.3	0.0
Oil Crops	Castor seed	406.3	172.5	-57.5	1995.8	2011.3	0.8
	Groundnut	117.4	56.7	-51.7	2171.8	2203.5	1.5
	Jatropha	0.0	0.0	0.0	0.0	0.0	0.0
	Sesamum	2030.0	847.9	-58.2	2666.2	2617.4	-1.8
	Soya Bean	1080.3	1692.7	56.7	3130.4	2946.0	-5.9
Horticulture crops	Mango	0.0	3.1		0.0	8371.0	
	Onion	0.0	0.0	0.0	0.0	0.0	0.0
	Orange	0.0	0.2		0.0	5809.0	
	Tomato	258.6	55.9	-78.4	2979.4	3122.0	4.8
Fodder Crops	Fodder Maize	3561.7	4366.6	22.6	10557.4	10995.2	4.1
	Fodder Sorghum	5931.0	6288.6	6.0	10540.8	11026.8	4.6

*Reference climate (CRUTS32: 1981–2010); **E-Mean: Ensemble mean-ESM2M of all five models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) for period (2041–2070) are taken into consideration to avoid extreme variations in the result.

Table 4.8: Area harvested (*000 Hectare) and yield (kg/ha) for irrigated crops in the State of Gujarat:

Crop Type	Irrigated Crops	------------------------------ VS+S ----------------------------					
	† Rabi Crops	Area (*000 Hectare)			Yield (kg/ha)		
		1981–2010*	2050s**	% Difference	1981–2010*	2050s**	% Difference
Food Grains	Bajra	1223.5	303.6	-75.2	1810.0	1487.6	-17.8
	Barley†	1343.0	51.0	-96.2	3822.8	3875.5	1.4
	Maize	4086.0	4521.0	10.6	7764.0	7863.6	1.3
	Rice (rcb)	1535.5	1474.6	-4.0	4382.2	4253.0	-2.9

Crop Type	Irrigated Crops	------------------------------ VS+S ---------------------------					
	† Rabi Crops	Area (*000 Hectare)			Yield (kg/ha)		
		1981–2010*	2050s**	% Difference	1981–2010*	2050s**	% Difference
	Rice (rcw)	1563.4	2954.6	89.0	7560.8	4837.6	-36.0
	Sorghum	6964.5	7081.7	1.7	6538.4	6686.4	2.3
	Wheat†	2255.3	234.3	-89.6	3969.3	3864.0	-2.7
Cash Crops	BT cotton	6815.9	7923.4	16.2	1032.4	1135.6	10.0
	Cotton	6202.5	6702.3	8.1	906.8	953.8	5.2
	Sugarcane	5789.7	2554.3	-55.9	10074.8	9402.4	-6.7
	Tobacco	9.8	15.7	60.2	853.0	1000.0	17.2
Pulses	Gram	1223.5	303.6	-75.2	1810.0	1859.5	2.7
	Pigeon pea	2499.9	1031.3	-58.7	2219.2	2175.6	-2.0
Oil Crops	Castor seed	961.0	290.0	-69.8	2209.6	2187.4	-1.0
	Groundnut	1518.5	337.5	-77.8	2473.6	2472.5	0.0
	Jatropha	5234.0	3464.8	-33.8	3155.6	3031.0	-3.9
	Mustard†	56.9	0.8	-98.6	1398.5	1558.0	11.4
	Sesamum	4060.4	2349.3	-42.1	3087.2	2997.4	-2.9
	Soya Bean	2722.6	1601.5	-41.2	3429.0	3444.0	0.4
Horticulture crops	Banana	36.0	745.4	1970.6	6818.5	6836.4	0.3
	Mango	6024.8	3152.1	-47.7	10710.4	10235.0	-4.4
	Potato†	2.5	0.0	-100.0	8109.0	0.0	-100.0
	Onion	53.9	7.5	-86.1	6331.0	6599.0	4.2
	Onion†	2407.5	2362.0	-1.9	7188.8	7281.4	1.3
	Orange	2329.3	8.2	-99.6	7621.0	6956.0	-8.7
	Orange†	2329.3	2324.5	-0.2	7621.0	7644.8	0.3
	Tomato	34.7	19.6	-43.5	5075.5	3831.0	-24.5
	Tomato†	2585.4	2227.8	-13.8	5696.2	5636.0	-1.1
Fodder Crops	Fodder Maize	4086.8	4521.4	10.6	11815.0	11965.8	1.3
	Fodder Sorghum	6968.3	7087.7	1.7	11966.6	12237.4	2.3
Spices	Cumin†	1460.6	825.1	-43.5	958.0	885.0	-7.6

*Reference climate (CRUTS32: 1981–2010); **E-Mean: Ensemble mean-ESM2M of all five models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) for period (2041–2070) are taken into consideration to avoid extreme variations in the result.

The output shows the likelihood of negative impacts on site suitability, Climate suitability and crop yield for several crops. Modeling the impacts of an increase in temperature on irrigation water requirements in Palakkad district showed that the total crop water requirement of all the major crops like coconut, paddy, and banana, increased with increase in temperature and thereby increasing the irrigation water demand (Surendran et al. 2014). The rise in the mean temperature above a threshold level will cause a reduction in agricultural yields. Soil temperature affects the rates of organic matter decomposition and release of nutrients. At high temperatures, though nutrient availability will increase in the short-term, in the long-run organic matter content will diminish, resulting in a decline in soil fertility. The results include a continuous representation of the calculated suitability index (i.e. a weighted sum of the extents of different suitability classes occurring within a grid cell due to soil associations), a suitability index map in broad classes, share of each grid cell assessed as very suitable (VS) or suitable (S), share of each grid cell in the best three classes (very suitable, suitable, and moderately suitable), average potential output per unit area of a grid cell, and highest class yield occurring in each grid cell.

The AEZ analysis for Kozhikode district shows that for Ensemble mean-ESM2M and RCP 4.5 scenario, under rain-fed conditions, the yield of banana, areca nut, rubber, coffee, and black pepper shows a decline between 2.89 and 86.18 %. However, coconut and rice, under rain-fed conditions, shows a minor increase of 3.17 and 0.99 % respectively. Under irrigated conditions, the yield of coconut, areca nut, coffee, and black pepper shows a decline between 3.83 and 86.18 %. The yield of rubber and rice shows a minor increase of 1.55 and 1 % respectively. However, if we look at all the models and different RCPs showed that in most of the cases the yield tends to decline except a few. Similarly is the case with site suitability also, which is evident from the tables and crop climate suitability is changing abruptly with respect to climate change. The below tables provide a reference climate overview of harvested areas and yield for the top agricultural commodities of the Kozhikode district under rain-fed and irrigated conditions. Results of the analysis for the crops banana, rubber, coffee, black pepper, rice, coconut, and areca nut are summarized.

Table 4.9: Area harvested (˟000 Hectare) and yield (kg/ha) for rain-fed crops in the Kozhikode district:

Crop Type	Rain-fed Crops	------------------------------ VS+S+MS+mS+vmS ---------------------------					
		Area (˟000 Hectare)			Yield (kg/ha)		
		1981–2010*	2050s**	% Difference	1981–2010*	2050s**	% Difference
Horticulture crops	Banana	74102	70857.8	-4.38	2872	2051	-28.59
	Coconut	67371	69507	3.17	3418	2683.4	-21.49
	Arecanut	74102	31836.2	-57.04	690	693.2	0.46
Cash Crops	Rubber	72968	70857.8	-2.89	476	456	-4.20
	Coffee	71749	9915	-86.18	1291	1387.8	7.50
Spices	Black Pepper	74102	31836.2	-57.04	222	223.8	0.81
Food Grains	Rice	69507	70198	0.99	3004	3251.2	8.23

*Reference climate (CRUTS32: 1981–2010); **E-Mean: Ensemble mean-ESM2M of all five models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) for period (2041–2070) are taken into consideration to avoid extreme variations in the result.

Table 4.10: Area harvested (*000 Hectare) and yield (kg/ha) for irrigated crops in the Kozhikode district:

Crop Type	Irrigated Crops	------------------------------ VS+S+MS+mS+vmS ---------------------------					
		Area (*000 Hectare)			Yield (kg/ha)		
		1981–2010*	2050s**	% Difference	1981–2010*	2050s**	% Difference
Horticulture crops	Banana	74102	74102	0.00	3867	3054.4	-21.01
	Coconut	67371	64791	-3.83	2687	2076.6	-22.71
	Arecanut	74102	32166.8	-56.59	887	846.2	-4.59
Cash Crops	Rubber	72968	74102	1.55	1219	1297.6	6.44
	Coffee	71749	9915	-86.18	1069	1058.4	-0.99
Spices	Black Pepper	74102	32166.8	-56.59	266	252.8	-4.96
Food Grains	Rice	69506	70198	1.00	3015	3208.5	6.41

*Reference climate (CRUTS32: 1981–2010); **E-Mean: Ensemble mean-ESM2M of all five models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) for period (2041–2070) are taken into consideration to avoid extreme variations in the result.

The analysis using the AEZ model for the Ur River watershed shows crop suitability index and output density of various Kharif and Rabi crops. There are seven land suitability classes described as follow: very highly suitable, highly suitable, medium suitable, moderately suitable, marginally suitable, very marginally suitable, and not suitable for each LUT. The pearl millet and sorghum (grain) crop showed the maximum area under very high and high suitability index with output density of 4046 kg/ha and 5484 kg/ha respectively. The maize (grain), fodder maize and fodder sorghum are a medium suitable for most of the area of the Ur River watershed. The output density will vary for maize (grain-5209 kg/ha), fodder maize (8017 kg/ha), and fodder sorghum (8542 kg/ha) as per their suitability. These crops also show very highly suitable area along the Ur River watershed. Most of the Kharif crops are under limited suitability (in between moderate and marginal) category for future climatic conditions (HadGEM2-ES; RCP 4.5) during the 2020s (average of 2011–2030). The crops like colocasia (829 kg/ha), cowpea (1041 kg/ha), phaseolus bean (1208 kg/ha), cumin (358 kg/ha), dryland rice (1374 kg/ha), fodder cowpea (2788 kg/ha), green gram (1046 kg/ha), sesame (1203 kg/ha), soya bean (1660 kg/ha), sweet potato (3554 kg/ha), and groundnut (1049 kg/ha) are limited suitable in future agro- climatic condition, with rain-fed situation and high input level of seed, fertilizers and agronomic cultivable practices. Among these crops, phaseolus bean, cumin, fodder cowpea, and sweet potato are not being grown in the Ur River watershed. But, the agro-climatic analysis of the AEZ model showed limited suitability index over the watershed for these crops. The maximum area of the watershed is marginally suitable for pigeon pea, tomato, and jatropha with output density of 517 kg/ha, 1014 kg/ha, and 25 kg/ha respectively. The tomato crop shows two distinct categories of suitability as not suitable area and Marginal suitable area. Moreover, rice (Indica), green onions, and onions showed non-suitability for future climatic conditions.

The results of agro-climatic analysis of the AEZ model for the Ur River watershed also reveals the crop suitability index and output density of various Rabi crops for rain-fed conditions with a high level of inputs. It can be seen that all the Rabi crops are showing a not suitable category of the area under rain-fed conditions in the Ur River watershed. The Rabi crops of the watershed are almost dependent on the irrigation during growing season unless some winter showers occur during the season. The AEZ model also offers the capability of assessing the suitability of crops under gravity irrigation facility. Therefore, the suitability index and output density results of Rabi crops were also assessed for irrigation conditions. The maximum area of the Ur River watershed showed medium suitability index for growing wheat with output density 4039 kg/ha. The variation in suitability pattern of barley (marginal to high) and tomato (marginal to very high) was more within the watershed area. The output density of barley and tomato is 4184 kg/ha and 5053 kg/ha respectively. The Rabi crops like lentil (1906 kg/ha), mustard (850 kg/ha), potato (4364 kg/ha) and pea (1288 kg/ha) are under limited suitability (in between moderate and marginal) category for future climatic conditions (HadGEM2-ES; RCP 4.5) during 2050s (average of 2041–2070). Half of the watershed area falls under a not suitable category for growing pea in future climatic conditions. All the crops showed marginal to high suitability index for growing along the river which may be due to available soil moisture for a longer period.

Chapter 5: Adaptive Approaches to Land, Nutrient, and Water Management across Cases

Under the common but differentiated responsibility, the state has done commendable work to mitigate climate change and has the maximum number of registered projects under the clean development mechanism in India. The state is also gearing up to adapt to climate-related impacts through various programs such as climate smart agriculture, crop and soil management, micro-irrigation, better water resource management practices, climate smart livestock rearing, integrated coastal zone management, etc.

5.1 Gujarat: Land and Water Management for Climate Change Adaptation

5.1.1 Land Resources Management

Land resource management initiatives worthy of mention are seeking to increase agricultural productivity and ensure the security of land tenure. The Gujarat state soil health card program is one of those initiatives that seek to increase soil productivity by seeking to improve soil health. Twenty soil testing laboratories covering all districts in the state provide free testing facilities to farmers. On the basis of the soil test analysis report, soil health cards were prepared with the maintenance of computerized soil test data, fertilizer recommendation, soil recovery, crop planning, etc. Another initiative to increase sustainable agricultural practices is *Krishi Mahotsav*, researchers, scientists, experts, agriculture officials and ministers, interacting and providing information and advice on soil health, organic agriculture, modern technology, agricultural inputs, irrigation, etc. as well as infusing a new spirit of change and massive mobilization. Cultivation patterns in Gujarat have shifted to unsustainable agricultural practices. Inadequate rain-fed crops, soil type, and groundwater dependence have caused severe environmental disturbances that require immediate sustainable agricultural interventions. There is an urgent need to return to efficient crops in water use and help prevent further degradation of agricultural land. There must be a shift towards sustainable cropping patterns such as the crop intensification system to reduce groundwater depletion, while integrated nutrient management must be adopted to maintain sustainability.

Efficient water use practices such as SCI, micro irrigation, and water and soil conservation could make a significant contribution to the SGDP, as the central and southern hills of Gujarat produce a variety of crops commercial. To ensure long-term land productivity, immediate action is required to adopt sustainable agricultural practices. Agricultural practices must be sustainable rather than exploitative, leading to environmentally sustainable growth. Some of the technological and management interventions that could improve soil quality include structural methods for soil conservation such as soil and land fill and terraces in undulating areas, agronomic practices for the conservation and management of soils and waters such as minimum tillage, However, they have been implemented through capacity-building programs such as *Krishi Mahotsav*. Another government-initiated program is the Soil Health Card program that informs farmers about soil quality and interventions that can be undertaken to improve soil quality. It is unlikely that these initiatives will pay enough dividends unless proper soil conservation measures and appropriate cropping patterns are adopted.

Social forestry and joint forest management (JFM) could help improve forest cover in the state. Several NGOs have also been active with communities in the JFM program in Gujarat. The Gujarat Ecology Commission and the Gujarat State Forest Department have also initiated awareness-raising programs to communicate and share the benefits that can be gained and support for forest ecosystem livelihoods. Efforts need to be intensified to increase the natural resource base, promote sustainable and organic farming practices. Looking at efforts in the mining and waste sector Gujarat Ecology Society has undertaken the study "Ecological Restoration of Gujarat Mining Sites" at the behest of the Gujarat Mineral Development Corporation to intensify the protection and conservation of the environment in Mining areas. This is a small initiative that needs to be expanded as Gujarat is a state with the second largest mining lease in the country.

Various eco-restoration measures such as fallow land cultivation and soil moisture conservation have reduced the chances of drought. Farmers have also implemented various agricultural techniques such as crop rotation and land leveling, which have reduced crop failure, soil hardness and soil erosion, and increased agricultural production and income. Increased precipitation has had a positive impact on land conditions in the state of Gujarat, as soil moisture has increased and, as a result, agricultural production has increased. The use of drip irrigation and sprinklers help farmers reduce soil hardness, increase soil moisture, improve soil quality and eventually reduce crop failure and increase agricultural production. The use of manure also helps to reduce soil hardness and increase soil fertility and agricultural production.

5.1.2 Water Resources Management

5.1.2.1 Government Responses for Water Scarcity Mitigations

The major water scarcity mitigation tools that changed the Gujarat water availability scenario since 2000 relate to the progress made with respect to the completion of the *Sardar Sarovar* Dam on the Narmada River, the creation of a *Sujalam Sufalam Yojana*, From the Narmada canals, the interconnection of rivers, the filling of ponds, dams and rivers by the waters of Narmada, and the construction of verification dams and other structures of water collection Along the rivers.

I. Check-Dam Movement

A water recharge movement has been seen in Saurashtra as a response to growing water shortages until the late 1990s. The Movement has carried out a series of socio-technical actions, led mainly by local farmers, community leaders, and NGOs, with the financial support of a migratory population of the area, particular settlers from cities such as Surat, Ahmedabad, and out from of the State. As a result, this region has experienced a sharp increase in agriculture-based livelihood income, mainly through increased availability of groundwater, together with the improved quality of life (Mudrakartha 2008). Because of the enabling role played by the state government in recognizing the value of such initiatives and drawing lessons from its results, while introducing proactive policies and technical expertise along with the financial support provided by various government agencies, Gujarat has witnessed of a large mass, especially since the year 2000. The following figure shows the increase in the number of Gujarat dams as a result of the movement that could not have been possible without the participation of the people and the government after 2000. The failures of the monsoon before 2000 led to acute shortage of drinking water in the Saurashtra region, Kutch, and northern Gujarat. Of the total cumulative capacity of 2200 million cubic meters of water in 113 dams in the Saurashtra region, only 140 million cubic meters of water had accumulated in 2000. This accumulated water had been reserved exclusively for the supply of drinking water. Thanks to the good rain witnessed during the recently concluded decade, this situation has not been repeated. Gujarat had been implementing water conservation works before including the construction of control dams. The work was carried out either by tender or by departments.

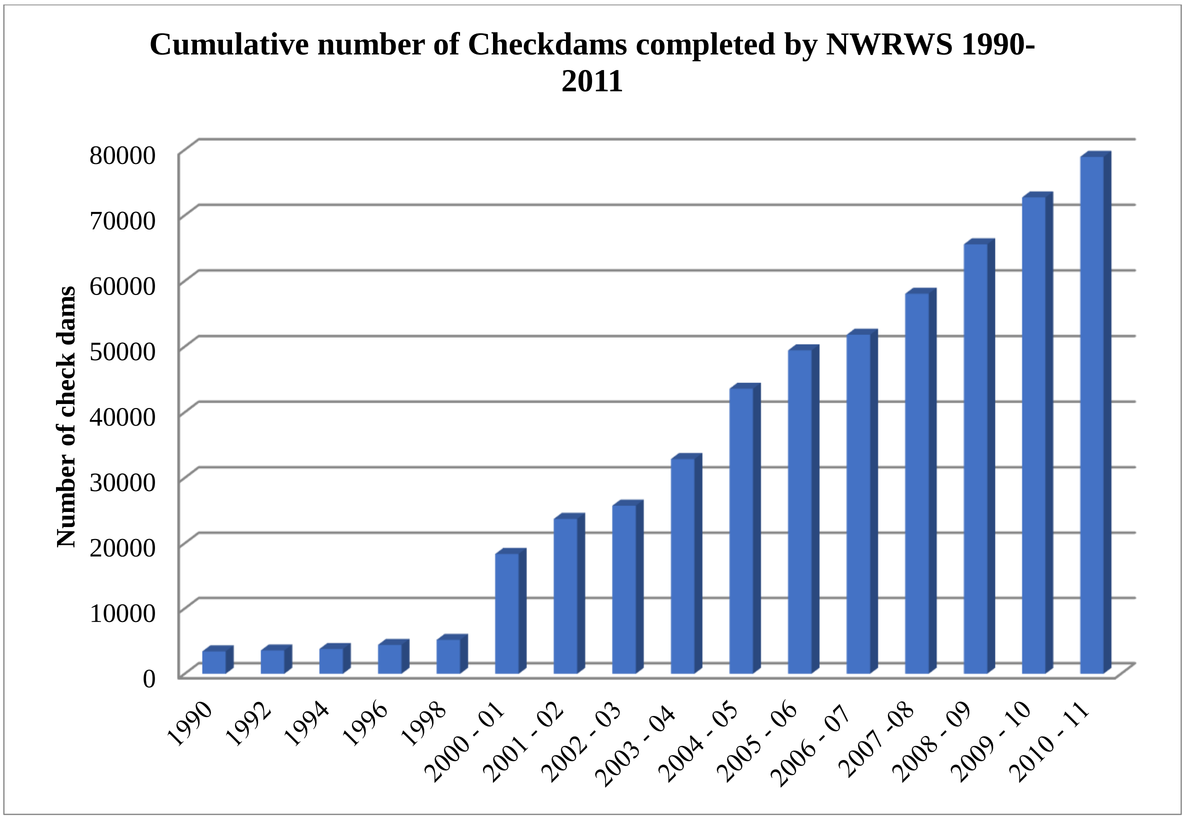


Figure 5.1: Check dam constructions in the State of Gujarat (1990–2011)

II. Sardar Patel Participatory Water Conservation Project (SPPWCP)

The State government became aware of the intense awakening among residents of the sparsely populated regions of the state. This mass consciousness complemented by the efforts of social activists and NGOs led to the construction of several water conservation projects in these regions. Voluntary village contributions supported activities in the context of rainwater harvesting to recharge groundwater. This was done with a view to satisfying drinking water as well as agricultural needs. Taking the example of these experiences, the government launched the SPPWCP that has seen four stages of implementation so far. The first phase of the project, which lasted from 17/01/2000 to 20/02/2001, sparked an enthusiastic response from the Saurashtra region. The first monsoon itself witnessed overflows in more than 7,000 control dams. This led farmers to benefit immensely from the increase in agricultural production. The second phase marked 21/06/2001 with suggestions for improvement ended on 31/03/2003. The third phase (from 01/04/2003 to 03/31/05) was observed for the 40% contribution it received from the beneficiary farmers. Farmers in tribal areas accounted for 20 percent of the total cost of the dam. The fourth phase began on 01/04/2005 with a government contribution of 80% and the village contribution of 20% (80:20) statewide. The participation of the people allowed the construction of 67929 control dams in stages I to IV of the SPPWCP.

III. *Sardar Sarovar* Project (SSP)

The Narmada is the fifth largest river in India and the largest in Gujarat. It crosses Madhya Pradesh, Maharashtra, and Gujarat to meet the Gulf of Cambay. The idea of the *Sardar Sarovar* Project (SSP) was concreted as the construction of a dam on the Narmada in 1946–1947. Sardar Vallabhabhai Patel conceived this idea as the underlying reason for the optimal use of river water for the well-being of the nation. The SSP, a multi-purpose project, was formulated by GoG in accordance with the commands contained in the Narmada Water Disputes Tribunal (NWDT) Award. The SSP has been a very controversial project in the history of Independent India. He has been at the Gujarat water safety center and overall development planning. The SSP, because of its size and potential to positively transform the state's water scenario, can be considered as the most crucial response to water-related concerns in the State. The *Sardar Sarovar* Dam together with other complementary measures have the capacity to transform the water sector into Gujarat. The project aims to provide the main benefits of irrigation, hydropower and potable water supply to the states of Gujarat, Maharashtra, Rajasthan, and Madhya Pradesh. The table above shows the silent feature of the SSP.

IV. *Sujalam Sufalam* Canal Network (SSCN)

Adopted in 2004, *Sujalam Sufalam* canal network envisages a plan to divert excess water from the Narmada canal to nine dams north of Gujarat through a network of 100 km of pipelines. It also envisages the construction of unlined canals along 21 rivers north of Gujarat while being built around two lakh ponds in the food for work scheme. The project is likely to benefit about 2.35 hectares of water scarcity in northern Gujarat by recharging groundwater through dams and ponds in the area surrounding the channel passage. A report examining the technical implementation of the *Sujalam Sufalam* canal network submitted to the State Department of Water Resources (SWRD) in June 2008 indicates that the area mainly retained as a channel beneficiary has been struggling with recurrent drought almost every three years due To a very high coefficient of variation. Nine dams in the region were filled up to 30% capacity in the last 10 years. What does it mean that while there were reservoirs reserved for drinking water, there was no water available for irrigation? In that sense, *Sujalam Sufalam* canal network, once completed, will address the irrigation needs of drought-prone areas.

V. Knowledge Domain

The relatively poor and unevenly distributed natural resources of Gujarat pose enormous management challenges in containing environmental degradation while ensuring the momentum for development. All stakeholders in the state must have a global understanding of the development and balance of the natural resources necessary for their sustained economic and social growth. The preparation of the report on the State of Environment can be considered a response to this effect. The State of Water is one of the reports produced as part of this exercise. The establishment of the Climate Change Department (2009) is also an initiative in the right direction as the dynamics of water and climate need to be properly understood to ensure healthy and sustainable water management in the state. This is all the more important as Gujarat has traditionally been a state affected by frequent droughts. State's long coastline (1600 km) only exacerbates the problem, as rising sea levels helped by the severe depletion of groundwater only serves to worsen the problems existing salinity in the coastal Gujarat. The World Bank supported the Integrated Coastal Zone Management Project (ICZMP), which identifies multidisciplinary interventions to stop the degradation of the coast, including coastal salinity, is a major effort for a healthy and sustainable development of the coast of the state. It is important to have knowledge about the climate-water relationship, while relevant research studies should help us develop an understanding of the phenomena that allow adequate responses to address issues related to climate change, industrial development, and water.

5.1.2.2 Water Resources Management as Perceived by the Communities

The output from the FCM study shows that the communities mainly face the issue of reduced water availability and low agricultural production during the summer and winter seasons. It is apparent that increased summer and winter temperatures influenced the natural and human assets the most. The communities have adopted various adaptation practices such as micro-irrigation, water resources management, and better water infrastructure to increase agricultural production. The regular supply of water through these micro-irrigation practices has helped to increase agricultural production. Many farmers in the study area use the drip irrigation system and sprinklers on their farms to use water optimally. These have increased soil moisture and improved soil quality, and also increased agriculture production. In order to acquire an adequate supply of water, both for agricultural and domestic purposes, the management of water resources and several other water structures have been introduced. Mainly these practices have helped to increase agricultural production. The construction of the check dam has increased the availability of water during the seasons of scarcity, increasing the agricultural production and the availability of fodder.

To address the issue of the availability of potable water, water storage tanks have been installed in several places that provide potable water to villagers, and it reduces painful work among women. Wells and tube wells drilling, and construction of irrigation canal increase the availability of water for irrigation and water consumption and solves water shortage problems. This has not only reduced drudgery among women but also reduced crop failure due to water scarcity and increased agricultural production. Check dams and ponds on the farm have been built to increase the availability of water for irrigation purposes. Generating awareness among people to conserve water has also led to increased availability of water. Communities also perceived that the various interventions undertaken in the framework of participatory irrigation management (PIM), such as the farmers' cooperative, the *Kisan* club, the capacity-building, and sensitization program and other technical services that help them to address the problems of scarcity of water and increase agriculture production.

5.2 Kerala: Land, Nutrient, and Water Management

5.2.1 Land and Water Management

Even though a lot of studies are available on the monsoon characters of the State of Kerala, linking the same with agricultural crop production under climate variability and strategies to sustain the same is lacking in the State of Kerala. Hence, such a documentation of climate change and the increasing climatic variability with future projections for the crops of Kozhikode district have been documented in this study. In addition, increase in temperature, uncertainty in rainfall and increase in carbon fertilization has been studied in detail and about these impacts on soil and water conditions and its influence on crop productivity under humid tropical conditions has been given a focus in the current study.

Brief description of the adaptation options, which potentially can reduce the vulnerability of agriculture to the effects of climate change are listed below:

Table 5.1: Adaptation options and their descriptions

Adaptations	Description
Climate-ready crop varieties	Crop varieties tolerant to drought, flood and heat giving higher yield even under extreme climatic conditions
Water-saving technologies	Drip, sprinkler and laser-aided land levelling to increase water-use efficiency
Integrated farming system	Inclusion of crop, livestock and fishery in farming system to sustain livelihood, particularly of poor farmers
Organic farming and Conservation agriculture	Use of organic sources of nutrients, avoiding use of chemical pesticides, zero tillage, crop rotation, mulching with residues of soil
Growing different crops/ mixed system	Growing tolerant/resistant crops to withstand the adverse impacts of climate change
Precision farming	Precise management of water, nutrients and pest, Site-specific demand-driven and balanced use of nutrients
Waste land management	Developing wastelands through water and nutrient management for forestry, agro-forestry, grassland and crop production
Improved weather-based agro-advisory	Forecasting of weather, particularly extreme events, for crop management planning
Agro-horticulture, agro-forestry	Agro-horticulture and agro-forestry are more tolerant to drought and flood compared to food crops
Rainwater harvesting	To reduce run-off loss, soil erosion, loss of nutrients and recharge groundwater
Crop insurance	Sensitizing the farmers for covering risks of climatic extremes

5.2.2 Decision Support System (DSS) for Soil Nutrient Management

To overcome the negative impacts of climate change, a decision support system (DSS) has been developed for nutrient management under this project with field experiments, nutrient budgeting/ modeling and developing strategies and the details are enclosed below. Structures of the DSS have been finalized based on the concept of nutrient budgeting and the techniques for the fertilizer recommendation. The concept of nutrient budgeting is as explained in Figure 5.2, which includes the set of inflows and outflows. The DSS calculate the nutrient inflows and outflows in different cropping systems at different spatial and temporal scales in Kerala soils.

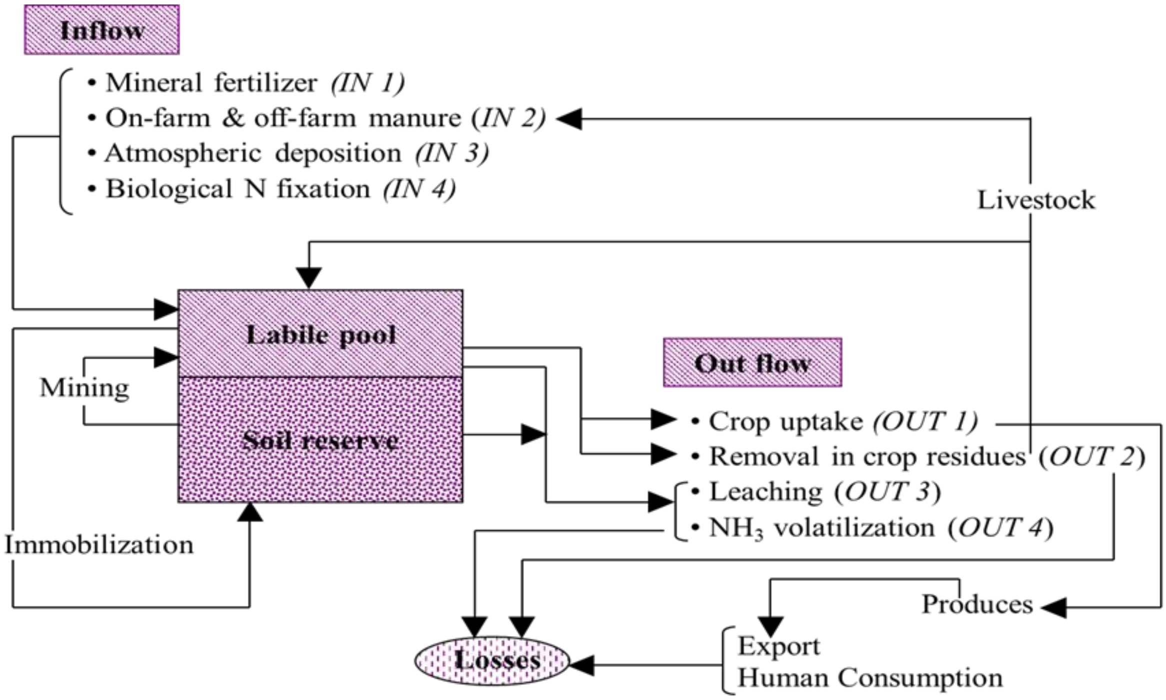


Figure 5.2: Concept of soil nutrient budgeting

The results indicated that 125% of recommended dose of NPK fertilizers recorded the highest yield of 7685.9 kg/ha and this treatment significantly improved the yield when compared to the other treatments. The results indicated that the soil loss ranged between 0.0 and 14.44 tons/ha for different rainfall events of low to high. Mean quantity of soil loss in relation to the rainfall results revealed that the quantity of soil loss was high under high rainfall event and was low in the case of low rainfall events. The correlation was significant with the r value of 0.90 and the R^2 value of 0.81.

Data collected from the field experiment with respect to all inflows and outflows are being compared using transfer functions or in-built regression equations of NUTMON-model by linking nutrient input with rainfall for calibration and validation. The observed and predicted values of soil loss using NUTMON-model is matching in most of the cases. But in few cases, the model prediction is not similar to the observed values and hence under such cases, the other environmental variables such as rainfall intensity, preceding soil moisture, and crop canopy cover are being analyzed to eliminate the error percentage. Calibration and validation of NUTMON-model were done using the data. The nutrient content in the eroded soil was significantly higher than the initial soil nutrient content of these plots, indicating that the eroded particles are finer in composition, and confirming the hypothesis. This equation will be utilized for developing suitable site specific water and nutrient management strategies for the regions where soil fertility data was available.

Soil nutrient balance at farm level

Soil nutrient balance at farm level is given by sum of all inputs minus sum of all outputs. Both partial and full balances were calculated for the selected farms using NUTMON-Toolbox. All possible inputs and outputs contribute to full nutrient balance, whereas, only IN1, IN2, OUT1, and OUT2 were considered for calculating partial balance. Positive farm balances indicate sufficient land management and sustainable land uses but high positive balance values may indicate a nutrient surplus. It may lead to nutrient runoff and consequences like eutrophication. Thus it contributes to environmental pollution. On the other hand, negative farm balances indicate a nutrient deficiency. It may lead to reduced production in the concerned farms. For the farm as a whole, the nutrient balance was expressed as the sum of inputs minus the sum of outputs covering all FSUs, SPUs, and RUs. There has been a slight variation in the nutrient balance of the farm than the individual PPUs.

Soil nutrient balance can indicate whether the farm is in a state of nutrient surplus or deficiency. While checking the selected farms, it is obvious that none of the farms have a nutrient surplus. The major negative contributor is the outflow through harvested crop production, which cannot be curtailed since the main aim of the farmers and policy makers is to enhance the productivity to feed the enormous population. Solutions to nutrient depletion and accumulation need to focus on economically feasible and socially acceptable technologies. There is a wide range of management interventions (nutrient saving technologies *viz*., increasing the use efficiency, preventing/minimizing the losses) to influence soil nutrient balances.

Details about the DSS

Nutrient depletion is the result of a net imbalance, between incoming and outgoing nutrients in farm inputs and outputs. Because of many aspects of farm management, influence these processes, there is a need for a ‘basket of technology options’, addressing the various causes of depletion. However, fertilizer and organic manure being the major input, a strategy was worked out for each PPU of an individual farm under study. The fertilizer and manure recommendation for the crops grown at both these farms by combining organic and chemical fertilizers were given to the farmers in the farm of soil health card along with few suggestions for increasing the nutrient use efficiency. Since it is a continuous process, soil sampling will be done in the next season and nutrient balance will be generated using NUTMON-Toolbox and checks whether the generated nutrient recommendation turns the system into sustainable one.

The DSS is linked with Geographic Information System (GIS) for ensuring sustenance of soil fertility and successful transfer of agro technology may be achieved. The DSS will help to:

a) Evolve nutrient recommendation for the crops (organic and inorganic fertilizers)
b) Soil suitability classification & problem soil management

Apart from the DSS, the AEZ model will help to generate the following information:

- Land and water resources—including soil resources, terrain resources, land cover, protected areas and selected socio economic and demographic data;
- Agro-climatic resources—including a variety of climatic indicators;
- Suitability and potential yields for up to 28 crops/ land utilization types under alternative input and management levels for historical, current and future climate conditions;
- Downscaled actual yields and production of main crop commodities; and
- Yield and production gaps—in terms of ratios and differences between actual yield and production and potentials for main crops

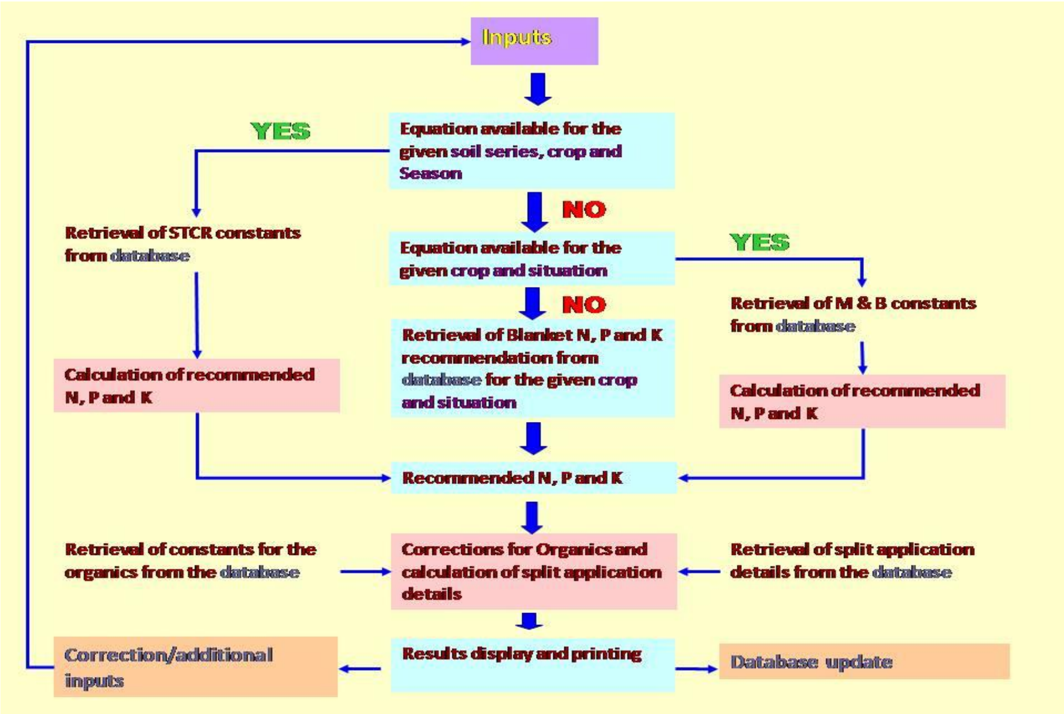


Figure 5.3: Flow chart of the DSS for soil nutrient management

Screen shots of the developed DSS is enclosed below:

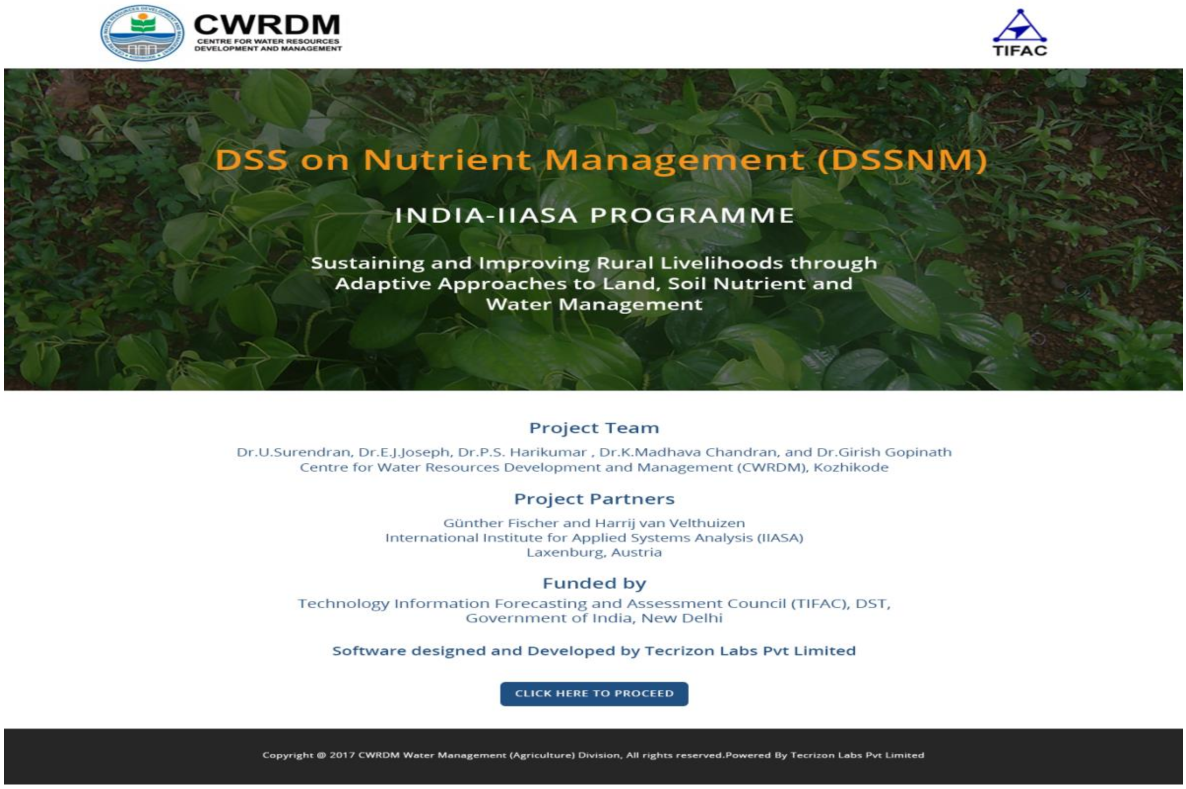


Figure 5.4: Landing page of the DSS for soil nutrient management

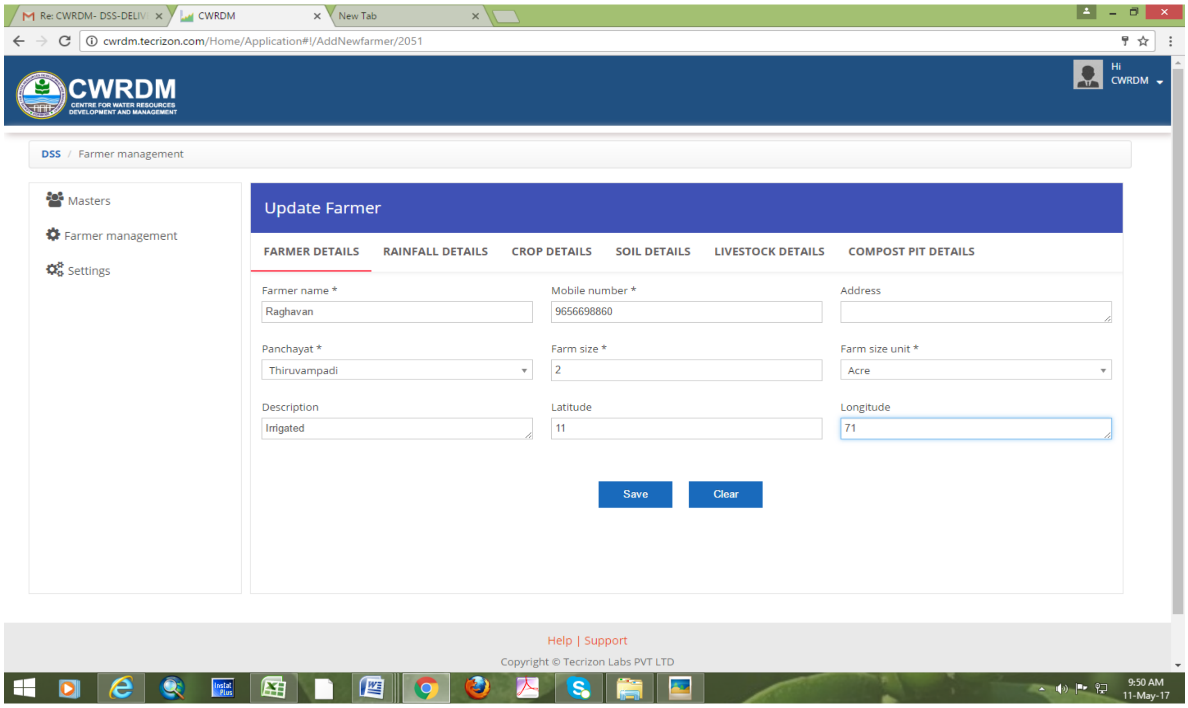


Figure 5.5: Data entry sheet for the farmers

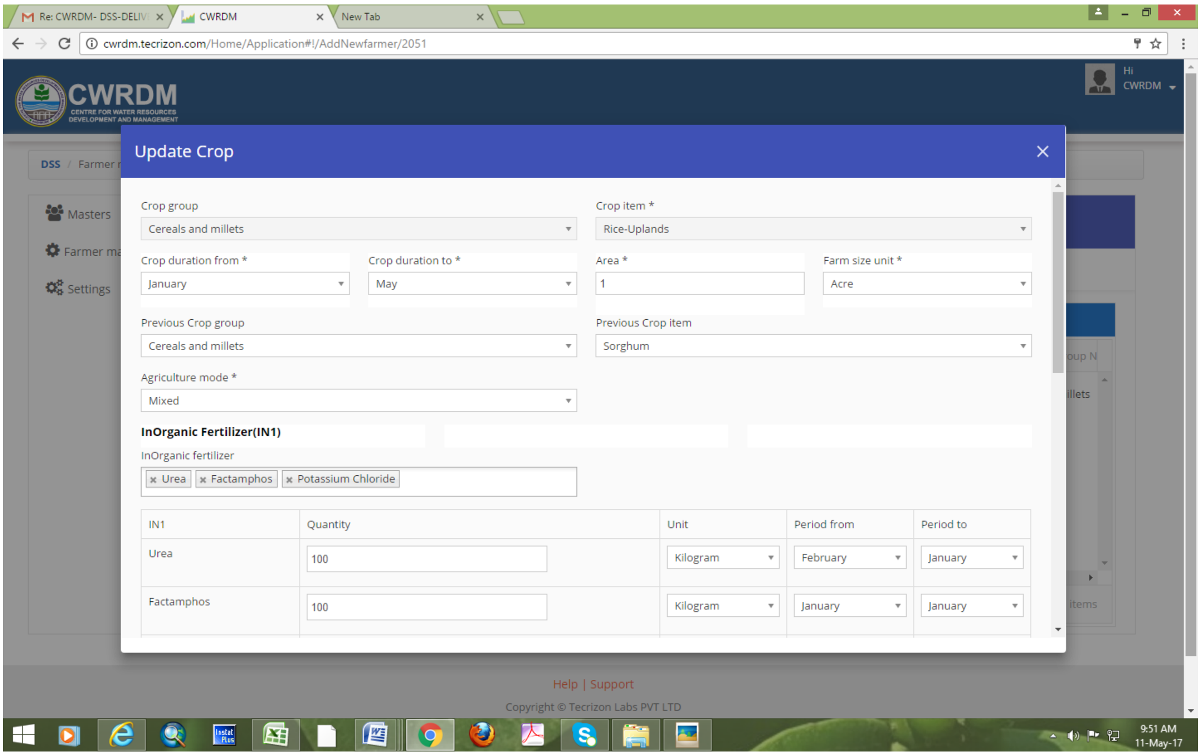


Figure 5.6: Data entry for crop details

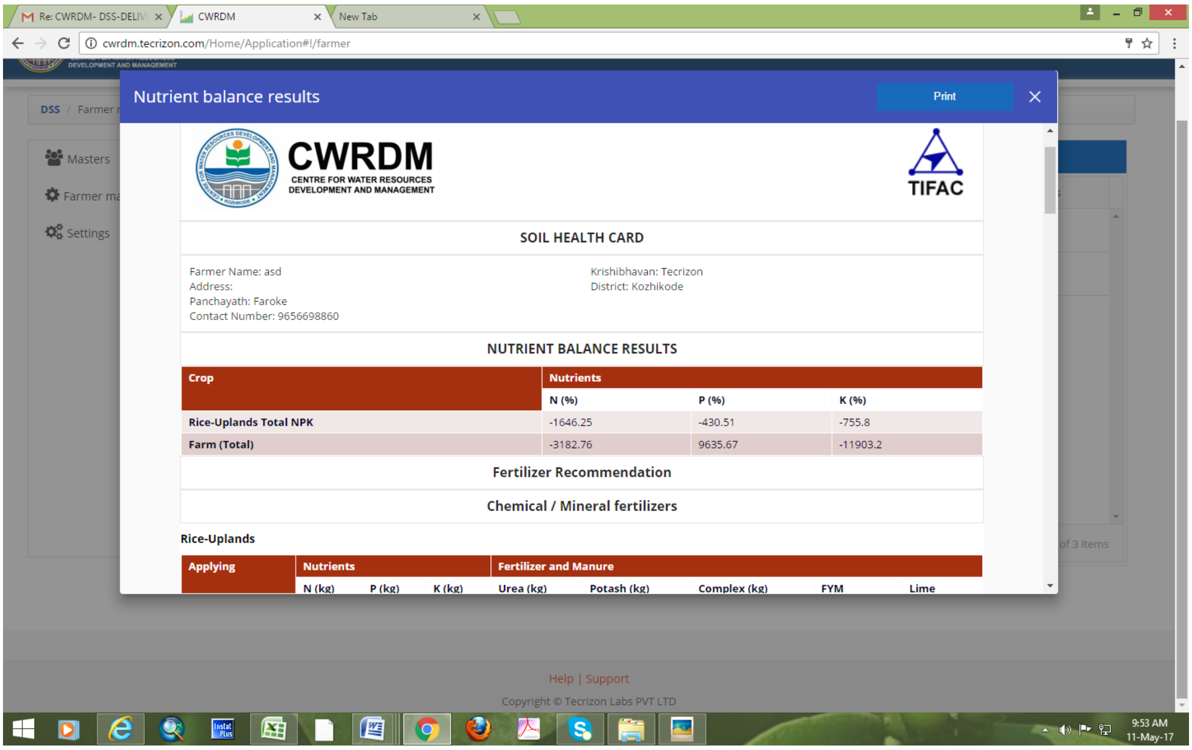


Figure 5.7: Output sheet: nutrient recommendation sheet

5.3 Bundelkhand: Land and Water Management

5.3.1 Land Resource Management

The purpose of the Land Resource Management Plan in Bundelkhand is to use land resources rationally to coordinate and allocate land use among different practices. The suggested land resources management actions are discussed in the following section.

In the Ur River watershed, having fine loamy and loamy soils with the land capability IIe, IIIe or gentle slope (0-1) being cropped area. The suitable crops which are practiced in the area are mustard, gram, soya bean, wheat, etc. Ley farming is an agricultural system where the field is alternately seeded for grain and left fallow. In ley farming, the field is alternately used for grain or other cash crops for a number of years and laid down to ley i.e. left fallow, used for growing hay or used for pasture for another number of years. In the Ur River watershed, the areas which are presently under wasteland & land with or without scrub developed over buried Pedi plain having the level to a gentle slope and moderate to good ground water potential condition, are suggested for lay farming. In the Ur River watershed areas which are presently under land with scrub or land without scrub having IIIe, IVe, VIe, VIIe, VIIIe land capability with moderate to good groundwater potential and level slope are suggested for fuel wood plantation.

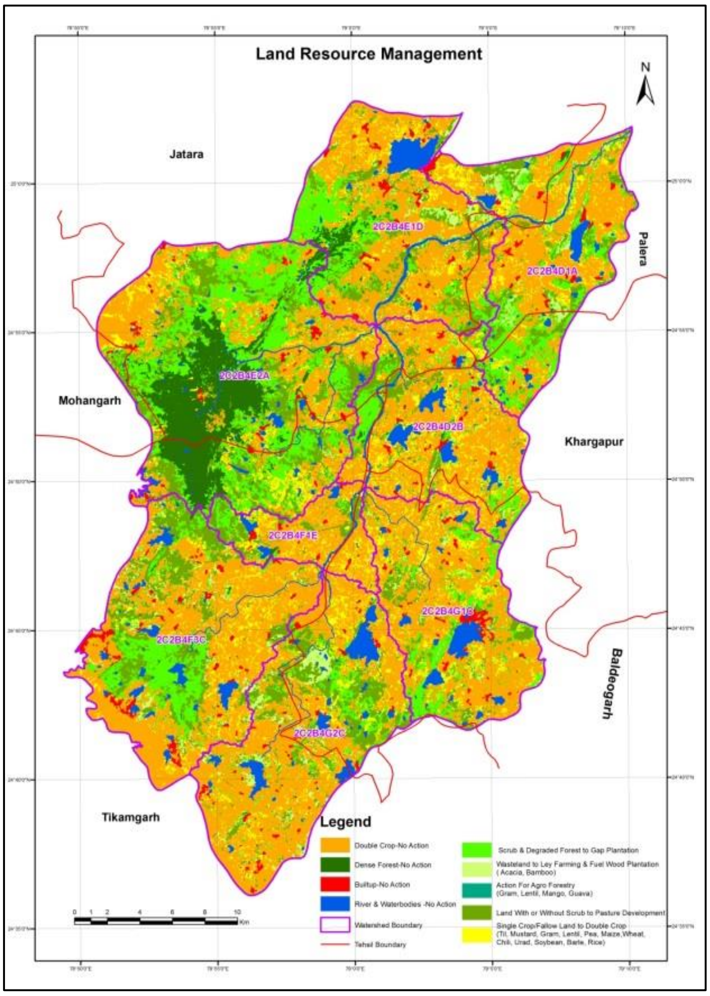


Figure 5.8: Land resources management map of the Ur River Watershed

Gap plantation is a modified afforestation technique applied to open forest areas. Suitable trees are planted in gaps development in the forest due to tree cutting and degradation of forests. To achieve the best result of this system it is necessary to select plants which are similar to existing naturally grown species. Such areas should be protected from grazing and other encroachment. Land units of Jatara watershed which are presently under scrub forest or degraded forest with fine loamy, loamy, coarse loamy, loamy skeletal, fine silty soil, and moderate to good groundwater potential, moderate groundwater condition having the level to a gentle slope (0-3%) are suggested for gap plantation. In the Ur River watershed, the area which is presently under fallow land having fine loamy, loamy, coarse loamy soil with land capability IIe, IIIe, moderate to good GWP, moderate groundwater potential and having a level to the gentle slope (0-3%), have been suggested for agro-forestry.

5.3.2 Water Management Modelling using WEAP Model

This study described the use of the Water Evaluation and Planning (WEAP) model to evaluate water resource availability in the Ur River watershed using GFDL-ESM2M model (RCP 4.5) climate series. The model was used to assess water availability and investigate the impacts of different irrigation scenarios on Kharif and Rabi crop yields. The WEAP model represents the system terms of its various supply sources (e.g. rivers, streams, groundwater, inter-watershed transfer, and reservoirs); withdrawal, transmission, and wastewater treatment facilities; ecosystem requirements, water demands (i.e. user-defined sectors but typically comprising hydropower, irrigation, domestic supply, etc.). The model essentially performs a mass balance of flow sequentially down a river system, making allowance for abstractions and inflows. Typically, the model was applied by configuring the system to simulate a recent (baseline) year, for which the water availability and demands can be confidently determined. The model is then used to simulate alternative scenarios to assess the impact of different development and management options. For modelling purpose, the Ur River watershed was divided into 8 sub-watersheds according to drainage network, topography and soil types and the WEAP schematic of the Ur River watershed was generated.

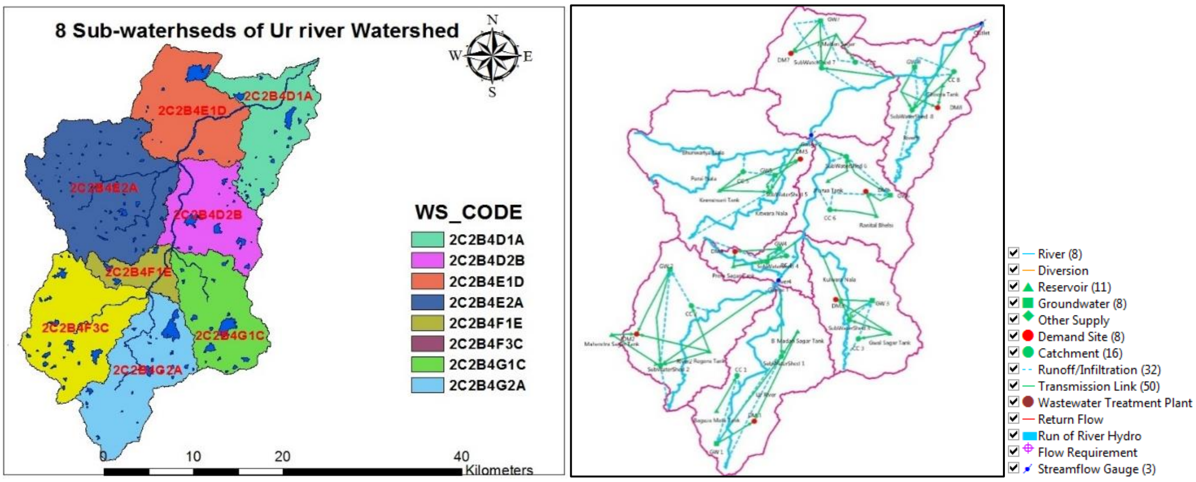


Figure 5.9: Eight sub-watersheds and WEAP schematic of the Ur River Watershed

The net annual groundwater availability of the district is 529.51 million cubic meters, whereas, existing gross ground water draft is 378.01 million cubic meters. The stage of ground water development of the district is only 71% (CGWB 2013). The agriculture in the Ur River watershed is purely dependent on rainfall but, the availability of water from tanks and other surface bodies is very important to sustain irrigated agriculture and provide security to farmers. Historically, the need for security of water was recognized and Bundelkhand region is known for well-distributed water bodies. The reservoirs of watershed include Madan Sagar tank, which is a very large tank with its canal system is located towards the north-west corner of the watershed. Gwal Sagar, Prem Sagar, Bahru Tal, Rayra Tal are the major tanks of the watershed. The details including designed capacity, present water level, culturable command area and beneficiary villages were obtained from tank gauge report of a minor irrigation scheme in Tikamgarh district.

5.3.2.1 WEAP Results

In-depth analysis of the status of water in the Ur River watershed using the WEAP model has provided many useful results that can be utilized in future for effective water management. The results are divided into three sections: Hydrologic analysis, water allocation, and agricultural scenarios. In the hydrologic analysis, a scenario of RCP 4.5 of GDFL-ESM2M model was used to calculate the rainfall, groundwater storage, runoff, etc. for sub-watersheds in future. These results not only represent the possible hydrological situation of the Ur River watershed in future but also provide an inter-comparison of the eight sub-watersheds. The land-use pattern and major crops were grown have also been represented in the same section. An overall picture of the watershed in terms of precipitation and agriculture was given under RCP 4.5, which is quite a possible situation for Bundelkhand region in coming years. The prediction of GFDL model for the year 2015–2016 (500 mm) and 2016–2017 (730 mm) are in correspondence with actual rainfall occurred in Tikamgarh district during 2015–2016 (540 mm) and 2016–2017 (cumulative rainfall 711 mm as on 29/09/2016).

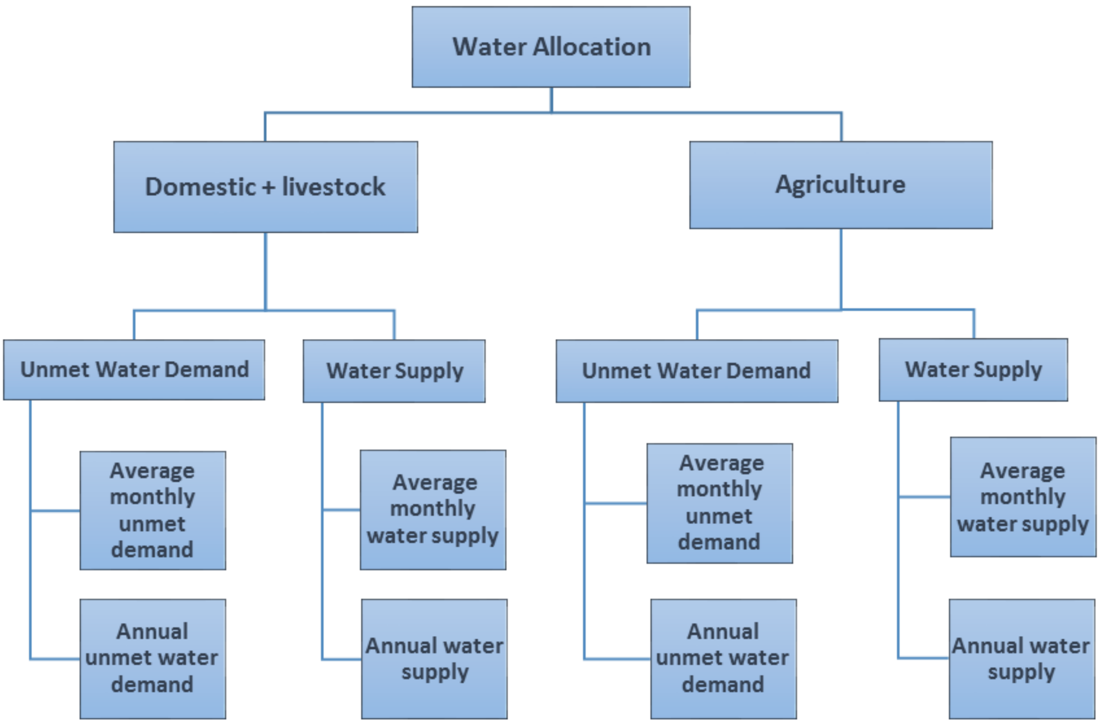


Figure 5.10: Flow chart representing water allocation in the Ur River Watershed

Water allocation measures how much water is dedicated to whom and for what purpose in a hydrological system. The needs and requirements of the environment are taken into account; based on that, the demand priorities and supply preferences are decided. This section elaborates water allocated for population, livestock and agriculture sector on average monthly (2015–2030; 15 years) and annual basis. Water allocation in three sectors has been defined in terms of unmet water demands and water supplied from different available water resources.

5.3.2.2 Conclusion

In the second section, water allocation for eight sub-watersheds has been represented by unmet water demand and supply delivered results of the WEAP model. The unmet demand and supply show the existing scenario of water distribution with defined preferences to domestic and agricultural water demands. The sub-watershed having the largest share of the population has the largest value of unmet demands as well. The demand and supply gap has also been given for agriculture for each sub-watershed. The unmet demands also exist in the case of agriculture since the first priority for water supply is meant to be for the domestic purpose. The area under agriculture in the Ur River watershed is large while respective water supply is low. This gap puts an extra pressure on water resources like groundwater leading to over extraction and related problems. Looking at this scenario, water allocation requires great attention to narrow down the gap between existing demands and water supply. Since the area under agriculture is large, water-efficient crops should be more emphasized. Also, agricultural practices which efficiently use water and also engage in harvesting water should be more centred.

5.3.3 Decision Support System (DSS) for Integrated Water Resource Management: "*Jal-Jan-Jeevan*"

The Integrated Water Resource Management (IWRM) plan, as defined by Global Water Partnership (GWP 2009) is "a process which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems". The watershed has been experiencing dry conditions for past few years as a result of low rainfall, but more importantly due to inefficient water usage practices. The water is more wasted and rarely harvested in the area. Farmers practice traditional water intensive crops (rice, ginger, and colocasia) and perform old and less efficient techniques of irrigation like flood irrigation. These practices altogether increase the pressure on existing water resources like surface ponds and groundwater (wherever used). The demand thus exceeds the water supply possible in an existing area and increase the proportion of unmet demands. The given IWRM plan proposes hydrological measures and some changes in cropping pattern to utilize the available water resources in its best possible way. The proposed plan has been derived by considering the topographic, physiographic, climatic, soil and agricultural status of the area. For a more elaborate approach, the Ur River watershed has been divided into eight sub-watersheds. The division has been done on the basis of topography and drainage network of the area and not on any village or block boundaries.

The land use pattern for all the sub-watersheds is almost similar with double crops (nearly 50%) being the area covering largest portion of the watershed, since agriculture is the primary livelihood option, and hence practiced at large scale. Double crop indicates the area which is being used for cultivation during Kharif as well as Rabi season. Kharif and Rabi crops are cultivated with almost same intensity in each sub-watershed. Scrubs and scrub forest also form a major portion of the region (together 20-30 % share in each watershed) after double crops.

The unmet demands for each sub-watershed have been calculated on the basis of standard water uses by the population as 70 litres per day per head (BIS standard) and livestock as 145 litres per day per livestock (DIP Jhansi 2016). The unmet demands basically define the part of total water demands which could not be fulfilled or do not get full coverage through the available waters supply.

The decision support system (DSS) developed for the Ur River watershed, named as "*Jal-Jan-Jeevan*", includes various modules related to mapped information on all natural resources of the watershed, questionnaire based support to the stakeholders, assessment of vulnerability to the climate change, livelihood option, success stories and recommendations to the user for improving their livelihood status. It is an integrated resourceful application for the line departments and to the farmers of the area. The developed DSS can certainly be used in the planning of the activities of soil and water resources of the area, farming activities and for formulating the schemes related to the livelihood of the people by considering the climate change vulnerability findings. The design of the DSS was finalized by taking inputs from stakeholders during 2nd stakeholders workshop under the project held at Tikamgarh, held on 18th June 2015. During the workshop, it was decided to develop the DSS in Hindi/ English language to support the various departments and stakeholders. The suggestions of the stakeholders were duly considered while developing the DSS and major content was converted into the Hindi language. The opening window of the DSS is given in Figure 5.11.

The next important module of the DSS is Map Information, which stores the database generated for the Ur River watershed in the form of GIS maps. The maps includes River and water bodies, groundwater prospectus, canal command area, soil average depth, soil maximum depth, soil irrigability, soil order, soil pH, soil texture, hydrologic soil groups, land use land cover, land capability, land irrigability, area under Rabi crops, area under Kharif crops, infrastructure map, lithology, topography, lineament, and slope.

Figure 5.11: Opening window of the DSS for *Jal-Jan-Jeevan*

The most important module of the DSS is *Questionnaire*, which provides support to the user in the form of questions. The answers to these questions are obtained from different project components and studies carried out during the project period.

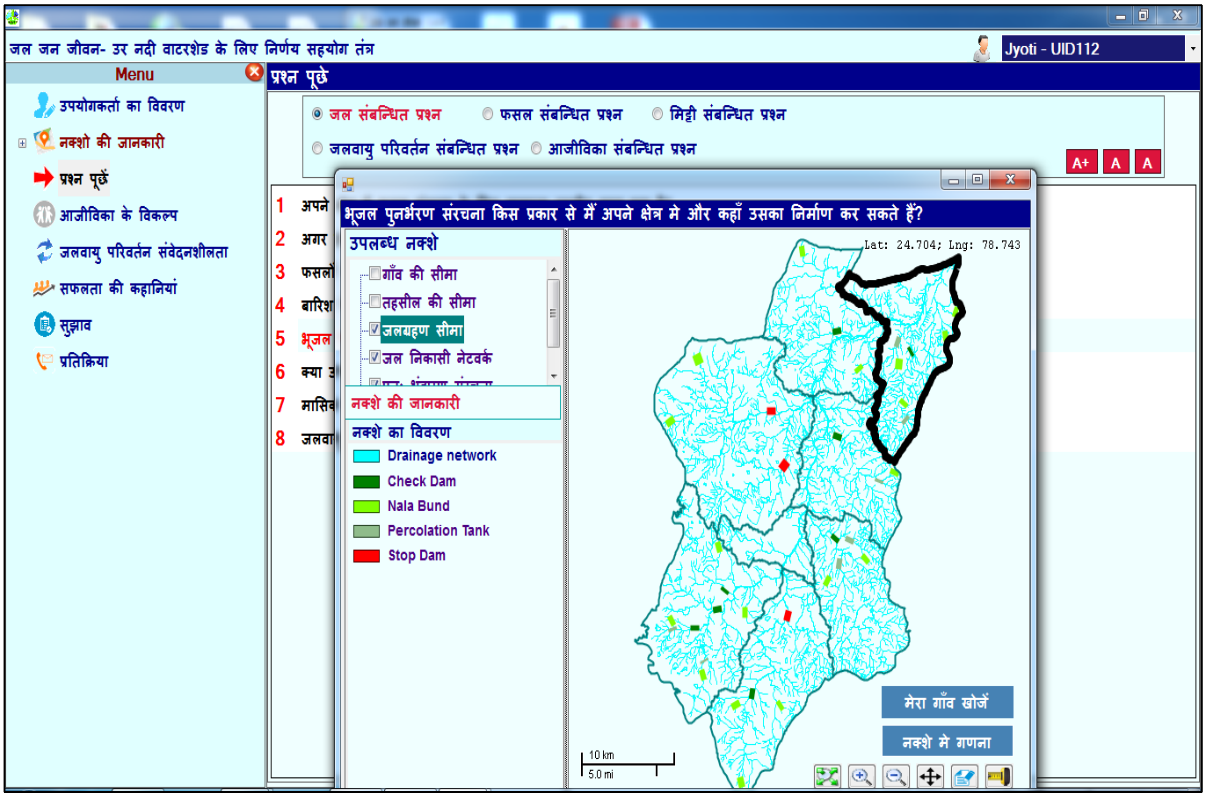


Figure 5.12: Questionnaire module of DSS for *Jal-Jan-Jeevan*

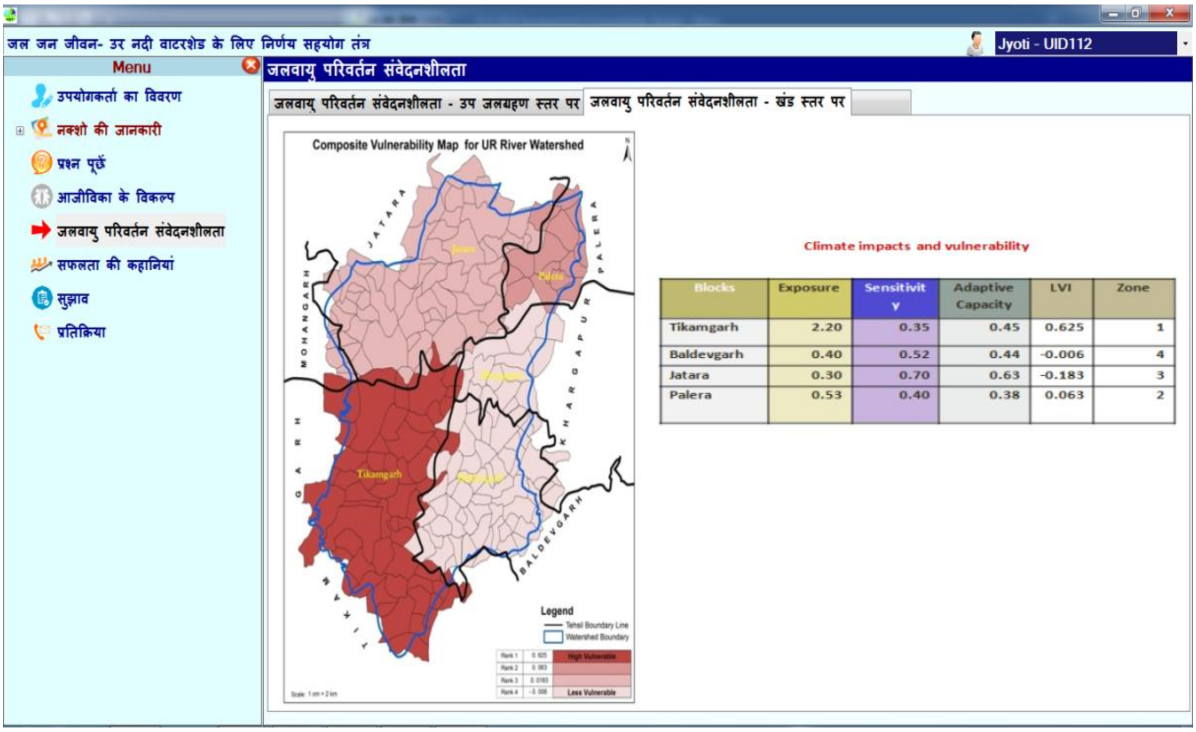


Figure 5.13: Livelihood vulnerability assessment module

The *Livelihood options* module enables the user to obtain the information on various livelihood options such as farm options, off-farm options, non-farm options, institutions supporting livelihood through education/ training, schemes of Madhya Pradesh Government and Government of India, and markets available to sell the agriculture or non-farm products.

The *Vulnerability* module incorporates the findings of the assessment of livelihood vulnerability to climate change using the IPCC approach and fuzzy cognitive mapping (FCM) approach. The assessment was done at the block level as well as sub-watershed level. The Figure 5.13 shows the block level vulnerability assessment of the watershed, wherein, livelihood in Tikamgarh block is most vulnerable to climate change in future.

Recommendations- Based on the information provided by the user, the DSS suggests suitable livelihood options to the user, as per his current occupation and free months during the year. The DSS provides a summary sheet in the recommendation module which includes his basic information, current livelihood status, how his livelihood is vulnerable to the climate change and what are additional livelihood options he can adapt.

Chapter 6: Guidance Toward Policies and Governance

6.1 Management of Land Resources

Gujarat is divided into five regions namely south, central, north, Saurashtra, and Kutch. Seven agro-climatic regions have been identified based on soil characteristics, temperature, rainfall and water availability. These are the south of Gujarat (strong rainy zone), south, middle, north, south of Saurashtra, north Saurashtra, north-west of Arid (Kutch). Technological changes have favoured intensive farming in water, thus changing the pattern of cultivation of Gujarat since the 1960s. These changes have favoured crops such as cotton, rice, etc. At the expense of areas under vegetables, oilseeds and coarse grains. This change can be attributed to the agro-climatic conditions, technological changes, institutional changes and infrastructure changes associated with agriculture that has taken place in recent years. Gujarat has witnessed tremendous changes in cropping intensity over the last few decades. The high growth of agriculture in Gujarat has attracted much attention from agricultural planners and policy makers. These remarkable results were made possible by meticulously planned and coordinated action plans that ensured eight hours of uninterrupted power supply to agricultural fields throughout the state (under the *Jyoti Gram* scheme). The soil health card program is also once an initiative that attempts to increase soil productivity by seeking to improve soil health. 20 soil testing laboratories covering all districts in the state provide free testing facilities to farmers. Based on the soil test analysis report, soil health cards were prepared with the maintenance of computerized soil test data, fertilizer recommendation, soil recovery, crop planning, etc. Another capacity building initiative to increase sustainable agricultural practices worth, further promoting is the *Krishi Mahotsav*, where, farmers with researchers, scientists, experts, agricultural officials and ministers interact and provide information and advice on soil health, organic agriculture, modern technology, agricultural inputs, irrigation, etc., as well as infusing A new spirit of change and mass mobilization.

Cultivation patterns in Gujarat have shifted to unsustainable agricultural practices. Inadequate rain-fed crops, soil type, and groundwater dependence have caused severe environmental disturbances that require immediate sustainable agricultural interventions. There is an urgent need to return to efficient crops in water use and help prevent further degradation of agricultural land. There must be a shift towards sustainable cropping patterns such as the crop intensification system to reduce groundwater depletion, while integrated nutrient management must be adopted to maintain sustainability. Efficient water practices including SCI, micro irrigation, and water and soil conservation. To ensure long-term land productivity, immediate action is required to adopt sustainable agricultural practices. Agricultural practices must be sustainable rather than exploitative, leading to environmentally sustainable growth. Some of the technological and management interventions that could improve soil quality include structural methods for soil conservation such as soil and land fill and terraces in undulating areas, agronomic practices for the conservation and management of soils and waters such as However, they have been implemented through capacity-building programs. Another government-initiated program is the Soil Health Card program that informs farmers about soil quality and interventions that can be undertaken to improve soil quality. It is unlikely that these initiatives will pay enough dividends unless appropriate soil conservation measures and appropriate cropping patterns are adopted.

Forest cover in Gujarat is low compared to the national average. The mode of mission in social forestry and joint forest management (JFM) could help improve forest cover. Several NGOs have also been active with communities in the JFM program in Gujarat. The Gujarat Ecology Commission and the Gujarat Forest Department have also initiated awareness-raising programs to communicate and share the benefits that can be gained and livelihood support for forest ecosystems. Efforts need to be intensified to increase the natural resource base, promote sustainable and organic farming practices. Appropriate land acquisition measures that could provide a win-win situation for all stakeholders is the need of the hour. There is also a need to increase the number of common hazardous waste incineration plants and common effluent treatment facilities, as the land allocated to the SEZ, SIR, and GIDC areas is large and the number of industries that are often in Gujarat is increasing. Likely to generate more waste. The Gujarat Urban Development Company was established to study the issues of solid waste management. However, the solid waste management system needs to be further modernized. Concerning efforts in the mining and waste sector, Gujarat Ecology Society has undertaken the study "Ecological Restoration of Gujarat Mining Sites" at the request of the Gujarat Mineral Development Corporation to intensify the protection and conservation of the environment in mining areas. This is a small initiative that needs to be expanded as Gujarat is a state with the second largest mining lease in the country. A dynamic and scientifically advanced system of land use and land registry management is needed to better govern land resources. Advanced scientific tools should be used for land-use mapping. The standard land use classification system should be adopted by departments dealing with land issues. There must be a land-use policy that can reconcile the ecological, economic, and equity dimensions prevailing in the state.

The soil research has focused on soil chemical and physical factors, with a comparative neglect of biological factors. Consequently, there is a relatively limited understanding of how best to capitalize on the dynamics and potentials of soil biology in order to increase the regenerative capacity of soil systems for agriculture. More agronomic research and empirical experience for organic farming are required. Although better understanding and practices can serve the immediate needs on farms, they are unlikely to achieve desired changes in farming systems. Institutional policies and arrangements profoundly influence agricultural research and practice, and effective soil health initiatives must also address broader social and political considerations. In particular, we advocate a better balance between research and education to emphasize biology and ecology, the links between research and extension, new interinstitutional partnerships and collaboration, and increased stakeholder participation in research. This macro-level formulation and implementation should help guide cost-effective soil fertility technologies at the macro level. This type of nutritional balance will provide a methodology for national planners and other stakeholders at the meso-level to better articulate and focus on specific measures to increase soil fertility to ensure that targeted food security policies are sustainable in the long term. In similar lines, using the results of the present study, attempts were made to propose policy interventions that are measures of soil fertility improvement that should be followed at the district level to mitigate negative trends in nutrient budgets. These interventions have been broadly classified into one as research needs and another at the implementation level. Crop management for soil health offers an exciting value proposition for farmers and society. This cluster project is constrained by our mission and the size of the benefits to people and nature and also to lend our support to this important cause. In doing so, we will attempt a more concerted and coordinated effort, accelerating the adoption of soil health systems and achieving economic and environmental results on a scale that addresses our most pressing global challenges. The scientific agenda for soil health will require significant and long-term investments and collaborations. The CWRDM is expanding its scientific capacity through suggestions on soil testing services as a new role for soils other than water resources. As such, we will be a more capable partner with organizations that chart the future of soil health research. It is clear that new business models will be needed to align the economic interests of farmers, landowners and agricultural retailers on the benefits to soil health. The expansion of the Soil Health Partnership's successful model will be a priority given the importance of farmer-to-farmer knowledge transfer with adaptive and locally adapted health solutions.

6.2 Management of Water Resources

Given the positive developments of the last decade or so it may appear that Gujarat has overcome its water problems yet a lot remains to be done. Rapid industrialization and urbanization of the state have compounded the already complex water management issues faced by the state. Constitutionally speaking, water being a state subject, it is the responsibility of state governments to plan, develop and manage their water resources. Government responses have a central role to play while addressing the issues related to water. Meeting water demand in the future, even for a business as usual scenario by the mid-century will be difficult. Climate change impacts will further enhance the demand if the water availability reduces as indicated. Therefore, an integrated approach to water management needs to be instituted to also take into account the constraints posed by climate change. At present, it is the central and state governments that play the key role in the management of water resources. Besides, the involvement of the local people is crucial so that they can conserve, develop, and manage the water resource at the local level. For this purpose, the present organizational structure would have to be suitably restructured. The thrust on participatory village level institutions through Water and Sanitation Management Organization (WASMO) has played an effective role in improving water management at village level with a definite scope for further improvement. Participatory village level institutions in case of watershed and irrigation management require strengthening and scaling up. Schemes like *Sujalam Sufalam*, the interlinking of rivers, plus a state-wide grid for domestic and drinking water supply have intensified the positive impact of good rainfall and an almost complete SSP over the Narmada. WASMO and *Jyoti Gram* are two institutional responses that have had major positive impacts on the water sector in Gujarat.

Appropriate changes at the macro-level in the governmental organizational structures and the adoption of the river basin approach to the integrated planning and management of water resources. At the micro-level we suggest strengthening of community organizations—Watershed Committees (WCs) in rain-fed areas, Water Users Associations (WUAs) in irrigated areas, joint forest management (JFM) committees in forest areas. These community organizations will be the organizational mechanism through which people can be involved in the management of water resources. Watershed management and minor irrigation projects would be most suitable for drought prone, tribal, and hill areas, which should be allowed and encouraged to be developed by the local communities, with technical and financial help from the government and non-government organizations (NGOs). The management of these projects should be with the local communities, through WCs/ WUAs. The Government should transfer the authority for regulating groundwater use to the lowest level, the *gram sabha*. The first right to groundwater should be to the concerned community and not to an individual on the land-ownership basis. In areas with a scarcity of water, the respective community organizations should have the right to inspect and monitor the use of groundwater by private landowners to ensure that groundwater beyond permissible limits is not being withdrawn. Development of groundwater resources should be regulated in such a way that it does not exceed the annual recharge. The detrimental environmental consequences of over-exploitation of groundwater need to be effectively prevented by legislation and its enforcement by local government bodies, local committees, and *gram sabhas*, who will have to play a vital role in this. The prime concerns for Gujarat's water managers seem to be shifting from water augmentation to the redressal and management of the quality of water. There are obvious signs, as the findings of this report suggest along with various other reports on the deteriorating quality of ground water and surface water bodies like rivers, lakes, and ponds, that there exists an alarming situation with respect to water pollution. Just as the state has set an example in taking lead to set up Climate Change Department probably a model town planning framework to save, develop and conserve our water bodies is need of the hour. In this context, Gujarat needs to look for a paradigmatic change in terms of managing its water holistically to sustain its hard-earned growth momentum.

Integrated Water Resources Management (IWRM) creates a framework for water management options to be introduced into broader national development planning in a structured way. At national and basin level, IWRM principles are used to integrate water demand from different sectors of society and to balance this with water availability and to coordinate up-stream with down-stream users. At the local level, IWRM is also linking water demand, water supply, and water resources management in a sustainable way, involving communities in the decision making process. Being based on a holistic and bottom-up approach, IWRM plan for villages and watershed areas is expected to address the emerging trends and challenges in the rural water sector, and are likely to be a game-changer for rural development in the country. Through judicious crop and water management planning, such IWRM plans address the theme of enhancing farmers' income. IWRM plan should be prepared in sync with the District Irrigation Plan (DIP) so that the district officials and NGOs/VOs are able to use the recommendations. In an IWRM plan, enhancement of livelihood opportunities is considered to be a useful component of watershed development activities. Also, the activities covered in an IWRM plan will provide valuable inputs to the various flagship schemes of the GoI, such as PMKSY, NMCG, NMSA, *Saansad Adarsh Gram Yojna*, Rurban Mission, etc. The project was an attempt to showcase the utility of S&T interventions at a watershed scale based on the IWRM principles, which include sustainable development and management of all available resources with a focus on livelihood improvement. The project included distinct yet integral components of participatory research, scenario building, pilot scale demonstrations, capacity building, and suggesting a road map for the scaling up.

In a watershed development project, all available resources e.g. natural, physical, human, and livestock resources are addressed for development on a sustainable basis. A scientific assessment of the water availability and demand is a prerequisite for developing a sound strategy for soil and water conservation and management. In this context, it is important that the research should explore and identify the best approaches to adapt agriculture to the vulnerability factors by determining crop mix which would be most resilient to the impacts of climate change and other anthropogenic factors. While preparing the District Agriculture Plan (DAP)/ DIP for government's schemes in the districts and DPRs of watershed projects, the district officials need support in terms of scientific inputs. A simple DSS, as developed in the present project, can be a useful aid in this process. Geo-tagging of sites and structures being constructed and/or being monitored in a watershed is an emerging requirement in the watershed development projects. The developed DSS can certainly be used in the planning of the soil and water conservation activities, farming activities and for formulating the schemes related to the livelihood of the people with due consideration of the vulnerability assessments. Even the ongoing activities and events in a watershed can also be tagged with the DSS, which provides an effective platform for this purpose.

Development of an effective DSS requires a strong database on hydro-geological parameters required for water resources assessment including surface water and ground water systems, climatic parameters, water quality, soil properties, land use and land cover, cropping systems, demographic data, livelihood, domestic and industrial water use, water supply and demand, water supply priorities etc. This should be available through government line departments, field experimentation, and filed surveys. Dynamic nature of some parameters e.g. population migration, seasonal water demand, contamination of water bodies, should be kept in mind while developing the database in such projects. The micro-level database should be developed of the watershed resources so as to get more accurate and localized results. A Watershed Scorecard is an important tool for determining the baseline and health of the watershed, and for the planning of the specific watershed development activities.

6.3 Policies Towards Research

Critically re-looking into the existing fertilizer recommendations through fresh research efforts and redefining the present blanket fertilizer recommendations, which are evidently sub-optimal for the present day crops and varieties and the native soil fertility status. Basic research on water, carbon and nitrogen footprints and their role in soil-crop management with special reference to climate change and climate vulnerability. Developing efficient techniques of water and nutrient management for their economic use in different agro-ecosystems. Efficient technologies for utilization of diverse biomass from different sources (agricultural, agro-industrial, municipal etc.) for improving soil productivity under integrated nutrient management and organic farming. The role of resource conservation agriculture in abiotic and biotic stress management with special reference to climate change. Soil quality assessment, developing soil quality index and periodic monitoring through identification of minimum data set under different agro ecosystems. Invest in research and development of locally-adaptable crops, management practices, input sources etc., decision support system (DSS), and models for analyzing the impact of climate change and mitigation strategies, particularly in arid and semi-arid regions in view of their greater vulnerability. Prioritize regions vulnerable to climate change with a particular focus not only on arid and semi-arid regions but including humid regions like Kerala in climate change action plans, and prepare and implement comprehensive district-wise agriculture and livelihood contingency plans. Developing models for predicting the impact on soil quality under different climate change scenarios.

For effective and economical management of water resources, the frontiers of knowledge need to be pushed forward in several directions by intensifying research efforts in various areas, including the following: (i) hydro-meteorology, (ii) assessment of water resources, (iii) groundwater hydrology and recharge, (iv) water quality, recycling and reuse, (v) prevention of salinity ingress, (vi) prevention of water-logging and soil salinity, (vii) water harvesting in rural areas in an integral manner, (viii) water harvesting and groundwater recharge in urban areas, (ix) economical and easy to operate and maintain designs for water resource projects, (x) better water management practices and improvements in operational technologies, (xi) crops and cropping systems, and (xii) sewage treatment on smaller scales and reuse of water after treatment.

Since the overall thrust of the policy is towards people's participation at all stages, the highest priority should be accorded to the training of those who are to manage the water resources at all levels. The training must sensitize all partners to the demands of a people's planning approach to water resource development. Training should also ensure the technological empowerment of all local institutions and communities who are to plan for, develop and manage water resources. These include panchayats, *gram sabhas*, NGOs, watershed associations, WUAs, WCs, etc. It should cover training in information systems, sectoral planning, project planning and formulation, project management, the operation of projects and their physical structures and systems and the management of the water distribution systems. The training should have a strong component of attitudinal and behavioral change.

6.4 Policies Towards Implementation

Expanding the capacity of soil testing program by providing infrastructural facilities at block level either as public sector units or as subsidy linked private sector units to provide soil test based site specific integrated nutrient management (INM) practices that will help to enhance soil fertility. Promoting green manuring through a supply of quality seeds at a subsidized price to farmers and ensuring minimum water availability in the command areas to exclusively grow green manure as a preceding crop before the crop season. Training extension workers and farmers on 'on-farm composting', which is a proven technology for effective recycling of farm wastes to generate low-cost nutrient rich organic manures in a shorter period and linking 'on-farm composting' by farmers to subsidy linked Government schemes. Establishing a linkage with fertilizer industries to promote the use of slow/controlled release fertilizers and controlling their price by appropriate subsidy, which will help to minimize nutrient losses through leaching and volatilization and to increase the nutrient use efficiency by matching the nutrient release with crop requirement. Integrate climate change initiatives such as INCCA, NAPA, NMSA, NICRA, NDMA, etc. with national agricultural policies/ programs of food security, disaster management, natural resource conservation, livelihood enhancement etc., to enable rural communities to take advantage of new technologies and tools. Developing GIS based computer maps for each district by superimposing soil fertility, Length of growing period days (LGD), and moisture index as layers to subdivide the district into sub-zones, each of which will require a uniform set of management that will help to enhance and sustain soil fertility. Establishing block level automatic weather stations to enable rainfall predictions that will help to the reduce risk associated fertilizer addition to rain-fed crops. Distributions of Soil Health Cards to all the farmers with follow up to assess the impact on crop productivity and profitability. Encourage diversification of rural income through off-farm and non-farm livelihoods; build a significant stake for climate change adaptation interventions in the newly-launched national livelihood mission. Create a favourable environment to attract public and private funds for investment in Climate Resilient Agriculture (CRA). Much of the corporate social responsibilities funds from leading private sector players in the country should be channelized to promote CRA in vulnerable regions. Increase concessional credit to small and marginal farmers for adoption of climate resilient agricultural practices. Evolve a new verification system at field level to sensitize farmers through credit and input subsidies. Establish efficient cooperatives, community organizations and associations/ groups to tackle critical needs of farmers like resource mobilization, custom hiring, marketing their outputs and efficient natural resource management.

Suitably empower *Gram Panchayats* all over India to play a leading role at the grassroots level in developing and implementing concerned programs. Identify, critically document and share most successful stories in climate change management and organize pilot demonstrations of most successful modules, and in a partnership mode scale-up and scale-out the selected ones to establish climate smart villages throughout the country. Introduce soil and water conservation practices on a large scale for achieving long-term sustainability of the systems, including revitalization and management of Common Property Resources. Farmers must be given incentives to adopt CRA practices. Institutionalize a mechanism to collect and collate micro-level information continuously (climate, crops, socio-economic, natural resources etc.) and establish credible database as well as efficiently disseminate it which can be used as an input for macro-level policies. Improve techniques for water (rainwater harvesting, micro-irrigation), nutrient (SSNM) and energy (reduced tillage) conservation to adapt the crops to climatic stresses and also contribute to mitigation. Encourage adoption of location-specific conservation techniques (cover cropping, *in-situ* moisture conservation, rainwater harvesting, groundwater recharge, locally adapted cropping systems etc.) for water efficient agriculture and demonstration of such technologies on farmers' fields. Establishing a Soil Health Philanthropy Network (SHPN) by involving the fertilizer industry, fertilizer distributors, and retailers, agricultural professionals, farmers, self-help groups (SHGs), NGOs, etc. to enable promotion of soil health by advocating proper agricultural input products and technologies that will help to enhance soil fertility. To streamline and create awareness about managing the climate risks through weather-based agro-advisories, and affordable weather insurance products.

Chapter 7: Conclusions and Way Forward

Temporal variability of climatic factors shows heterogeneous changes across RCPs and models. However, the spatial variability of each of the agro-climatic factors tends to have a similar trend in all the results obtained from different RCPs and Models. In Gujarat, current climatic conditions are projected to increase annual mean rainfall and temperature in future. Projecting higher annual actual evapotranspiration in this region is directly related to higher temperature as well higher water availability from rainfall. Net primary production under rain-fed condition has a close relation with actual evapotranspiration because it is related to plant photosynthetic activity which is also driven by radiation and water availability. The projection for annual mean rainfall and temperature in Kozhikode district illustrates a rise in future. The projection for annual actual evapotranspiration and reference evapotranspiration deficit also show a rise in the region. The Ur River catchment of Bundelkhand region is witnessing fluctuations in extremes weather conditions–long drought spell and intense monsoon rainfall. The future projection shows an increase in annual mean rainfall and temperature in Tikamgarh district.

For the most part of the year, people in Gujarat and Bundelkhand experience acute scarcity of water for domestic and agricultural use. Agriculture is the major source of livelihood and is rain-fed in most parts of the study areas. Therefore, to improve the water situation in the regions, it was felt that an integrated approach to water management, linked with livelihood issues, has to be undertaken. Natural resource management issues are inherently complex as they involve the ecological cycles, hydrological cycles, climate, animals, plants, geography, etc. All these are dynamic and interrelated. Additional stresses come from climate variability and climate change resulting in impacts on water availability in time and space, potentially increasing rainfall variability resulting in more powerful monsoons and more frequent floods and droughts, and changing the water requirements, climatic suitability and yield of crops, as well as the incidences of pests and diseases. Cropping patterns in the State of Gujarat have shifted to unsustainable agricultural practices. Growing crops not very suitable for rainfall, soil type, and reliance on groundwater have caused serious environmental perturbations calling for immediate sustainable agricultural interventions. The agricultural productivity in Kerala is very low because of low fertile lateritic soils, nature of topography with undulating terrain, coupled with high-intensity rainfall, leads to top fertile soil loss through severe erosion and nutrient loss through leaching which might have been one of the contributing factors for low productivity. However, at this juncture, the low yield of crops associated with high cost of production is a great concern in Kerala’s agriculture.

The State of Gujarat has come up with various major and minor projects adding to the surface storage capacity of its rivers while enabling ground water recharge in its parched regions. From Drought Prone Area Programme (DPAP) to Integrated Watershed Management Programme (IWMP) the focus has shifted from piecemeal solutions to a more integrated approach towards watershed management through GIS-based planning and management of watershed and convergence with other developmental schemes. However, robust grassroots institutions for watershed management are yet to emerge. The government and other stakeholders took bold steps towards the augmentation and management of available water in Gujarat in the last decade. Its efforts have yielded positive results partly due to favorable climatic conditions since last decade. The state witnessed a trend of increasing rainfall in most of its regions over the 15 years, despite many regions being chronically drought prone due to erratic rainfall. Factors like good rainfall, the arrival of Narmada waters, and the massive recharge effort undertaken by communities and the government through the watershed treatment have all come together to play an important role in the increased water availability, which has improved ground water tables, and increased access to drinking and domestic water in most parts of the state. A state-wide water supply grid based on Narmada waters, presently in an advanced stage of development, is expected to provide drinking water to 75% of the state's population. Although drinking water quality remains an issue in some parts, particularly quantitatively, a lot has been achieved in terms of the substantial number of villages covered by WASMO.

To assess the soil fertility status and nutrient balance/ budgeting of major crops/ cropping systems at different spatial scales in Kerala, a decision support system (DSS) has been developed for managing soil fertility and sustain the crop productivity. This was done in a holistic manner by way of soil fertility assessment in terms of nutrient stocks/ flows as an individual crop/ cropping system/ mixed crop and farm as a whole through field experiments and also as a district/ regional level to know about the status of their soils and the strategies needed to sustain the fertility besides explore the possibilities for increasing the crop productivity in an environmentally sustainable way. The DSS was developed as an output by combining all the data bases generated from the project apart from using all available secondary data sources. The DSS *viz*., CWRDM-Integrated Crop Nutrient Management Software (CWRDM-ICNMS) will help in generating a nutrient recommendation to most of the crops in Kerala by considering all the inflows and outflows from the farm. The DSS will serve as a tool to identify the depletion of soil nutrients and helps to suggest the management options using a systematic approach. The output will be a cost effective, eco-friendly conservation and management technology for higher input use efficiency, agricultural productivity & profitability without deteriorating natural resources for the whole of the farming community in Kerala.

The overall outcomes of the study in the Ur River watershed can be summarized into three broad sections *viz*., watershed scorecard, decision support system (DSS), and Integrated Water Resources Management (IWRM) plan. A watershed scorecard is like a report card, which was designed in order to understand the condition of natural resources. The five major indicators *viz*., surface water quality, ground water quality, agricultural condition, forest condition, and soil condition were used to develop a scorecard of the Ur River watershed wherein forest condition was highlighted for protection and improvement in future. A DSS called "*Jal-Jan-Jeevan*" was developed under the project, which includes various modules related to mapped information on all natural resources of the watershed, questionnaire-based support to the stakeholders, assessment of vulnerability to the climate change, success stories and recommendations to the users for improving their livelihood status. It is an integrated resourceful application for the line departments and to the farmers of the area.

Many studies are available on the monsoon characters of the state of Kerala, however, linking the same with agricultural crop production under climate variability and strategies to sustain the same is lacking. Hence, such a documentation of climate change and the increasing climatic variability with future projections for the crops of Kozhikode district have been documented in this study. In addition, the increase in temperature, uncertainty in rainfall and increase in carbon fertilization has been studied in detail and about these impacts on soil and water conditions and its influence on crop productivity under humid tropical conditions has been given a focus in the current study. To overcome the negative impacts of climate change, apart from the developed a DSS of soil nutrient management, several other adaptation strategies need to be focussed to improve or at least sustain the productivity. A brief description of the adaptation options, which potentially can reduce the vulnerability of agriculture to the effects of climate change is also discussed in this report along with suitable policy decisions and future directions.

The most important deliverable part of the study in the Ur River watershed was IWRM plan, which was divided into three major sections: water management, crop management, and livelihood management. The IWRM plan suggests measures of water harvesting and changes in cropping pattern utilize the available water resources in a best possible way. The water management plan suggests suitable sites for new water harvesting structures. Land resource management plan suggests the best utilization of the available land resource of the area and provides options for improving land use, agricultural productivity, and soil health. It also suggests suitable livelihood options for the local communities. Based on the experience of this project, it is recommended that more of such "action research" projects should be conceived and supported in complex and problematic areas such as Bundelkhand region. Action research in a participatory mode gives the best possible results in such cases. The watershed scorecard and IWRM plan provide actionable points on which the concerned authorities can act upon. Institutional arrangements with the local line departments, NGOs, academics, PRIs, and KVKs are vital components of such projects in not only obtaining the required inputs for creating the database but also for implementation of the IWRM plan recommendations.

There is an urgent need to return to water efficient crops and help prevent further degradation of water and agricultural land. Farmers need to be educated to shift towards the cropping patterns based on results of the AEZ modelling. There needs to be a shift towards sustainable cropping patterns like the system of crop intensification to reduce groundwater depletion while integrated nutrient management needs to be adopted for maintaining sustainability. To ensure long-term land productivity immediate steps need to be taken towards sustainable agricultural practices. Many attempts are required to strengthen farmland productions and maintain ecological balance to survive against the climate-related impacts and shocks. There has to be a drive to build the resilience of farming and vulnerable communities who are most likely to be affected by climate variability and change. Hence, the government has to take initiatives to help communities to build resilience and adapt to the effects of climate variability and change through scientific, indigenous knowledge and evidence-based decision. Scoping studies need to be conducted to understand communities and ecosystems that are vulnerable to climate change. Communities are in a better position to identify their needs and risks after having accumulated knowledge and experience in the context of climate change impacts. Therefore, it is very important to incorporate their views, observations, and experiences in decision making and policy planning. Investments in climate smart agriculture, climate smart livestock management, better water conservation practices, quality agricultural inputs, micro-irrigation practices, development and management of natural resources through watershed and afforestation activities, conservation of biodiversity including crop biodiversity, etc. will not only increase production from farmland, but also prove to be transformational adaptation practices.

This study looks at future of agriculture in Arid, Semi-Arid, and Humid agro-ecological zones of India through three case studies. However, Sub-Humid, Dry Sub-Humid, and Mountain Ecosystems are not covered in any of the study. Although India has a huge crop diversity, these studies could cover only a limited number of crops. Besides this, there are several critical socio-cultural dimensions in different regions of the country which need to be integrated for better natural resources management. Hence, a national level study with high-resolution soil series data is need of the hour.

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