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By Subhra Halder

Seasonal Variation of Use of Irrigation Water and Its Management: Case study in West Bengal

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List of Journal Publications

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PROFORMA – 1

"<u>Statement of Originality</u>"

I…**Ms. Subhra Halder**… registered on …**17th June, 2019**… do hereby declare that this thesis entitled "**Seasonal Variation of Use of Irrigation Water and its Management: Case Study in West Bengal**" contains literature survey and original research work done by the undersigned candidate as part of Doctoral studies.

All information in this thesis have been obtained and presented in accordance with existing academic rules and ethical conduct. I declare that, as required by these rules and conduct, I have fully cited and referred all materials and results that are not original to this work.

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This is to certify that the thesis entitled "**Seasonal Variation of Use of Irrigation Water and its Management: Case Study in West Bengal**" submitted by **Ms. Subhra Halder** who got her name registered on **17th June, 2019** for the award of the Ph.D. degree of Jadavpur University is absolutely based upon her work under the supervision of **Dr. Subhasish Das**, Associate Professor of School of Water Resources Engineering, Jadavpur University and that neither her thesis nor any part of the thesis has been submitted for any degree or any other academic award anywhere before.

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Abstract

Irrigation water management means to manage the irrigation water as crop requirements. The process of storing and supplying irrigation water is considered as irrigation water management. Globally, reservoirs and dams portray a significant role in irrigation development. The present study focuses on seasonal irrigation water management and its impact on land use patterns. For this purpose, the Shali reservoir which is a medium irrigation scheme run by the Irrigation and Waterways Department (I&WD) under Government of West Bengal (GoWB) has been chosen. Shali reservoir is situated in Gangajalghati block of Bankura district, West Bengal. The Shali reservoir stores rainfall and conveys it through the Shali river for irrigation in the villages of the Shali River Basin. Moreover, almost no research so far has been done about the seasonal variation of irrigation water of the Shali reservoir in Bankura, West Bengal and its impact on agricultural production.

Therefore, in the present research, an attempt has been made to examine the seasonal variation of irrigation water of the Shali reservoir giving special emphasis on water management in the Rabi (winter) period. The prime objectives are to examine the seasonal water level trend of the Shali reservoir and identify suitable irrigation lands in the Shali River basin. The study also analyses the impact of the Shali reservoir scheme on LULC and predict future landuse maps and assesses the impact of irrigation through the Shali reservoir on seasonal crop production. Lastly, it examines the impact of the Shali reservoir on irrigation, cropping and agricultural labour intensity.

Several geospatial and statistical methods are incorporated to justify the objectives of the study. Mann Kendall trend analysis has been applied to identify the seasonal water level trend of the Shali reservoir and seasonal crop production. The linear regression (LR) method has been used to determine the correlation between irrigation and cropping intensity. Analytical Hierarchy Process (AHP) and weighted overlay analysis have been applied to identify suitable irrigation lands in the Shali River basin area. A random forest classifier has been applied in LULC classification to identify the LULC classes precisely and the cellular automata method has been applied to predict future LULC patterns. Autoregressive integrated moving average method has been adopted to identify future trends in the crop production area and multiple linear regression has been applied to identify the correlation between irrigation, cropping and agricultural labour intensity.

The study reveals that the water level of the Shali reservoir varies seasonally. The maximum water level has been identified in the monsoon season. In the Shali reservoir, a high-water level trend has been observed in monsoon and post-monsoon, and a low positive trend was observed in pre-monsoon and winter. Study reveals that the Shali reservoir can provide irrigation water throughout the season. Therefore, a huge transformation in LULC has been observed, around 52% growth in agricultural land has been observed from 1986 to 2021 in the Shali River basin area. The predicted LULC map of 2031, also shows that the amount of agricultural land will be increased by around 57%. Thus, it has been proven that the Shali reservoir plays a vital role in agricultural development in the Shali River basin area. In crop

production, both Kharif and Rabi production areas have been increased in the Shali River basin area. Rice mapping also shows a positive change in the rice production area. It can be said that after the creation of the Shali reservoir crop production area has increased especially in the Rabi season. The study reveals a positive change between irrigation, cropping and agricultural labour intensity from 1991 to 2011 in the Shali River basin area.

In conclusion, it can be said that After the creation of the Shali reservoir, irrigation intensity has been accelerated in the Shali River basin area but the villages of Gangajalghati and Barjora blocks are getting more irrigation water due to their location than the other two blocks i.e., Sonamukhi and Patrasayer. These two blocks yielded more quick flow than Gangajalghati and Barjora blocks. Therefore, it is advisable to imply rainwater collecting structures to store monsoonal rainfall that will help to increase irrigation intensity in future. During the study period, it has been observed that there is a communication gap between the reservoir authority and farmers. The reservoir authority does not inform the farmers before the water discharge from the reservoir. Therefore, huge misuse of water has been observed. The Shali reservoir maintenance officials should inform the villagers before water release from the reservoir. Social media can be a good option for this purpose. The farmers do not know about crop water requirement (CWR), therefore, sometimes crops are affected due to over-irrigation. Hence, the I&WD, GoWB should implement awareness programs which will help farmers to learn the proper usage of irrigation water. Reservoir sedimentation is a big problem. It reduces the water holding capacity of the reservoir. In the case of the Shali reservoir, no sedimentation analysis has been found. The I&WD, GoWB should implement desilting programme in the Shali reservoir.

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List of Abbreviations

A1: Appendix 1

AHP: Analytical Hierarchy Process

ANN: artificial neural network

ARIMA: Autoregressive Integrated Moving Average

ARLBINTST: Agricultural labour intensity

CA: Cellular automata

CHIRPS: Climate hazards group infrared precipitation with station data

CI: Consistency index

CR: Consistency ratio

CRPINTST: Cropping intensity

DEM: Digital elevation model

DI: Drainage intensity

EROS: Entire earth resources observation and science

EVI: Enhanced vegetation index

FAO: Food and Agricultural Organisation

GDP: Gross Domestic Product

GEE: Google earth engine

GIS: Geographical information system

GoWB: Government of West Bengal

GPZ: Groundwater potential zone

GWL: Groundwater level

I&W Dept: Irrigation and Waterways Department of West Bengal

ICAR: Indian Institute of Agriculture and Research

IMD: India Meteorological Department

IRINTST: Irrigation Intensity

J&K: Jammu and Kashmir

LC: Land cover

LR: Linear regression

LSWI: Land surface water index

LU: Land use

LULC: Land Use and Land Cover

MCDA: Multi-criteria decision-making approach

MIF: Multi Influencing Factor Analysis

MK test: Mann Kendall test

MLC: Maximum likelihood classifier

MLP: Multiple linear regression

MODIS: Moderate resolution imaging spectroradiometer

MOLUSCE (Modules for Land Use Change Evaluation)

NAIP: National agricultural imagery

NDBI: Normalised difference built-up index

NDVI: Normalised difference vegetation index

NDWI: Normalised difference water index

NFSM: National Food Security Mission

NIR: Near-infrared

PPPM: phenology and pixel-based paddy mapping

RF: Random Forest

RI: Random index

RS: Remote sensing

RUSLE: Revised Universal Soil Loss Equation

SAR: Synthetic aperture radar

SD: Standard deviation

SRB: Shali River basin

SRS: Satellite Remote Sensing

SST: Sea surface temperature

SWOT: Strength, weakness, opportunities, and threat

UP: Uttar Pradesh

WBDES: West Bengal Directorate of Economics and Statistics

WBDWIP: West Bengal Drinking Water Improvement Project

WL: Water level

WRIS: Water resource information system, India

Chapter 1

Introduction

1.1 Irrigation

Irrigation is an artificial process that provides water towards land. It helps to maintain crop growth by retaining moisture in the soils of low-rainfall areas. Irrigation has several benefits such as intensifying crop production, protecting against food crises, raising high-yield crops, eliminating mixed cropping, enhancing economic development, generating hydropower, supplying household, industrial water etc. Crop yield intensification: Irrigation enhances crop production by supplying enough water depending on crop requirements. Protects from famine: In drought-prone regions, without irrigation farmers must depend on rainfall for cultivation which may cause famine. So, irrigation ensures protection from famine in low-rainfall regions. Cultivation of high-yield crops: High-yield crops require a certain amount of water, so with the help of irrigation farmers can cultivate high-yield crops easily. Eliminate mixed cropping: irrigation eliminates the tendency of mixed cropping. In rainfed areas, farmers tend to cultivate more than one crop in the same field because if one crop dies due to lack of water then they would get yield from another one which reduces the overall production. With the help of irrigation, farmers can cultivate a single variety of crops. Enhance economic development: irrigation increases crop production which enhances the economic growth of farmers. Generate hydropower: in certain places, mostly in canals where the high elevation is used for hydel power generation. supplies domestic and industrial water: the irrigation canals also provide water for domestic and industrial usage in nearby areas (Reddy 2010).

1.2 Development of irrigation in India

According to historians' the practice of irrigation was started in India during the Indus Valley civilization (2500 BC). In Dholavira, water storage structures were found. Dholavira is an archaeological site at Khadir bet in Bhachau Taluk in the Kutch district. The site contains ruins of the Indus Valley Civilization/ Harappan city. It was bounded by two stormwater channel which was made of stone. A massive reservoir was also exposed. The people of the Indus Civilization stored rainwater in this reservoir and small rainwater harvesting structures were also found for personal usage (Bharadwaj, 1990; Verma et al., 2014; Reddy, 2017; Lata, 2019).

During the medieval period, Ghiyasuddin Tughlug, Emperor of the tughlug dynasty (1220–1250) was the first who assisted in digging canals and Fruz Tughlug (1351–1386) was considered the greatest canal builder in India. He constructed the Western Yamuna canal in around AD 1355, to transfer Yamuna river water to the hunting place at Sefidem in Hisar district (Haryana). In 1586 Akbar renovated this canal for irrigation purposes in the Hisar district. Mughal ruler Shahjahan re-established the Western Yamuna canal to irrigate the orchards of Red Fort, New Delhi. He also structured ~179 km canal from the River Ravi to

Lahore. A division of this canal conveyed water to the Golden Temple of Amritsar, and a huge segment of Kashmir and Punjab benefited from this canal. In Southern India, irrigation was the main reason for the growth of the Vijayanagar empire. Emperors of Vijayanagar built Ananta Raj Sagar tank in the Cudapah district of Andhra Pradesh. (Bharadwaj, 1990; Verma et al. 2014; Reddy, 2017; Lata, 2019).

In the British phase, after the 1898 and 1900 famine (Bharadwaj, 1990), the first irrigation commission was formed in 1901 to protect India from famine. The main recommendations of the commission were, various public irrigation projects were undertaken in Madras, Bombay, Bengal, Gujarat, Bihar and in the Indus basin and private irrigation was also encouraged such as the construction of wells. Britishers constructed the Kaveri delta structure in Tamilnadu and Godavari canal structure in Andhra Pradesh which can irrigate 0.5 and 0.4 million ha. In 1854 Upper-Ganga canal structure was constructed in Uttar Pradesh, the Sone canal in Bihar, and the Orissa canal on river Mahanadi for irrigation purposes. (Bharadwaj, 1990; Verma et al., 2014; Reddy, 2017; Lata, 2019).

After Independence, due to partition, the irrigation sources were divided between India and Pakistan. At that time the major concern in India was food production. For this purpose, huge investments were made by Indian Government towards surface irrigation. Therefore, soon after independence Bhakra Nangal, Hirakud and Damodar valley projects were taken up and other schemes were taken up for irrigation development (Bharadwaj 1990; Verma et al 2014; Reddy 2017; Lata 2019).

Table 1.1 Irrigation development during five-year plan (FYP) in India (Lata, 2019)

FYP	Duration (Year)	Irrigation expenditure (₹ million)	Irrigation potential (Million ha)
1	1951 - 1956	4560	3.66
2	1956 - 1961	5220	2.83
3	1961 - 1966	9090	4.52
4	1969 - 1974	17500	7.10
5	1974 - 1978	30730	7.92
6	1980 - 1985	93180	11.30
7	1985 - 1990	143600	13
8	1992 - 1997	366490	-
9	1997 - 2002	636820	-
10	2002 - 2007	957430	-
11	2007 - 2012	2323110	-

1.3 Sources of irrigation water

In India, sources of irrigation water are classified into two categories: irrigation by surface water resources and irrigation by groundwater sources (Asawa, 2006; Lata, 2019).

In irrigation, surface irrigation remains a very old and popular technique. In this system surface water transfers from reservoirs, canals, lakes, ponds, and tanks through canals to the farming field. According to the amount of water, farmers decide the type of crop for cultivation. In this process, less than 50% of water reaches the crop because of leaching, evaporation, and non-beneficial practices. Correspondingly, it happens due to the lack of knowledge of the farmers. In the surface irrigation method, canal is first used to transfer water from one place to another. It is an artificial canal which is constructed to carry river water to the agricultural fields. Canals are of two types: perennial and non-perennial. The perennial canal has an uninterrupted source of water supply whereas the non-perennial canal draws water in the high phases of the river. In the nineteenth century before independence, the British administration and planning department developed the great canal system of India. In surface irrigation, tanks are considered the most significant traditional source of water for surface irrigation. Tanks are small plus shallow reservoirs which are used to store monsoonal rainfall. In groundwater irrigation, rainfall penetrates through the soil and is stored beneath the earth's surface which is known as groundwater. In this type of irrigation water is lifted through wells from the groundwater storage for irrigational usage. The groundwater depth ranges between 1 to 40 mbgl (CGWB, 2020). In India, around 60% of the land is irrigated through groundwater wells, between the years 2000 to 2007 (Mishra et al., 2018). A huge number of wells and tube wells were constructed for irrigation purposes (Asawa, 2006; Lata, 2019).

1.4 Irrigation methods in India

Irrigation methods are classified into four categories: surface, sprinkler, sub-surface, and drip irrigation. Again, the surface irrigation method is classified into four sub-groups: uncontrolled flooding method, border strip method, basin method and furrow method (Asawa, 2006; Reddy, 2010) (Figure 1.1).

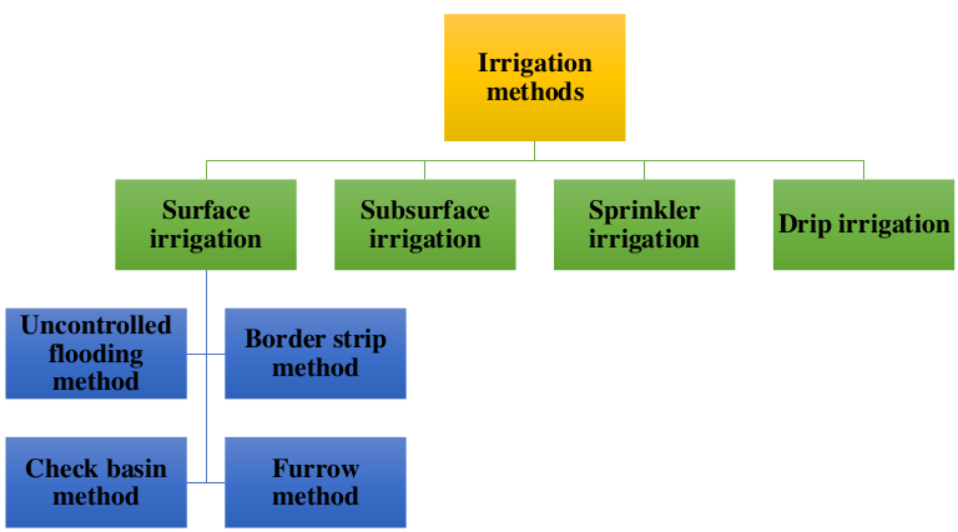

Figure 1.1 Different irrigation methods in India

Surface irrigation

It is the oldest technique of irrigation. In this method water transports from rivers, ponds, lakes, and reservoirs through channels (Asawa 2006; Reddy 2010).

Uncontrolled flooding

This type of technique diverts water to the agricultural land without any land preparation and water flows directly into the field without any restriction. In uncontrolled flooding, the inlet region of the field gets the excess amount of irrigation water and the outlet end gets insufficient irrigation water. Due to deep percolation, application efficacy is reduced and thus the outlet ends occasionally receive insufficient water. The application effectiveness depends on the depth of flooding, soil water intake capacity, stream size and topography of individual fields. Therefore, this method is suitable when water is obtainable in large quantities. Another disadvantage of this method is that grown crops may get affected due to surplus water. Whereas, the benefit of this technique is low-priced land preparation in the initial stage (Asawa, 2006; Reddy, 2010).

Border strip method

In the border strip method, water is transferred to agricultural land in a controlled surface flooding method. In this method, the agricultural land is divided into around 3-19 meters wide and 100-390 m extensive strips. Low levees are created to divide the strips. The slopes of the levees are very gentle. In the case of steep slopes, proper care is required to check soil erosion. Clay and clayey soils have low infiltration rates so in this type of soil the slopes of strips are flat (around 0.2%). Medium soils have a 0.2 to 4% slope and sandy soils have a 0.25 to 0.6% slope. This method is appropriate for every variety of crops and it requires land preparation which has a high cost (Asawa, 2006; Reddy, 2010).

Check basin method

In the check basin method, the whole land is separated into several sections enclosed by levees. This method is suitable for very porous to impermeable soils. In this method, cultivators can control the supply of water in different parts of the farm. The application efficiency is high in this method because of water loss due to deep percolation. In this method, surface runoff can manage very easily because this method needs continuous attendance. In the check-basin method, the levees occupied areas are responsible for certain losses in the cultivable area. To grow 'row crops' wide surface levees are made sometimes. It commonly, benefits orchards by providing irrigational water. In this method, each basin is created for each tree. Though, where situations are advantageous, one basin can have more than one tree (Asawa, 2006; Reddy, 2010).

Furrow method

In this method to avoid flooding, small channels are made across the field to control the direction of water flow. These small channels are known as furrows. The length of the furrows varies from 10 meters to 500 meters (Asawa, 2006; Reddy, 2010), but very long furrows increase percolation and soil erosion. Slopes between 0.3 to 5% are preferable for furrows.

Otherwise, proper care should be taken to prevent soil loss in steep slope areas. The depth of the furrows should be around 7 to 11 cm (Asawa, 2006; Reddy, 2010). Water is spread to furrows via canals or tanks. Furrows require wetting of only 20 – 25% (Asawa, 2006; Reddy, 2010) of half of the field surface. This helps to reduce evaporation. It offers improved farm water management flexibility under several surface-irrigation situations. However, the furrow method has some disadvantages: it increases salinity and erosion, and this method also needs extra more labour than other types of surface-irrigation methods (Asawa, 2006; Reddy, 2010).

Sub-surface irrigation

In this method water transfers directly into the soil under the surface. In this method through capillary action moisture reaches the plant roots. The favourable conditions of the subsurface method are impervious subsoil (depth 2 m), porous loamy or sandy loamy soil, permeable subsoil, even topographical environments, and medium ground slope. Here, the water is supplied through a sequence of canals around 0.5–0.9 metres deep and around 0.3 m wide. During the production of high–priced crops, a pipe distribution system is put under the soil surface (Asawa 2006; Reddy 2010).

Sprinkler irrigation

In sprinkler irrigation, water is sprayed in the air then it falls on the ground surface uniformly. Initially, this spray method was restricted to nurseries and orchards. Mainly in humid regions, this method of irrigation was used as supplementary irrigation. The sprinkler method is very conventional in advanced nations but, nowadays it gaining recognition in developing nations also. In sprinkler irrigation, it has revolving sprinkler head systems which spread water to a specified zone. The extent of the specified zone depends on the nozzle size of the sprinkler and water pressure. This method can be operated on all types of soils, topography, and slope. The favourable conditions of the sprinkler irrigation method are pervious soil, land with steep slopes and easily erodible soil, small irrigation channels, shallow soil lands and undulating topography (Asawa, 2006; Reddy, 2010).

Drip irrigation

The drip irrigation method contains a mainline (35-70 mm diameter pipe), sub-mains (25–35 mm pipe), valves (controls flow), laterals (6-9 mm pipe), drippers (supplies water toward the pant), pressure gauge, water metres, purifiers (removes debris), pumps, fertiliser containers, void breakers, compression regulator. The drippers supply water directly to the soil. Drip irrigation comprises usefulness. It prevents water loss, expands crop production and plant development, protects labour, energy and regulates unwanted plant growth, reduces soil loss, cost-effective (no land preparation cost). Whereas, this method has some limitations. It needs advanced expertise in planning, operation and application (Asawa, 2006; Reddy, 2010).

1.5 Irrigation projects in India

In India, irrigation projects are grouped into three groups: major irrigation projects, medium irrigation projects and minor irrigation projects.

Irrigation schemes having more than 10000 ha culturable command area are considered major irrigation projects. They are mainly surface irrigation projects which comprised large-scale storage and diversion works. Whereas, irrigation schemes having 2000 to 10000 ha culturable command area are named medium irrigation projects. These are also surface irrigation projects. In minor irrigation, culturable command area up to 2000 ha. Further, minor irrigation is divided into two classes: surface and groundwater minor irrigation schemes (Reddy, 2010). Here, Figure 1.2 and Table 1.2 show the locations and details of major irrigation projects in India, respectively.

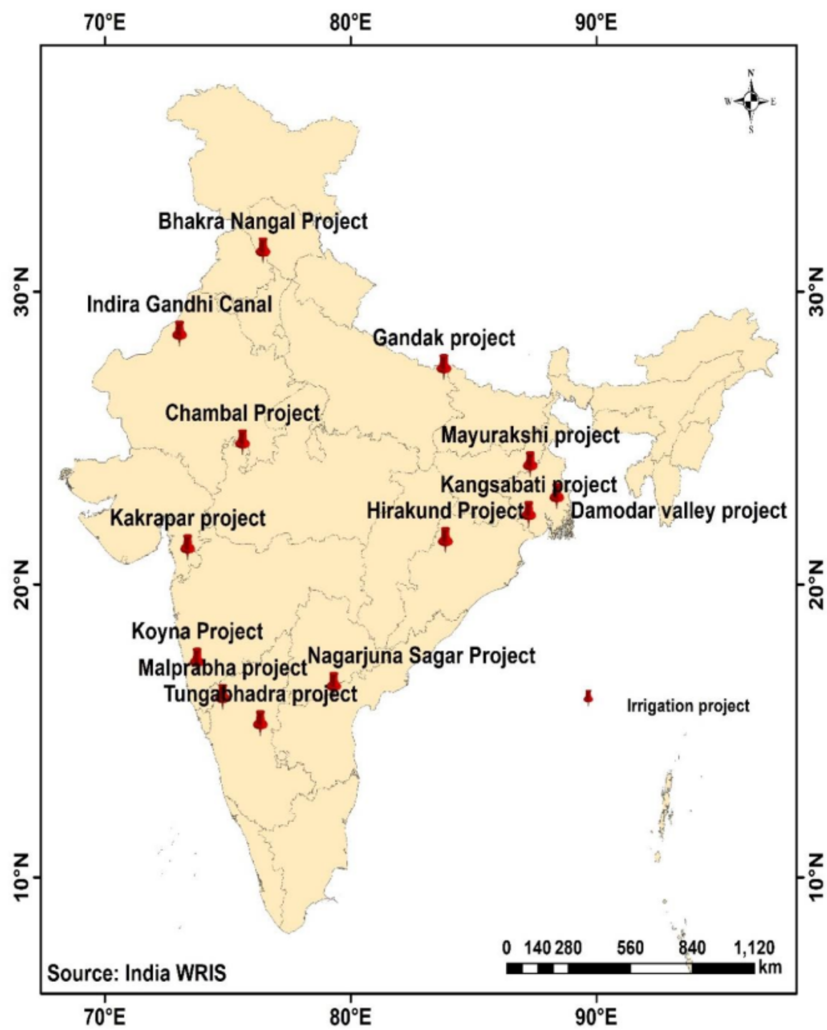

Figure 1.2 Major irrigation projects in India

1.6 Irrigation water management

Irrigation water management means managing the irrigation water as crop requirements. The process of storing and supplying irrigation water is considered irrigation water management. In India, since prehistoric times many profitable and natural traditional irrigation systems have been created based on rainwater and groundwater utilization. Different Archaeological excavations disclosed that traditional irrigation systems were present in India for about 5000 years. Local farmers designed and maintained these traditional irrigation systems. At present very few of them have remained only at religious places.

Table 1.2 Major irrigation projects in India

Project name	Completion year	River	State benefitted
Bhakra Nangal	1963	Sutlej	Punjab, Himachal Pradesh
Indira Gandhi canal	1965	Sutlej and Beas	Punjab
Gandak	1970	Gandak	Bihar, Uttar Pradesh
Chambal	1960	Chambal	Rajasthan, Madhya Pradesh
Mayurakshi	1956	Mayurakshi	West Bengal
Kangsabati	1956	Kangsabati and Kumari	West Bengal
Hirakund	1957	Mahanandi	Orissa
Damodar valley	1948	Damodar	Jharkhand, West Bengal
Kakrapar	1954	Tapti	Gujarat
Koyna	1964	Koyna-Krishna	Maharashtra
Malprabha	1972	Malprabha	Karnataka
Nagarjuna Sagar	1960	Krishna	Andhra Pradesh
Tungabhadra	1953	Tungabhadra - Krishna	Andhra Pradesh, Karnataka

1.6.1 Local Traditional Irrigation water management Systems (TIS)

Despite unpredicted rainfall patterns and uneven land topography, Indian farmers developed several traditional irrigation systems for irrigation water management (Debnath et al 2020) (Figure 1.3).

Diversion channels

In rural India, with the help of boulders and tree branches, farmers divert water from rivers to agricultural grounds for irrigation. In arid and semi-arid regions, seasonal water is stored in tanks through this system but in the floodplain region, the farmers used the local bamboo pipelines to carry water from the nearby natural springs (Debnath et al., 2020).

Tanks or rainwater harvesting structures

The tank-based irrigation system is very popular in southern portions of India such as Andhra Pradesh, Telangana, Karnataka and Tamilnadu. This kind of system is essential in locations, where the number of rivers is very few with uneven rainfall patterns, undulating topography and low water-holding capacity soils (Debnath et al., 2020).

Wells

In Rajasthan, people have constructed obstructions across the river to capture the surface runoff. They stored this captured water in the stepwell. Kundis and kunds are made where the land resource is abundant. These kundis are covered underground tanks to store runoff. The traditional irrigation systems are discussed region-wise here:

Northern region

In the northern part of India, terrace cultivation is the most popular agricultural method. In mountainous regions, Zings (small tanks) are made to collect glacier-melted water for irrigational purposes. In the hill region of Uttarakhand, stone-like structures are used for drinking water which is collected from streams and springs known as Nauls. Kuhls, an irrigation system that carries glacial water from the streams into the agricultural lands. It has a headwall for storage and moghas for diversion of the flow into the nearby fields. Local engineers are made kuhl with the help of public donations. During the monsoon season, kuhls are made, the length of the kuhls varies from 1 to 15m, kuhls and can irrigate ~20 ha area. Guhls are natural contour water channels mainly located in Dehradun and Nainital regions. This type of construction helps to channelize water along the hill slopes. To perform this process locally available trees and branches are used to make barriers. Small water tanks are known as Bauli, used for water storage, whereas, Nawn is a large tank irrigation system that provides water for domestic purposes. Khatris are pits that are made of rocks to store rainwater. These are made for personal and community usage. In Khatris, rainwater is directly collected from the roof through pipes that are used for domestic purposes. Dighi is a square-shaped reservoir with a sluice gate, mostly constructed in Delhi and surrounding regions. The steep wells of Delhi are known as Baoli which are mainly used for domestic purposes. Some examples of Bauli are Gandak Bauli, Rajon Bauli, Dayah Bauli, Kaki Sahab Bauli and Muradabad Bauli etc. Ahar-Pyne is a catchment channel, found in low-rainfall areas of South Bihar. It is a floodwater harvesting system (Debnath et al., 2020) (Figure 1.3).

Eastern Region

The eastern part of India is dominated by rice fields. This region has plenty amount of surface and groundwater resources. In Arunachal Pradesh, farmers used a scientific irrigation method named Apatani. In this system, fields look like contour bunds and both the surface and groundwater are utilized for irrigation. Aji is another form of irrigation system where finger millet is cultivated. Zabos or Ruzas are water storage structures used for agriculture, forestry, fishery, and domestic purposes, mainly found in Nagaland. Cheo-o-zithi is a bamboo channel to transfer water to agricultural fields. The length of the channel is about 8 to 10 km. Tuikhar or Jhoras are the traditional irrigation systems mainly found in Manipur and Mizoram, used to store spring waters for jhum cultivation. The bamboo-based drip irrigation system is known as Bamboo irrigation. The tribal farmers of Revoi and Jowai districts in Meghalaya and Khasi, Jayantia hills of Cherrapunji mainly used Bamboo irrigation to cultivate betel leaf and black pepper. In this system, different types of bamboo are used to divert the direction of water to the lowland fields. Dongs are pond-like structures made to harvest water for irrigation. Dungs or Jampois are small irrigation channels that cut the mainstreams to get irrigational water. The broad and shallow channels are used to transport overflowed monsoon water in southern West Bengal is known as Inundation Canals or Overflow Irrigation system. The farmers of West Bengal also used Pukur to store rainwater for irrigational usage (Figure 1.3) (Debnath et al., 2020).

Central Highlands

In this portion of India, wells and tanks are considered as main irrigation systems. The popular irrigation practices of this region are Haveli, Bandhas and Pat. Havelis are closed by embankments on four sides until the sowing time, after sowing these open. In Pat systems, different embankments are made to divert water from streams to irrigation channels. Kata and Munda are old types of water diversion systems that are constructed along the drainage line (Figure 1.3) (Debnath et al., 2020).

Western Region

The western portion of India resides in the water scarcity region citation. Different types of water-conserving structures are found here for example dug well, step well, tanks, and pits. Embankment, reservoir etc. Kuis or Beris are smallmouths and broad base pits of 10 to 12m depth are built near the water bodies to collect seepage water. Step wells are known as Baoris or Bers, mainly discovered in Rajasthan. These structures are very deep; steps are created near the water bodies. It gets narrower from the top to reduce the amount of evaporation. It helps to recharge groundwater. Paar is a rainwater harvesting structure with a 5-12 m depth. Kunds are also the rainwater harvesting structure made to store rainwater. Local ponds are known as Talabs and Nadis used to store monsoonal rainfall. Tanka is an underground pit used to store rainwater for drinking purposes. A natural embankment made across the river to accumulate surface runoff for agricultural practice is recognized as Khadin. Square-shaped step-wells of Rajasthan are distinguished as Jhalaras, used for bathing, and drinking purposes. At present eight Jhalaras are observed in Jodhpur city among them Mahamandir Jhalara is the oldest. Virdas is a dry well constructed in the beds of a temporary stream. In Virdas, saline water flows beneath the sweet freshwater because of its high density. Naturally constructed reservoirs with valleys and depressions are called Bandhis or Talabs. It is utilized for domestic purposes. Beris, where wells are situated on the beds of Talab. Circular-shaped open pits are identified as Saza or Kuva. Johads are made across the contour to stop surface runoff and to store rainwater. Stone-made check weirs across the gully to stop runoff are known as Naada or Bandha. Vav or Vavdi are the traditional stepwells used to irrigate fields. A percolation tank named Rapat is used to irrigate. It can irrigate about 5 km of land. Chandela and Bundela are the earthen embankments and tanks used to block the water flow in small rivers.

Bandharas are found in Western Deccan. It is a permanent or temporary check-dams which is built across the rivers. Bandhini is practised in Konkan Maharashtra where fields are flooded during the monsoon season. Narrow water-courses are made to divert the flow direction of the streams known as Shilohris. Ramtek is found in Maharashtra that is composed of ground and surface water bodies (Figure 1.3) (Debnath et al., 2020).

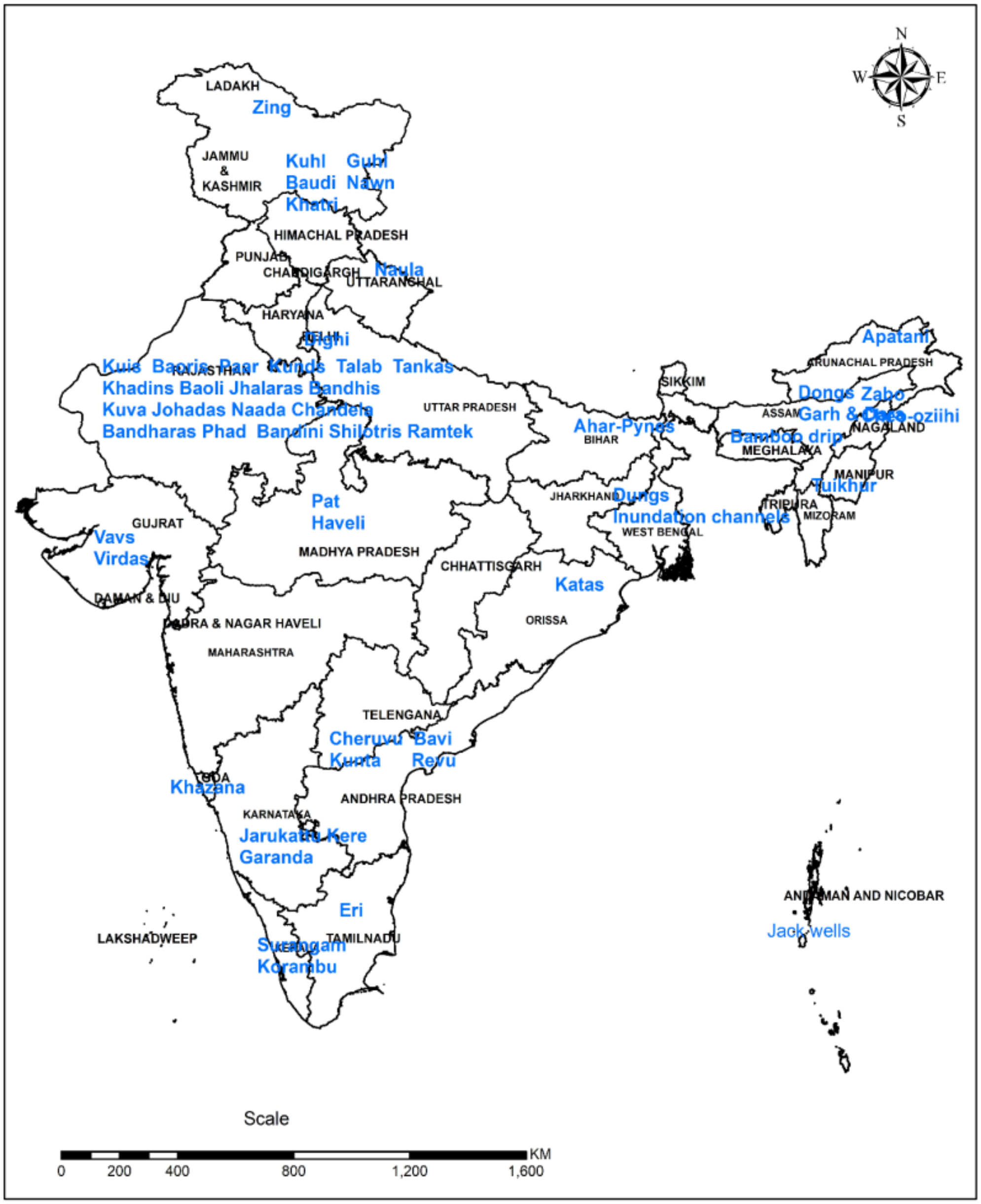

Figure 1.3 Traditional irrigation management systems in India

Southern region

In southern India, Bavi (well), Kunta (tank) and Revu (diversion channel) are found in Andhra Pradesh and Telangana. Cheruvu is used to store runoff. These are the type of reservoirs made with embankments, sluices, weirs and canals. Jarukattu resembles like check dam. The local springs of Karnataka are named Talpariges. A series of tanks constructed in Karnataka are known as Kere. Garanda is a small-diameter well that is built within a large well to capture percolation water. The cascading irrigation tanks are known as Eris. In this system, one tank is built-in a higher elevation and the other one at a low elevation. It helps in runoff storage, soil loss, and flood prevention. Surangam is a tunnel-shaped irrigation structure that extended from high elevation to low elevation. Korambu or Chira helps to increase water levels in the canal and diverts water into the channel. Oranis are found in south Travancore. These are the mini-irrigation tanks that help to cultivate small agricultural patches. Panamkenis are found in Wayanad, Kerala. These are the special type of wells to store rainwater. Khazana is a rainwater harvesting structure mostly concentrated in Goa (Figure 1.3) (Debnath et al., 2020).

Islands

Shompen and the Jarwa tribes of Andaman and Nicobar Islands make shallow pits, known as Jackwells, for irrigation purposes. These are pond-like structures used for rainwater harvesting (Figure 1.3) (Debnath et al., 2020).

1.6.2 Present modern water management systems in India

Mission Kakatiya-Telangana

It is an irrigation water management program in Telangana. The main objective of this program is to restore minor irrigation sources (ponds, lakes etc.) and enhance the minor irrigation infrastructure. In this program, farmers are motivated to tank de-siltation, renovation of feeder canals, repair of the weir and sluice etc. that increased tanks and water-bodies storage capacity. Both small and medium farmers are benefitted from this program. It also increases the nutritive value of soil. High-value crop cultivation also increased (Mission Kakatiya, 2022).

Narmada canal project, Rajasthan

In this program sprinkler and drip irrigation were made compulsory. A tree plantation program was taken up along the 1570 km length canal and salinity-resistant crops were planted also. Further steps for canal construction, and surface and groundwater management were also taken. This program increased the culturable command area. the crop production also increased in the kharif season (CWC, 2022).

Chittoor, Andhra Pradesh- Har Khet ko Paani

In this program repair, renovation and restoration initiatives were taken up to restore the tanks. By using geospatial techniques bore well mapping was done and farmers were encouraged to construct rainwater harvesting structures. Farmers were encouraged to incorporate solar pumping, sprinkler, and, drip irrigation methods. The impact of this program was outstanding. Irrigation potential was increased to 5023 ha. Around 45000 water harvesting structures have been constructed around the district (NITI Aayog, 2017).

Participatory Irrigation Management (PIM) - Waghad, Maharashtra

In this program, awareness was created among the farmers about the usage of surface and groundwater. Special emphasis was given to achieving equitable distribution of water resources. The total irrigation area amplified from 7884 to 9354 ha from 2004- 2015. Around 25% of drip irrigation coverage was increased (NITI Aayog, 2017).

Micro-irrigation in Gujarat

In this initiative, farmers were educated to adopt scientific water management techniques. Farmers were encouraged in micro irrigation systems. In 2014, around 6 lakh farmers adopted micro-irrigation systems. The total irrigated area also increased to around 10 lakh ha (GGRC, 2022).

Root zone watering by water system for agriculture rejuvenation (SWAR): Andhra Pradesh

SWAR launched an exclusive irrigation method that measures moisture content at the plant root zone. The SWAR system requires an overhead tank and a clay pot. Water transfers through a small diameter pipe from the overhead tank to the clay pot. The clay pots are buried in the root area. Clay pots have micro pipes which convey water to the roots. This slow discharging method provides moisture to the roots for a long period. SWAR system requires very little quantity of water, so here wastage of water is less. SWAR system is appropriate for the tree plantation program. In 2015, the SWAR technique is also applied to cultivate flowers and vegetables (NITI Aayog, 2017).

Bhungroo – Ground Water Injection Well – Gujarat

In this system excess rainwater injects and stores underground for irrigation usage during summer. Farmers are getting irrigation water throughout the year after launching the Bhungroo program. This method reduces the salinity of water and makes it for agricultural usage. Mainly, this is a concept of the underground reservoir that can hold up to 40 million litres of rainwater. It can produce water for around 10 days per year and delivers water for around eight months. These wells can store up to one crore litre of rainwater (Bhungroo, 2022).

Pani Panchayat: Orissa-Water Resource Consolidation Project

This project was initiated to improve the water resources of Orissa. Participatory Irrigation Management was launched to enhance agricultural productivity. This program increased the agricultural productivity in that region (NITI Aayog, 2017).

1.7 Irrigation development in West Bengal

In the pre-colonial period, the irrigation of West Bengal was mainly based on ponds and wells. In the colonial period, large-scale canal systems were introduced in West Bengal. After independence, tube wells were the significant development in the field of irrigation in India but in West Bengal, progress in tube-well irrigation was very low. In 1994 – 95, according to statistical abstracts of West Bengal, around 3,100,000 hectares of land (~ 35% of the total geographical area of WB) were irrigated and canal-irrigated land was ~35%, ~39% was by shallow tube wells, ~4% by deep tube wells, and ~10% by minor irrigation schemes. The maximum irrigation was done by tube wells. Around 54% was irrigated by tube wells, ~11% by canals, and 16% by other sources (Rawal, 2001).

According to the census 2011, the major sources of irrigation water in West Bengal were tanks, lift-irrigation systems, open wells, canals, bore wells, micro irrigation, and other sources (Table 1.3). The 2011 census data showed that a major portion of West Bengal was irrigated by canals.

Table 1.3 District-wise different sources-of-irrigation according to Census 2011

Districts	Canals (in ha)	Tanks (in ha)	Open-wells (in ha)	Bore-wells (in ha)	Lift irrigation schemes (in ha)	Micro irrigation (in ha)	Other-sources (in ha)
Bankura	65.1	12.1	0.9	0	19.6	0	2.3
Bardhaman	89.2	0	0	0	10.7	0	0
Birbhum	89.99	0	0	0	0	0	0
Cooch Behar	2.5	9	0	0	51.5	0	31.5
Dakshin Dinajpur	0	11.2	0.004	57.8	24.34	0	5.9
Darjeeling	0	0	1.9	24.9	46.5	46.4	8
Purba Medinipur	37.56	17.5	0	0	41.01	0	56.8
Howrah	66.63	19.05	0	0	14.3	0	0
Hooghly	23.43	9.39	0	47.75	8.49	0	3.63
Jalpaiguri	62.4	2.2	3.6	0.6	9.5	0.2	15.1
Malda	0	61.5	15	0.7	21.3	0	0
Murshidabad	16.5	3.8	0	0	10.9	0	69.2
North 24 Parganas	3.7	7.53	0	0	86.94	0	1.84
Nadia	0	0	0	11.1	5	78.6	0
Purulia	6.56	6.57	0	0	0.93	0	2.05
South 24 Parganas	38.8	13	0	29.92	18.3	0	0
Uttar Dinajpur	0	1.53	0	5.36	3.1	0	80
Paschim Medinipur	26.9	4.24	1.66	0	31.76	0	6.98

In Birbhum district around 89% area was irrigated by canals. Except for Birbhum, canal irrigation was very much popular in Bardhaman, Howrah and Bankura districts, where more than 50% of lands were irrigated by canals. In using tank irrigation, Malda, Howrah, Purba Medinipur, and South Twenty-Four Parganas were popular. Whereas, Jalpaiguri, Darjeeling, Paschim Medinipore, Bankura, Dakshin Dinajpur, and Malda were popular in open wells irrigation. In using bore wells irrigation, Dakshin Dinajpur, Hooghly, South Twenty Parganas, Darjeeling and Nadia districts were popular and major portions of North Twenty-Four Parganas, Cooch Behar, Darjeeling, Purba Medinipur, Paschim Medinipur, Nadia, Uttar Dinajpur, Purulia and Birbhum were irrigated by lift irrigation schemes (Figure 1.4).

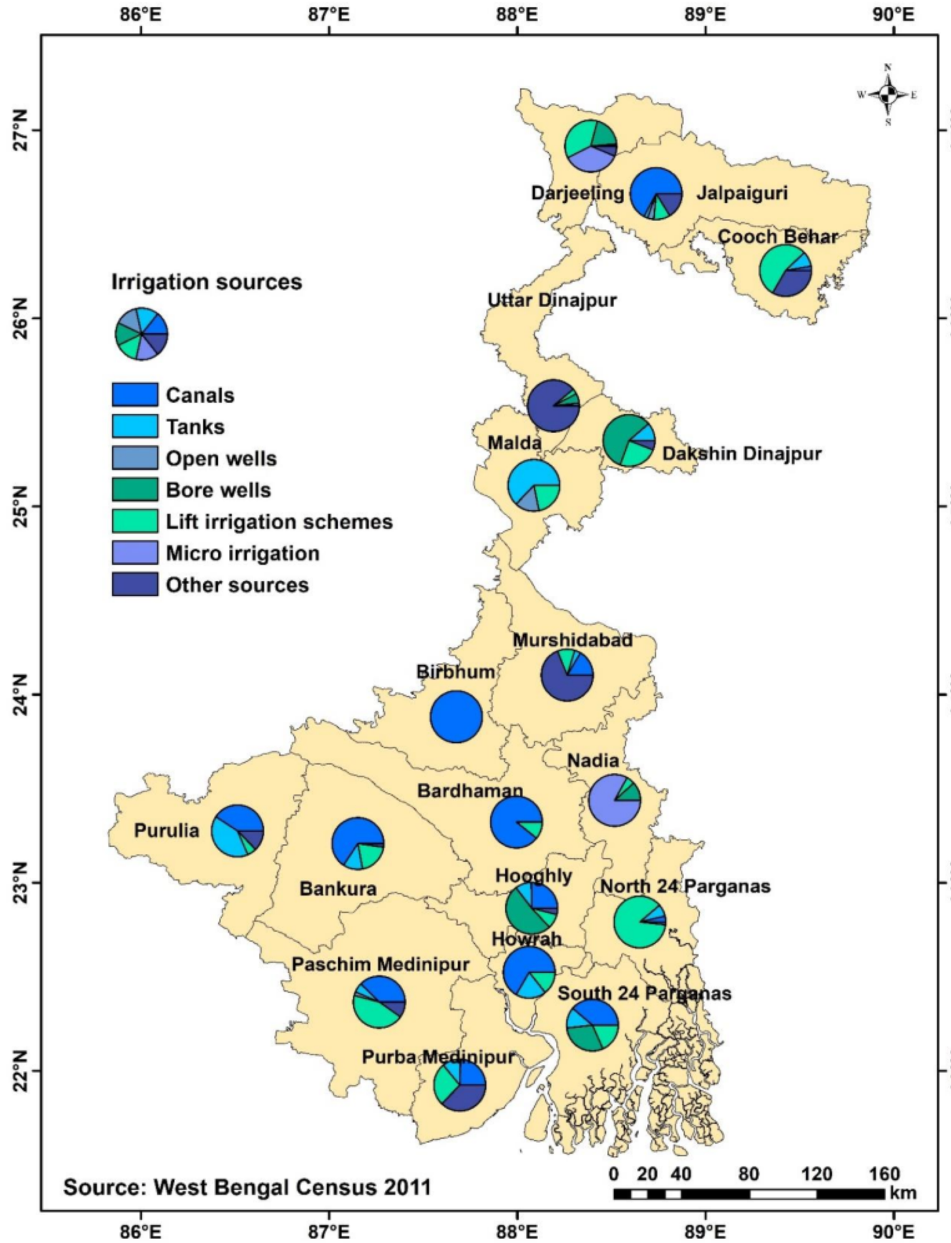

Figure 1.4 District-wise different sources of irrigation in West Bengal

According to irrigation intensity, West Bengal has been classified into five categories, very-high (81-1000 %), high (61-80%), moderate (41-60%), low (21-40%), and very-low (0-20%). In the very high category, Bankura and Birbhum districts were observed. Whereas, Uttar Dinajpur, Bardhhaman, Nadia, Hooghly and North 24-Parganas were in the high category. In the moderate category, Dakshin Dinajpur, Malda, Murshidabad, Howrah and Purba Medinipur districts were found. While, Jalpaiguri, Cooch Behar, Purulia and South 24-Parganas were in a low category and Darjeeling, and Paschim Medinipur were in the very-low category (Table 1.4 and Figure 1.5).

Table 1.4 District-wise irrigation intensity

Districts	Net sown area (ha)	Irrigated area (ha)	Irrigation intensity (%)
Birbhum	318.5	315.95	99.19
Bankura	345.4	276.9	80.16
North 24 Parganas	259.22	200.56	77.37
Nadia	280.2	209.6	74.80
Bardhaman	452	331.6	73.36
Uttar Dinajpur	241.3	173.58	71.93
Hooghly	219.91	157.52	71.62
Purba Medinipur	292.73	169.26	57.82
Howrah	80.73	44.03	54.53
Murshidabad	398.7	204.3	51.24
Malda	260	125.13	48.12
Dakshin Dinajpur	188.6	82.54	43.76
Cooch Behar	248.1	79.4	32
South 24 Parganas	372.29	115.73	31.08
Jalpaiguri	335.7	87.7	26.12
Purulia	317	71.13	22.43
Paschim Medinipur	558.7	82.4	14.74
Darjeeling	143.86	8.94	6.21

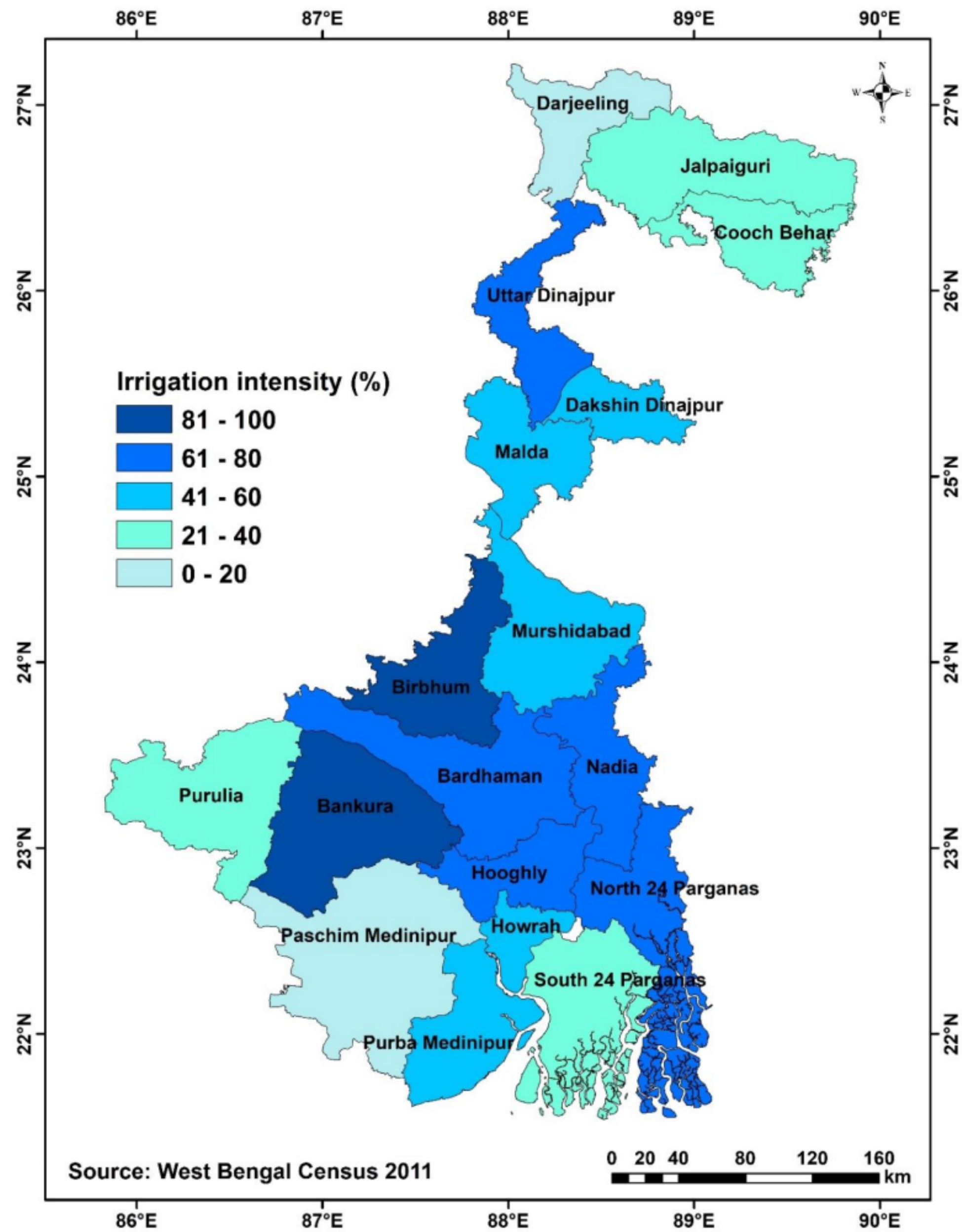

Figure 1.5 District-wise irrigation intensity in West Bengal

1.8 Literature reviews

A brief literature review has been conducted on the impact of the reservoir on land-use and land-cover (LULC) changes, irrigation and agricultural development. Dams and reservoirs play an imperative role in agricultural development. According to the World Commission on

Dams report (2000), around 50% of the world's large dams were only constructed for irrigation. About 31-39% of the 273,000,000 ha of irrigated lands depend on dams globally.

Dams are approximated to supply around 12-17% of world food production (Altinbilek, 2002). Globally, around ten-thousands lakh people rely on reservoir-produced crops associated with irrigation. Maximum dam ventures not just take place for economic advances, but also deal with the entire socio-economic growth of individuals in that region. The prime irrigation projects, that rely on dam creation, also check the relocation of people to the cities from villages, also provide quality of life to the rural peoples in their indigenous areas. It is challenging to cultivate any type of crop in a major portion of the world without irrigation (Altinbilek, 2002).

Zhang et al. (2009) used multi-temporal datasets in the tree George reservoir area of China to understand the LULC change from 1977 to 2005. The study identified the occurrence of huge vegetation loss during the study period as the vegetation covers were replaced with the built-up areas.

Naik et al. (2011) evaluated the loss of LULC due to reservoir construction on the Godavari River at Polavaram Village. It supplies irrigation water in deltaic and upland areas of the Krishna, east Godavari, and west Godavari districts. The reservoir also conveys water for domestic and industrial usage in Visakhapatnam city. The region faced a lot of environmental issues after the construction of the Polavaram multipurpose plan. The study revealed that around 58 thousand ha area was submerged after the construction of the reservoir and around one lakh people were rehabilitated. Also, around 300 schools and colleges were submerged. Further, around 24 tourist places and roads were submerged. Ernest et al. (2014) analysed the impact of small dams on the socio-economic expansion of Ghana, and examined social, physical, and economic indicators to analyse the performance of the dam. The study resulted that the small dams improved the livelihood of the people of Ghana. Antwi Agyei et al. (2019) assessed the influence of LULC on the Owabi reservoir of Ghana from 1970 to 2014. The study showed that high-density and sparse vegetation covers disappeared while bare lands and built-up areas increased significantly.

Wang et al. (2020) assessed LULC transformation from 2000 to 2015 in Danjiangkou Reservoir, which is one of the significant water sources in China. Other objectives were to identify landscape patterns and associations among the LULC categories and the topographic pattern. The study resulted that water bodies and cultivated lands decreased by around 10% and 23%, respectively. While built-up zones increased to around 113%. Bonansea et al. (2021) studied the impact of the Los Molinos reservoir on LULC from 1990 to 2021. The reservoir is situated in Calamochita Valley, in the central province of Argentina. They applied a support-vector-machine (SVM) algorithm to evaluate classification. wetland, timer plantation, natural forest, and bare land, natural forest, were considered as LULC categories. The study resulted that after the creation of the Los Molinos reservoir both urban and agricultural areas were intensified which improved the economy of Los Molinos.

Nandi and Sarkar (2021) assessed the impact of the Kangsabati dam on the people, especially those living in the upstream zone. The study observed about 35.99 ha of land was submerged under the dam. Therefore, about 84.44% multiple cropping area of Itaamara village under the command area of Kangsabati dam descends below Kangsabati dam water. Ultimately, only one-crop land stayed for agricultural usage. Thus, agricultural yield decreased and proportionately agricultural labourers decreased by around 79% annually. Therefore, the people of Itaamara village lost their economic growth and natural capital which affected severely the living of villagers. Loss of living resources caused unemployment, changes in occupation, inadequate production, migration, poverty, and deteriorating health situation.

Owusu et al. (2022) reviewed the implication of minor reservoirs in supporting the agricultural environment in West Africa. The arid zones of west Africa have around 2000 small reservoirs. The study revealed that the small reservoirs have minimal impact on water management. Due to poor management productivity has been reduced. Reservoir sedimentation is the main issue and the water quality is not monitored so waterborne diseases increased. They concluded that small reservoirs can improve agricultural production if the government develops long-term support programs for the reservoirs.

1.9 Research context and volition of study area

Previous studies related to the impact of reservoirs on LULC revealed that the maximum study on reservoirs focused on reservoir sedimentation, the impact of reservoirs on climate changes, soil erosion, ecosystem, and livelihood of the local people. Very few articles have been found on the impact of reservoirs on LULC change. Especially for West Bengal, very few articles were found on the impact of reservoirs on LULC change. Moreover, almost no research so far has been done about the seasonal variation of irrigation water of the Shali reservoir in Bankura, West Bengal and its impact on agricultural production. Therefore, in the present research, an attempt has been made to explore the seasonal variation of irrigation water of the Shali reservoir giving special emphasis on water management in the Rabi (winter) period.

Shali reservoir also known as Gangdua dam is a medium irrigation project run by the Irrigation & Waterways Department (I&WD) of the West Bengal Government (GoWB). The reservoir is situated at the origin of river Shali near Bhairabpur village of Gangajalghati block in the Bankura district. Shali reservoir stores the rainfall and coveys through the river Shali in the Shali River basin (SRB) area.

Three types of irrigation are provided by this reservoir: (a) irrigation through the Shali river system, (b) lift irrigation from the reservoir and (c) river lift scheme. The Shali River basin is situated in the north-eastern part of the Bankura district in West Bengal, India. Shali is a right-bank stream of the river Damadar which flows the northern portion of the Bankura district and it is positioned between 23°07′N to 23°26′N latitude and 87°3′E to 87°38′E longitude.

The entire area of Shali River basin is around 727.23 km^2. Shali River basin comprises the portion of Gangajalghati, Barjora, Sonamukhi and Patrasayer blocks and 339 villages. The major branches of the Shali river are the Subhankari Kanjar River (Nodi), Seengai Nodi, Jungne Nodi, Setaljar Nodi, and Badai Nodi (Figure 1.6).

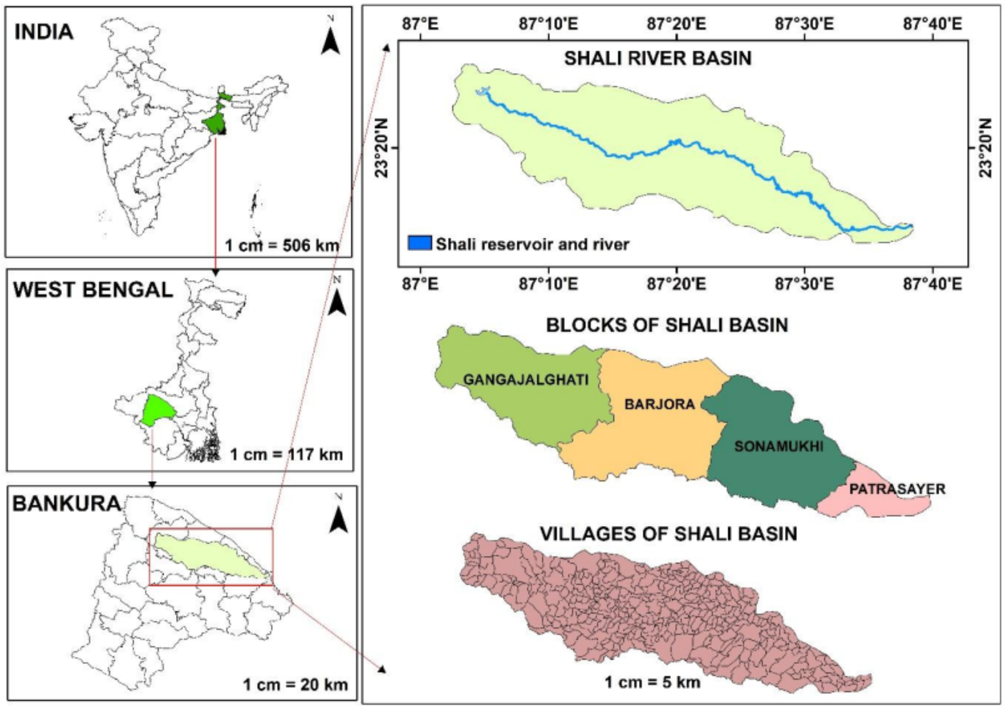

Figure 1.6 Location map of the study area

1.10 Objectives

The present study examines seasonal irrigation water management through the Shali reservoir irrigation project and its impact on agricultural development. Thus, the key objectives of the present study are as below.

- To study the geographical and socio-economical properties of the Shali River basin.
- To examine the seasonal water-level trend of the Shali reservoir.
- To identify suitable irrigation lands for the Shali River basin.
- To analyse the impact of the Shali reservoir scheme on LULC and predict future LULC maps.
- To assess the impact of irrigation through the Shali reservoir on seasonal crop production.
- To examine the impact of Shali reservoir irrigation on irrigation intensity, cropping intensity and agricultural labour intensity.
- To analyse the distribution of irrigated areas under the command area of the Shali river and reservoir
- To summarise the conclusions, recommendations and discussions about the future research scopes.

Table 1.5 Block-wise villages in the Shali River basin

Block name	Village name
Gangajalghati	Chhotalalpur, Kelai, Rajamala, Balikun, Sedara, Lachmanpur, Baradihi, Bararampur, Sagarye, Nutongram, Khajure, Jamsala, Chhotalacchipur, Nadehi, Bamundihi, Chholabaid, Hari Banga, Shuabasa, Keshiara, Ita Dangra, Mallikdihi, Garjuria , Ukhradihi, Jam Bedya, Shirsha , Taljhitka, Lakhyara, Ekchala , Ranganathpur, Amjor , Macha Parulia , Gobinda Dham, Mautara, Thumkonra, Ranbahal, Salera, Kanra, Bhairobpur, Mande, Chhotakumira, Kenduadihi, Nabagram, Kotmadanmohanpur, Kapishtha, Nischintapur, Saltora, Salbedya, Madhabpur, Kallapur, Ramnagar, Suara, Radhashyampur, Sankara, Brahmanara, Charadihi, Rampur, Khopaganj, Birra, Jemua, Balejora, Gopalpore, Jhamberiya, Bheringi, Malkanra, Borojuri Dandulia, Ramkonali, Kendubari, Arba, Ason Chuaa, Arjunpur, Bihar Juria, Hore Krishnopur, Gabordhonpur, Piraaboni, Dhoboni Gobindopore, Radha Krishnopore, Kantaboni, Gopinathpore, Maldaga, Tentuliya danga, Shimlagor, Batla para, Manjua, Avirampur, Sitarampur, Tilaasuli, Bhalukapahari, Bayermara, Raniara, Arbetal
Barjora	Sahorjora, Muktotar, Beleshala, Chok Keshia, Sitla, Koch Kundo, Manjmoora, Manahorbati, Kanchanpur, Pabayan, Dakaisini, Khanrari, Uara, Deucha, Dejuri, Hathasuria, Mandarboni, Dewangarya, Saralee, Madanhaati, Numuigariya, Gururband, Kotolpukur, Radhaballabhpur, Arjuni, Metiya, Narayaanpur, Mahidara, Krishnaboti, Naykana, Paermohan, Radhanagar, Shushunia, Sahabdihi, Bisanpur, Ashuriya Madhobpur, Talanjuri, Kantabad, Harirampur, Beliyanarayanpur, Horekrishnopur, Dodhimukha, Gapkande, Puruniya, Shangrampur, Lakshminarayanpur, Bahora Khulia, Gangadhorpur, Kalpaine, Banshal, Dharampur, Dhwajamonipur, Phulberrya, Damodarpur, Dangapara, Notungram, Bahadurpur, Madhobpur, Oltara, Kanchchala, Samontomara, Dhoboni, Ramchandropur, Chala, Kalberiya, Namaghansara, Kururia, Bolorampur, Malkuria, Ekaria, Majuddagara, Saragora, Gadardi, Gadordihi, Radharamanpur, Birsingapur, Gobindopur, Jhariya, Lalbajar, Kala, Sanagara, Talaanda, Nabosan, Chandar, Gobindopur, Murokata, Patashpur, Bhabarkhola, Chandoibat, Pashchim Brindabanpur, Sirsha, Palsana, Saaluka, Jaykrishnapur, Kushma, Swargyabati, Haarishpur, Gupinathpur, Birndabanpur, Shyamdashpur, Amthiya, Gosaipur, Bankuradanga, Belut, Shaldanga, Jaganathpur, Purushattampur, Asansala, Muktopur, Kadma, Bandorkada, Krishnapur, Benachapara, Mathuaberia, Bhairobdanga, Bhairobpur, Raautara, Barkura, Mathuradaga, Rajamadhabpur, Radhakantopur, Sri krishnapur, Kantabese, Nityanandopur, Gangabondh, Sauliya,

Sonamukhi	Khidirpur, Radhakrishnapur, Basu Chandanpur, Belut, Dhulae, Pathan Polashi, Manush Maari, Bank Shimla, Belgariya, Pashchim Dubrajpur, Krishnanagar, Belut, Horishchandrapur, Radharamonpur, Ulaai, Piar Bera, Proyagpur, Paschim Nandapur, Bashunandanpur, Sitaljor, Kuber Bandh, Dubraajhati, Shibdaga, , Jaypur, Kamardanga Katniya, Birsinghapur, Paschim Potrahati, Rupal, Karajbani, Palsahare, Aliganj, Boikunthopur, Rupat Ganj, Jamboni, Patjor, Parbatia, Bahuliya, Salchaturia, Shyamsundarpur, Hamirhathi, Bashumara, Rampore, Khausha, Jasra, Patshol, Ratnapore, Mathuraboti, Bara Narayanpur, Bhola, Keshesol, Khayrakura, Churamonipur, Tieura, Kalyanpore, Bedomushol,Dakshinsal, Idkata, Aamghata, Sopuradihi, Sonamukhi, Kshertamohanpur, Shalda, Siltia, Rau tara, Sahebganj, Maheshpur, Madanmahanpur, Galtor, Chaityanpur, Khuldanga, Aamshol, Nanchanhati, Purbo Patrohati, Bhalook Khan, Jaga Mohanpur, ShonaDwip, Ban Paruliya, Beeshe, Raajda, Junsara, Narula, Nischinapur, Ramchandrapur, Kundo Pushkorini, Kasipur, Kuchi gopalpur, Bahaarpur. Dhan Shimla, Kenduya, Rampur, Machdoba, Karachmani, Ranibandh, Chakdhoyakure, Bishnubati
Patrasayer	Rampur, Jaaljala, Ashanboni, Nehala, Parasia, Chapabani, Dhagariya, Hamerpur, Anandapur, Kendagare, Laalpur, Muktopur, Khoshalpur, Khamardihi, Hadal, Ram Nagar, Dhamsha, Sonatikiri, Balarampore, Telesanra, Paruliya, Keshabpore, Brindabonpore, Bendha, Dayalpore, Chak Patrasayer, Panch Para, Mamudpur

1.11 Methods

Several geospatial and statistical methods are incorporated to justify the objectives of the study as discussed below.

- Mann Kendall trend analysis has been applied to identify the seasonal water level trend of the Shali reservoir and seasonal crop production.
- Linear regression (LR) method has been used to determine the correlation between the Shali reservoir and the river water level. Besides, the correlation between irrigation and cropping intensity.
- Revised universal soil loss equation (RUSLE) and Satellite remote sensing (SRS) to estimate the sedimentation level of the Shali reservoir.
- SWOT (strength, weakness, opportunities, and threat) analysis has been applied to identify strengths, opportunities, weaknesses and threats of the Shali reservoir.
- Analytical Hierarchy Process (AHP) and weighted overlay analysis have been applied to identify suitable irrigation lands in the Shali River basin area.
- Random Forest (RF) classifier has been applied in LULC classification to identify the LULC classes precisely.

- The Cellular Automata method has been applied to predict future LULC pattern.
- A confusion matrix has been generated to justify the LULC classification results.
- The Z-Score method has been implemented to identify the village-wise distribution of irrigated areas.
- ARIMA (Autoregressive Integrated Moving Average) method has been adopted to identify future trends in the crop production area.
- Rice mapping has been done using Sentinel 1 SAR datasets.
- Irrigation, cropping and agricultural labour intensity analysis has been performed to recognise the influence of the Shali reservoir irrigation project on agricultural advancement.
- Multiple Linear Regression (MLR) has been applied to identify the correlation between Irrigation, cropping and agricultural labour intensity.

1.12 Data Sources

Data	Sources
Irrigation and Waterways Department of West Bengal	Shali Reservoir Water level data from 1990 to 2021
USGS Earth Explorer	Landsat 4 and 5 TM and 8 OLI datasets for LULC classifications, Shali reservoir surface area detection etc. Digital Elevation Model (DEM) for relative relief, basin demarcation and stream order.
Directorate of Economics and Statistics	Crop production area data of the Shali River basin from 1995 to 2020
Soil Grids	Soil physical and chemical properties data of the Shali River basin
Bhuvan	Soil texture data of the Shali River basin
India Meteorological Department	Rainfall and temperature datasets of the Shali River basin
Geological Survey of India	Geology and geomorphology datasets of the Shali River basin
Census of India	Population, agricultural labour, and irrigation datasets of the Shali River basin from 1991 to 2011

1.13 Softwares used in the study

Application	Software's name
GIS and Remote Sensing Softwares	1. ArcMap version 10.8 2. QGIS version 3.16 3. Erdas Imagine 2014 4. Google Earth Engine 5. Google Earth Pro
Statistical Softwares	1. R Studio 2. GraphPad Prism
Data Visualizing Softwares	1. Microsoft Power BI 2. Microsoft Excel 3. Grapher

1.14 Organisation of the thesis

Chapter 1

This chapter comprises the development of irrigation in India with special emphasis giving on West Bengal. It also discusses traditional and modern irrigation water management processes. Several irrigation sources and irrigation methods have been discussed. Besides, major irrigation projects in India have been discussed. A comparative analysis between different types of irrigation water sources and irrigation intensity of districts of West Bengal was also performed. Brief literature reviews have been done on the reservoir and its impact on agricultural development. Lastly, the research gap has been identified, discussed the choice of the study area, methods, and objectives.

Chapter 2

In this chapter, the geographical and socio economical properties of the Shali River basin have been examined. In the geographical category, geology, geomorphology, relative relief, river network, forest cover, soil, rainfall and temperature have been considered. Whereas, the socio economical category is comprised of population density, literacy rate, industry, agriculture, road network and amenities, etc.

Chapter 3

This chapter comprises three segments. In the first segment, the main reasons behind the erection of the Shali reservoir have been discussed. In the second segment, the Shali reservoir's annual and seasonal water level fluctuations have been analysed. Prior to water level fluctuation analysis, sediment level estimation of the Shali reservoir has been performed. In the third segment, a SWOT analysis of the Shali reservoir has been done.

Chapter 4

The entire study has been divided into five segments. In the first segment, LULC classifications are performed using supervised classification with Random Forest (RF) method for the period from 1986 to 2021. In the second segment, change detection has been performed for the periods from 1986 to 2006 and from 2006 to 2021. LULC change matrices are also developed. In the third segment, block-wise temporal LULC change and block-wise comparison of agricultural lands have been analysed. In the fourth segment, village-wise temporal changes in agricultural lands are illustrated. Lastly, in the fifth segment, the future land use pattern is projected by applying the cellular automata (CA) approach. Here, MOLUSCE (Modules for Land Use Change Evaluation a QGIS plugin, has been applied to simulate the future LULC scenario of 2031. This plugin requires some specific input data sets such as LULC classified maps of 2006 and 2021, DEM and transportation networks of the study area.

Chapter 5

This chapter has two segments. In the first segment, weightages of 12 parameters such as elevation, slope, rainfall, LULC, soil group, distance to the river, clay, sandy, silt, nitrogen, pH and organic carbon have been generated through the AHP and weighted overlay analysis has been applied to generate irrigation suitability map. Block-wise and village-wise suitability comparisons are also performed.

Chapter 6

This chapter comprises two segments. In the first segment, block-wise irrigated mean and standard deviations (SDs) have been analysed for 1991, 2001, and 2011. While in the second segment, the village-wise distribution of irrigated areas was analysed using the Z-score method for 1991, 2001, and 2011.

Chapter 7

This chapter is also categorised into two segments. In the first segment, the major produced crops: rice/ paddy, potato, wheat, and mustard of the Shali River basin have been discussed. Meanwhile, in the second segment seasonal crop mapping has been done by applying remote sensing techniques. Rice is the main crop of this region, therefore rice mapping has been done to produce a clear view of the rice production area.

Chapter 8

This chapter has been classified into three segments. In the first segment, a block-wise comparison of irrigation, cropping and agricultural labour intensity has been done. In the second segment, village-wise comparisons of irrigation, cropping and agricultural labour intensity have been discovered. In the third segment correlation analysis has been performed. The linear regression analysis has been done between irrigation and cropping intensities.

Multiple linear regression has been performed between irrigation, cropping and agricultural labour intensities.

Chapter 9

This chapter delineates the conclusion, limitations, and future research scopes.

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Profile of the study area

2.1 Introduction

In this chapter, the geographical and socio economical properties of the Shali River basin have been discussed to know the study area in a better way. In the geographical category, geology, geomorphology, relative relief, river network, forest cover, soil, rainfall, and temperature have been considered. Whereas, the socio economical category comprised with population density, literacy rate, industry, agriculture, road network and amenities, etc.

2.2 Geographical background

2.2.1 Geology

The Shali River basin comprises seven types of lithological units: pink granite or biotite granite gneiss, pyroxenite or pyroxene granulite rocks, phyllite and mica schist, laterite, ferruginous gritty sandstone and slate, rose-coloured soil with laterite and limonitic concretions, Sand silt and clay. Pinkish granite or biotite granite gneiss rocks are part of the Chotonagpur gneissic complex geological formation. The upper part of the Shali River basin is covered with these types of rocks. The south and south-western portions of Shali River basin are covered with such types of rocks. The largest portion of the Gangajalghati block is covered with pink granite or biotite granite gneiss rocks. Pyroxenite or pyroxene granulite rocks are formed in the anorthosite suite of the Bankura – Purulia formation. Pyroxenite or pyroxene granulite rocks are found in the western portion of the upper Shali River basin. These rocks are greenish in colour and very hard in nature. They form small hillocks which are present in the western part of the Shali River basin. These types of rocks are observed mostly in the Gangajalghati block. Phyllite and mica schist are from the pre-Cambrian period and are classified as unclassified metamorphic formations. A small patch of phyllite and mica schist has been observed in the upper portion of the Shali River basin (Gangajalghati block). Laterite, ferruginous gritty sandstone and shale, and reddish soil with laterite and limonitic concretions are part of the Lalgarh formation. The small patches of these rocks have been observed in the southern segment of the Shali River basin. Sand, silt and clay are part of the Sijua formation which is the oldest alluvium. The maximum portion of the Shali River basin is covered by these types of rocks (Figure 2.1) (Koley, 1993).

2.2.2 Geomorphology

The Shali River basin covers nine types of landforms: older alluvial plain, older flood plain, inselberg, pediment, pediplain, lateritic plain, residual hill, lateritic upland, and valley fill. The north-east part of Shali River basin covers by an older sedimentary plain. Mainly, Sonamukhi and Patrasayer blocks are comprised of older alluvial plains. The older flood plains are found along the Shali River and the lower segment of Shali River basin, whereas, the north-western segment of Shali River basin is comprised of inselbergs, pediments and pediplains. These are flat rock surfaces. It is formed by the joining of several pediments. Gangajalghati block is covered with these types of landforms. The Barjora and Sonamukhi blocks are enclosed with lateritic plains and uplands. The southern segment of Shali River basin is mostly confined to lateritic uplands. The basin terrain is composed of low hills, lateritic hummocks, valley fills, pediments, flood plains with terraces, etc. (Koley, 1993). Basin's upper part is covered with pre-Cambrian rocks, and the lower portion is covered with quaternary sediments. Lateritic uplands cover about 55% of the total basin, and about 14% of the area is covered by older alluvial plains. The western segment of Shali River basin is part of the Chotonagpur plateau so that portion is covered with residual hills (Figure 2.2) (Halder et al., 2022).

2.2.3 Relative relief

It means the variance between maximum and minimum height. In the Shali River basin, the highest and lowest relative reliefs are about 63 m and 3 m. The average relative relief is around 33 m. So, based on the highest and lowest relative relief, the Shali River basin has been categorised into four relative relief categories: very high (above 60 m), high (30-60 m), moderate (10-29 m) and low (below 10 m). The upper segment (north-west) of the Shali River basin is part of the Chotonagpur plateau so the relative relief is very high than other parts of Shali River basin. Whereas, the lower portion of Shali River basin is comprised of moderate to low relative relief regions. Around 21% area of the Shali River basin is covered by very high relative areas and about 39% is under high relative relief areas. Whereas, only 6% area of the Shali River basin comes under the low relative relief category. The Gangaljalghati block is covered with high/very-high relative relief areas. The maximum portion of the Barjora block is layered with high relative relief areas. Whereas, Sonamukhi and Patrasayer blocks are covered with low/moderate relative relief areas (Figure 2.3) (Bhukosh, 2022).

2.2.4 River network

Shali river originates from Kora hill and runs toward the east and joints Damodar river near Somsar village of Bankura district. It is a sub-basin of the lower Damodar region of the Ganga plain of West Bengal. It is a rainfed river that drains the district's northern portion. The prime branches of the Shali river are the Subhankari Kanjar River (Nodi), Seengai Nodi, Jungne Nodi, Setaljar Nodi, and Badai Nodi. According to Strahler stream order, the Shali River basin has 4th-order stream network (Strahler, 1952). All the streams depend on monsoonal rainfall (Figure 2.4) (Halder et al., 2022).

2.2.5 Soil

According to the U.S. Department of Agriculture (USDA) soil classification, the Shali River basin area comprises five soil groups such as ferralsols, gypsisols, fluvisols, luvisols and vertisols. Ferralsols covers around 40% area of the Shali River basin. Red and yellow tropical soils are known as ferralsols. It is formed with iron and aluminium. The ferralsols have good physical but bad chemical properties. It has a low water holding capacity. Thus, irrigation is required for areas covered with ferralsols (Jordanova, 2017). Gypsisols form with gypsum. It is mainly found in arid climatic zones. It has low water holding capacity but irrigated crops can be grown here. It covers around 5% land of the Shali River basin. Fulvisols, a dry land soil, covers only 4% area of Shali River basin with proper irrigation, rice cultivation can be done in this type of soil (Jordanova, 2017). Luvisols is a dark brown soil, mainly found in dry regions, which is superb for agriculture (Adams et al., 2019). Luvisols cover around 50% land of the Shali River basin. Vertisols types of soil are mainly found in arid or semi-arid regions. It can be used for crop production with proper irrigation. About 1% area of the Shali River basin is covered with vertisols (Figure 2.5).

2.2.6 Forest cover

The basin has numerous protected forests, for example, Beliatore, Sonamukhi, Pastol, Gangabandh, Gangajalghati, etc. The varieties of forest types are open mixed jungles, fairly mixed jungles, and dense mixed jungles (Malik et al., 2020). The northwestern and southern segments of the Shali River basin are covered with protected forest trees such as Sal (Shorea robusta), Eucalyptus (Eucalyptus globulus), Akashmoni (Acacia auriculiformis), Sonajhuri (Earleaf acacia), Mahuya (Madhucaa longifolia), Palas (Buteaa monosperma) and open shrubs, etc. The north-western and eastern parts are largely covered by productive farmlands (Figure 2.6) (Das and Gupta, 2014).

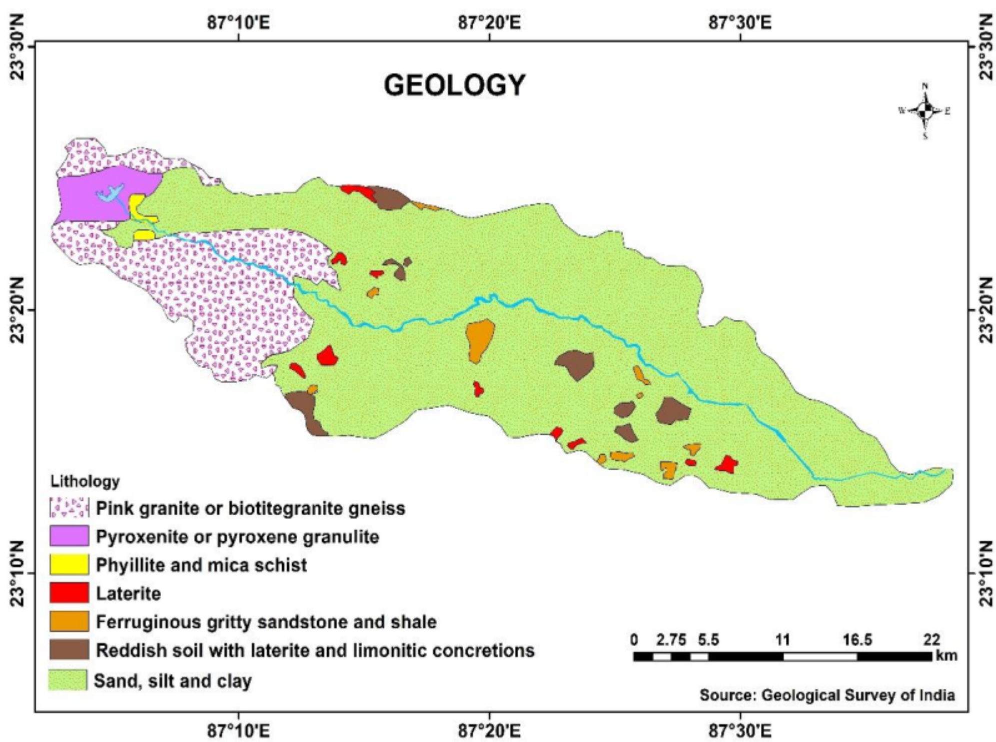

Figure 2.1 Geology of the Shali River basin

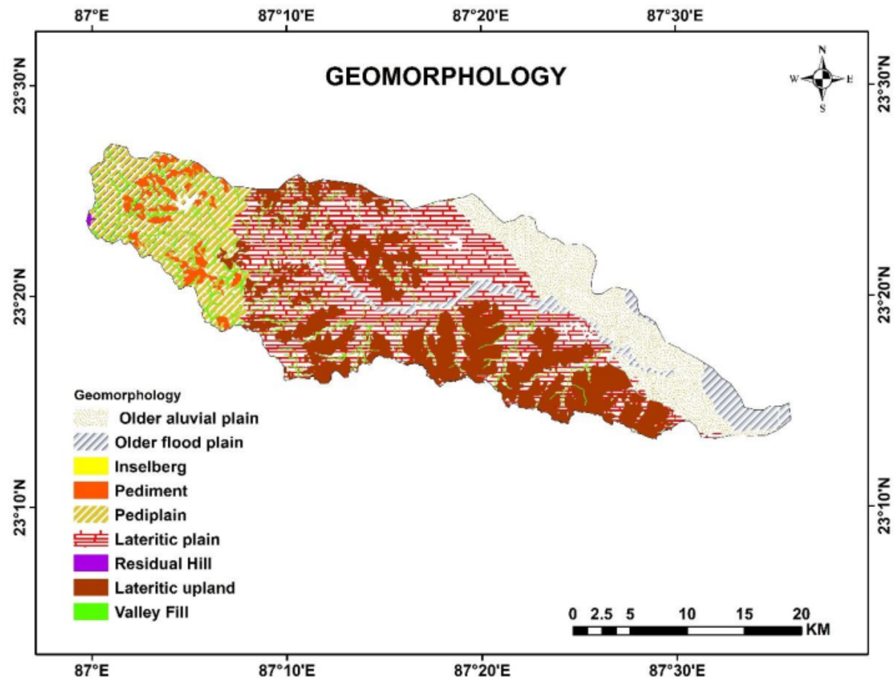

Figure 2.2 Geomorphology of the Shali River basin

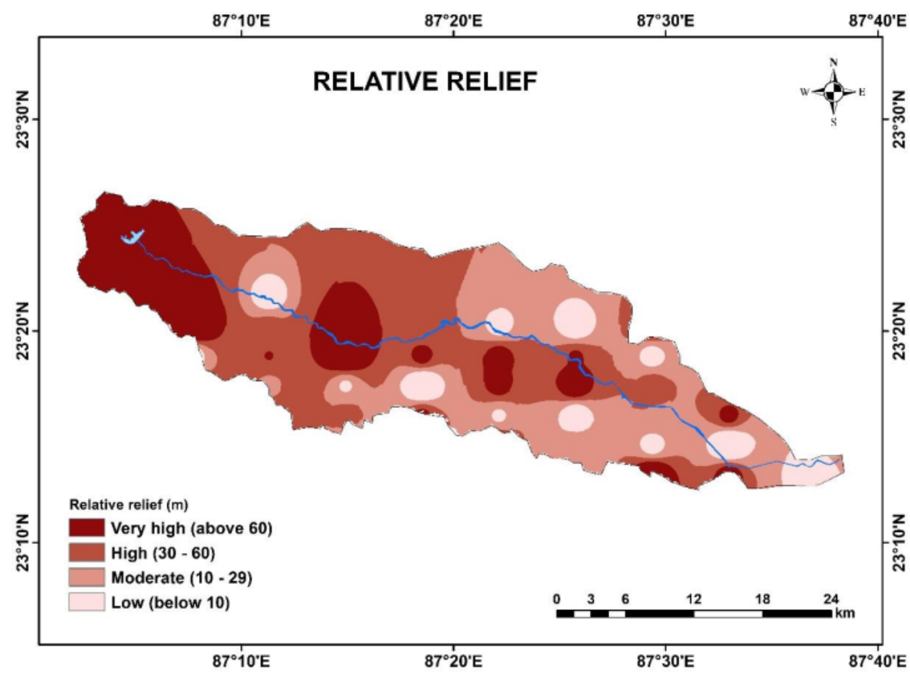

Figure 2.3 Relative relief of the Shali River basin

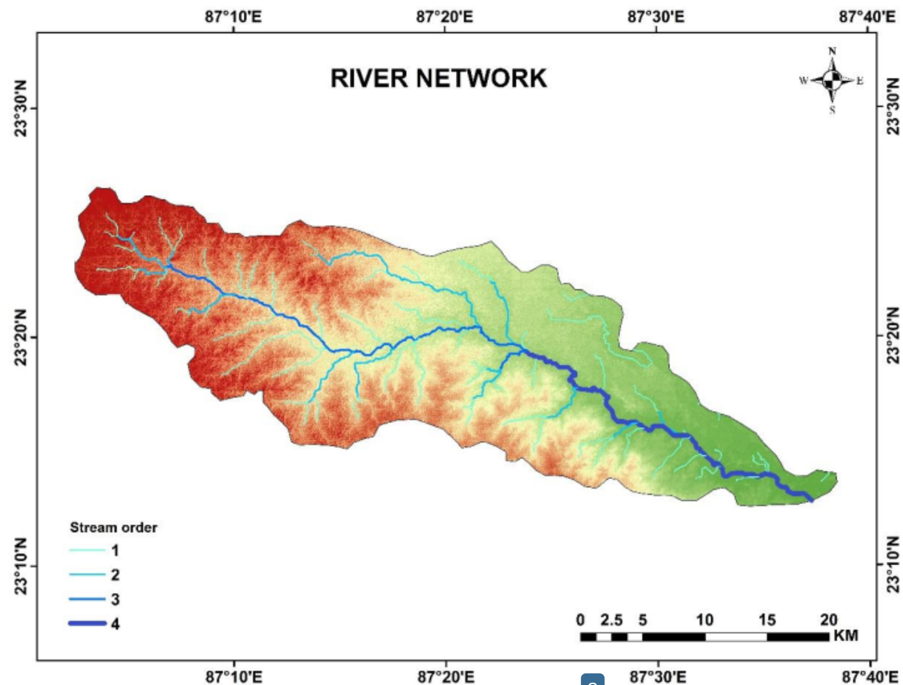

Figure 2.4 River network of the Shali River basin

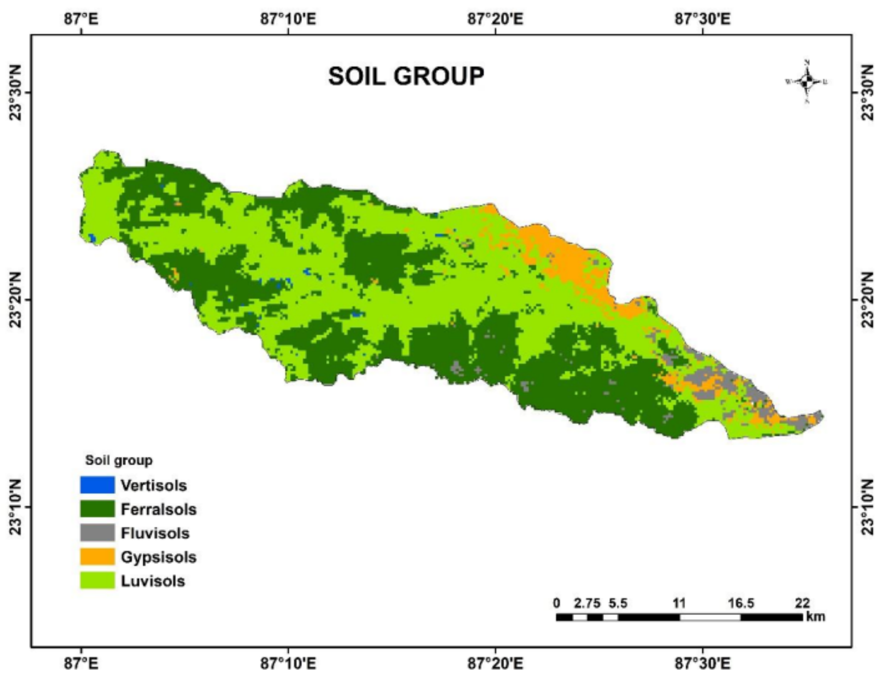

Figure 2.5 Soil group of the Shali River basin

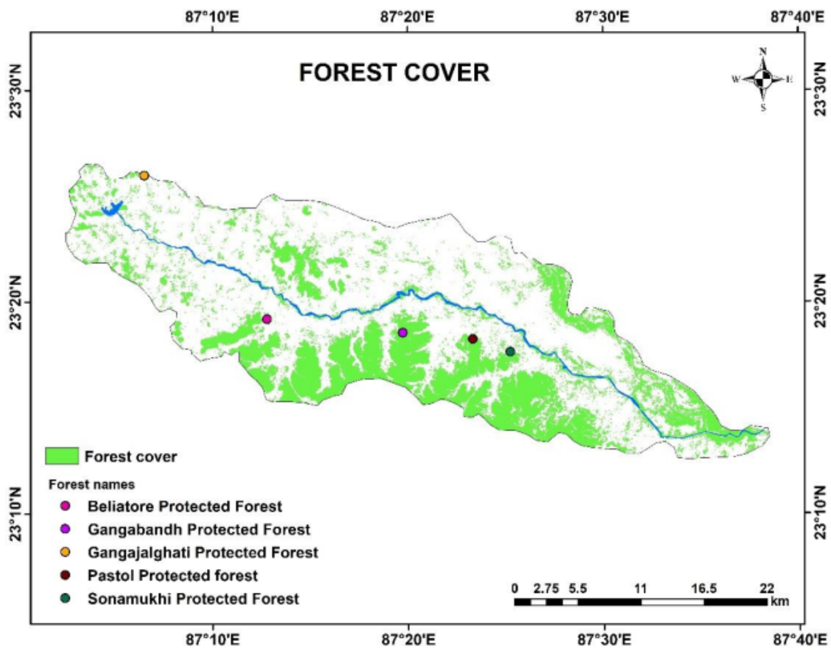

Figure 2.6 Forest cover of the Shali River basin

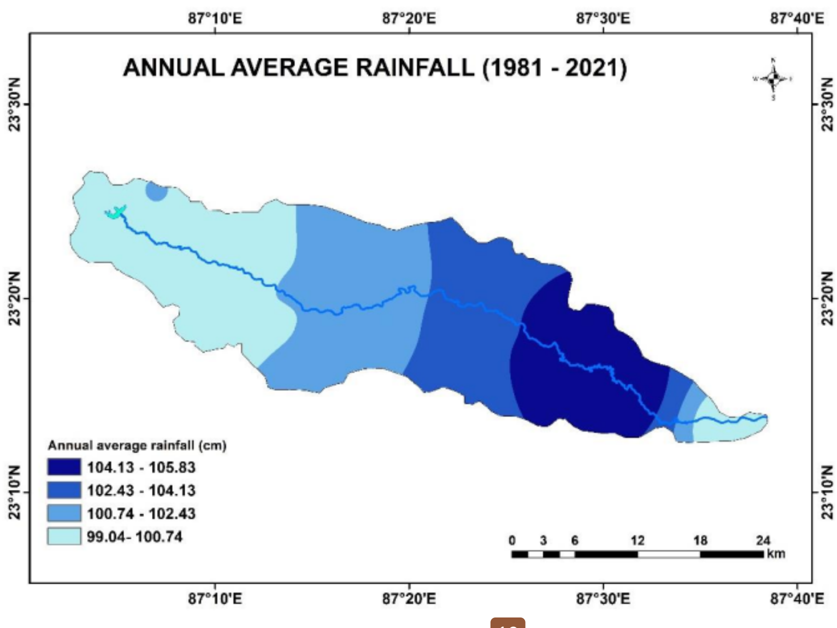

Figure 2.7 Annual average rainfall of the Shali River basin

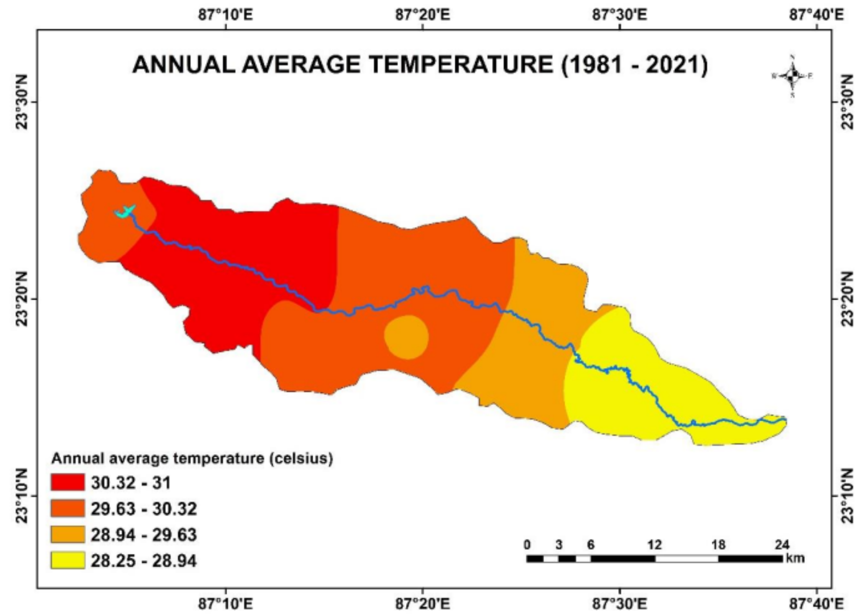

Figure 2.8 Annual average temperature of the Shali River basin

2.2.7 Rainfall

The Shali River basin experiences four distinct climatic seasons, such as (a) winter consisting of January to February, (b) pre-monsoon consisting of March to May, (c) monsoon consisting of June to September and (d) post-monsoon consisting of October to December. Annual rainfall differs between 700-1200 mm (Halder et al., 2022). Figure 2.7 analyses the annual mean rainfall of the Shali River basin from 1981 to 2021. The maximum and minimum annual average rainfall (1981 – 2021) are observed around 105.83 cm and 99.03 cm. The mean annual average rainfall is observed around 102.11 cm. Based on the highest and lowest annual average rainfall, the Shali River basin has been categorised into four classes: 104.13-105.83 cm, 102.43-104.13 cm, 100.74-102.43 cm and 99.04-100.74 cm, the upper segment of Shali River basin receives little amount annual average rainfall compared to the other parts of Shali River basin. Gangajalghati block comprises the upper segment of Shali River basin. It receives ~99 cm of average rainfall annually. The middle portion of the Shali River basin receives 104 cm annual average rainfall. The parts of the Barjora and Sonamukhi blocks are under the middle portion (TerraClimate, 2020).

2.2.8 Temperature

The Shali River basin experiences the hottest summer and the coldest winter. May is the peak summer season with the highest temperature of 43°C, whereas November to February is considered as winter with a minimum temperature of 4°C. Figure 2.8 shows the annual average temperature of the Shali River basin from 1981 to 2021. The average annual temperature of the Shali River basin is observed around 29.81°C. According to the highest and lowest annual average temperature the Shali River basin has been classified into four classes: 28.25-28.94°C, 28.94-29.63°C, 29.63-30.32°C and 30.32-31°C. The upper part of the Shali River basin has around 30.32°C annual average temperature which is comparatively higher than the lower part of Shali River basin. The lower segment of Shali River basin has around 28°C of average annual temperature. The Gangajalghati block is under the high-temperature category, Barjora and Sonamukhi blocks are under the moderate/high annual average temperature category and the Patrasayer block is under the low annual average temperature category (TerraClimate, 2020).

The climograph, in Figure 2.11, shows the annual average rainfall and temperature of the Shali River basin from 1981 to 2021. The bar graph signifies the average annual rainfall and the line graph describes the annual average temperature respectively (A1. Ch. 2.1).

2.3 Socio economical background

2.3.1 population

Figure 2.9 signifies the block-wise population comparison of the Shali River basin. According to the 1991 census data, Gangajalghati block had a total population of 74121 in 1991 and the population increased to 81303 in 2001. In 2011, 16% population increased. In the Barjora district, the total population in 1991 was around 77380 and it improved to 77416 in 2011. The total population was also intensified in the Sonamukhi block. About 21% of the population was increased in the Sonamukhi block. The Partsayaer block also showed positive growth in population, with around 26% population increase from 1991 to 2011. Overall total population of the Shali River basin has increased by around 20% from 1991-2011 (Census of India, 2011).

2.3.2 Literacy, language and religion

According to the 2011 census, Gangajalghati, Barjora, Sonamukhi and Patrasayer blocks have around 68%, 71%, 65% and 64% literacy rates. Bengali is the mother tongue of around 90% of the people of the Shali River basin but around 10% of people speak Santhali. In the Shali River basin, around 80% of people are Hindu and about 20% are Muslims (Census of India, 2011).

2.3.3 Livelihood

According to the district statistical handbook (2014), the major proportion of the population is involved in agricultural activities in the Shali River basin. In Gangajalghati block around 60% of total workers are engaged in agricultural activities. In Barjora block, around 55% of total workers are involved in agriculture. Whereas, in Sonamukhi block around 77% of workers are absorbed in agricultural activities. In Patrasayer block around 70% of workers are involved in the agricultural sector. Others are involved in the pottery and handloom industries (Census of India, 2011).

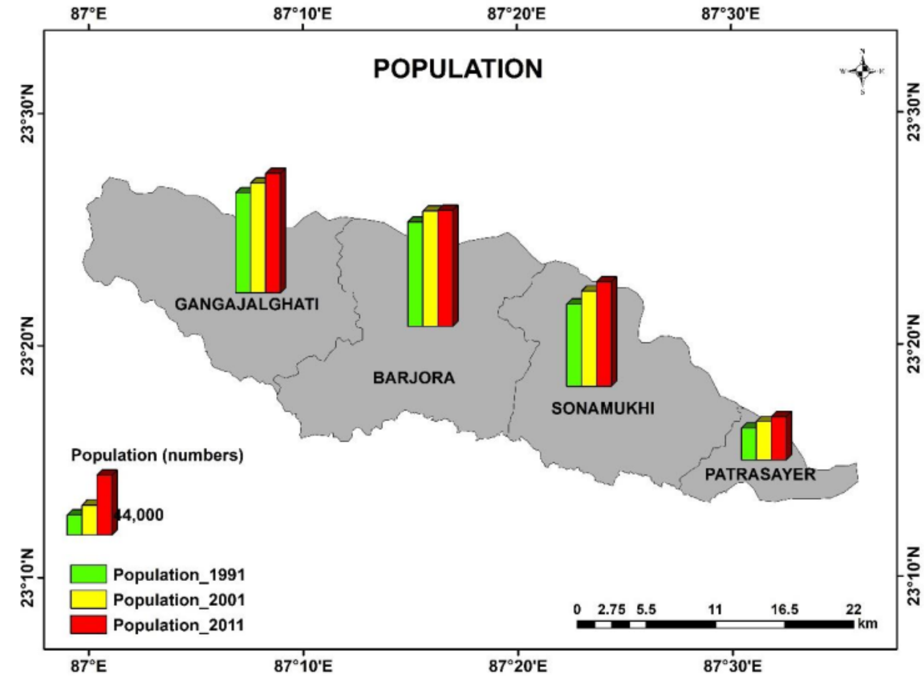

Figure 2.9 Block-wise decadal population distribution in the Shali River basin

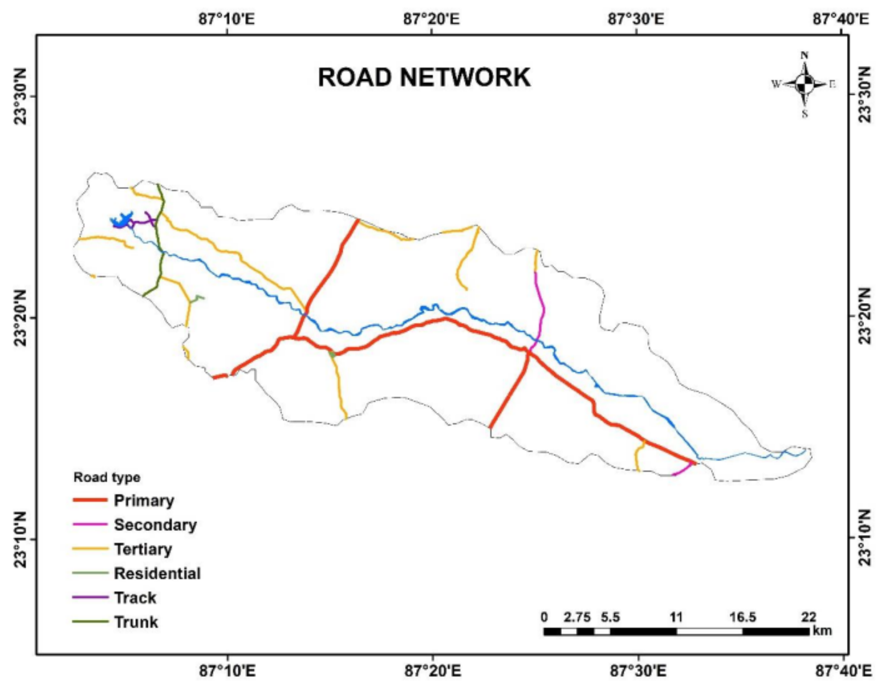

Figure 2.10 Road network of Shali River basin

2.3.4 Amenities

The Shali River basin area has very few commercial banks, gramin banks, primary, higher secondary schools and colleges. Every block has one rural hospital and health centre (Census of India, 2011).

2.3.5 Road network

As shown in Figure 2.10, in the Shali River basin, six types of roads have been observed such as primary, secondary, tertiary, residential, track and trunk (Census of India, 2011).

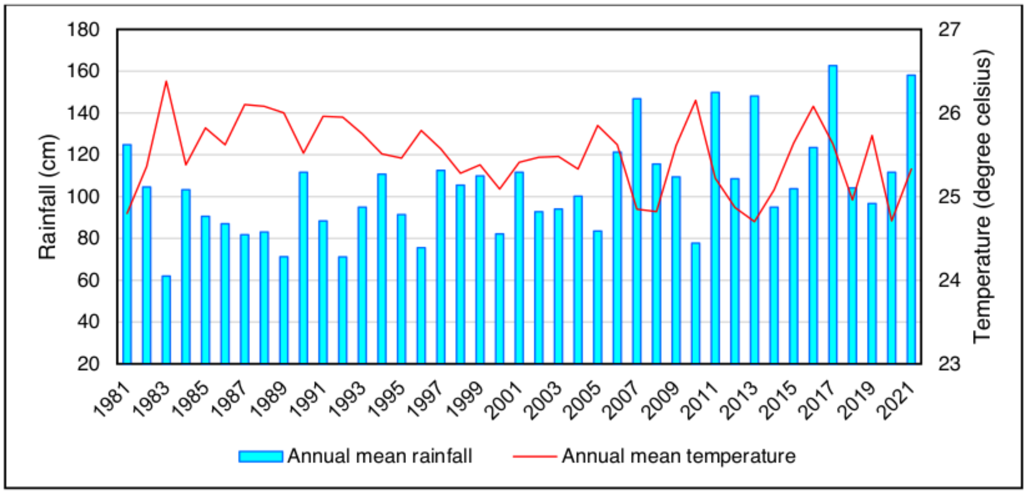

Figure 2.11 Climograph of the Shali River basin

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Role of Shali reservoir in irrigation water management

3.1 Introduction

The Shali reservoir is situated at the origin of river Shali near Bhairabpur village of Gangajalghati Gram Panchayet under Gangajalghati block in Bankura district. Before, the construction of the Shali reservoir, the Shali river was completely dried up during the premonsoon season. Therefore, the Shali reservoir was constructed to maintain the Shali river flow throughout the season. In 1978, the Shali reservoir was built and stores the rainfall and releases it through the Shali River. 341 villages of the Shali River basin are getting irrigational water through this scheme. Three types of irrigation are provided by the dam: (a) Irrigation through the canal system, (b) lift irrigation from the reservoir and (c) river lift scheme. The Shali reservoir can store up to 361 inches (9.17 m) but when the water level rises to 358 inches (9.1 m) then excessive water has been streamed to the Shali River canal for irrigational usage (Halder et al., 2020).

3.1.1 Irrigation through canal system

In this system, artificial canals are made to carry the irrigation water to the fields. In Shali reservoir medium irrigation project, the Shali River is used as a canal, it carries the irrigation water from the Shali reservoir to the fields.

3.1.2 Lift irrigation from the reservoir

In this system of irrigation, irrigation water is lifted directly from the reservoir with the help of diesel engines or electric-driven pumps. Here, in the Shali reservoir scheme water is lifted directly from the reservoir for agricultural usage.

3.1.3 River lift scheme

In this system, irrigation water is directly lifted from the river. Here, irrigation water is directly lifted from the Shali River for agricultural purposes.

3.2 Literature reviews

There is no research has been found on the Shali reservoir scheme and its influence on LULC change. Whereas, a few researchers have been found on the Shali River and the Shali River basin which are discussed below.

Koley (1993), worked on the geo-environment impact on the Shali River basin. He discussed the Shali River basin and Shali reservoir and their importance on agriculture in a small segment where he mentioned that, in the Bankura district, agriculture depends on monsoonal rainfall. Due to undulating topography, surface runoff is higher than in any other district of West Bengal. So, it is necessary to store rainfall water for agricultural activities. In the Gangajalghati block the soil type is very hard so the rainwater cannot percolate through the soil. It remains in the upper layers which help to dry up all the water in the summer months. In the monsoon season water level (WL) increases in the Shali river which is not sufficient for agriculture. For this purpose, the Shali reservoir project was implemented in 1978 at the mouth of the Shali River to store monsoonal rainfall. In 1989-90, it could irrigate only 2475 ha. The Shali River dries during the summer when the need for water is maximum. According to Koley (1993), the prime source of surface water in Shali River basin is rainfall. In the Kharif season due to undulating topography, a great amount of water resources is lost due to high runoff in the Shali River basin. During retreating monsoon, tropical cyclone helps to increase WL. About 35% of the Shali river is covered by coarse-grained sandy soils having a very poor water-holding capacity and 8% of the area is not cultivated every year due to the shortage of water.

Pan (2013) worked on the shifting river course of the Shali river applying RS and GIS methods to recognise river course changing patterns of the Shali river. For this study, the Landsat image series was used to identify river course patterns. Shali river is the prime tributary of the Damodar river that is directly flowing from the north-west of Bankura. The sinuosity index (SI) was calculated by considering continuous points down the entire river length using the formula RL/VL where RL is river length between two consecutive points on the river and VL is valley length - the shortest distance between the same two points. SI analysis showed that the channel pattern is straight and the SI value was 1.15 which is a weak type. From the satellite images in the last 30 years from 1972 to 2001, the Shali River shifted about 2.18 m.

Das and Gupta (2014) performed a morphometric investigation of the Shali River basin. The prime objective was to analyse morphometric characteristics of the Shali River basin to identify stages of erosion of the Shali river. The Shali River basin developed over a polygenetic surface. Stream order is the first step of basin morphometry. The study discloses that the Shali River basin is a fifth-order drainage basin. The whole stream length is highest in 1st order and it reduces as stream order rises. The DI value of the Shali River basin is 0.74 km^2 specifying low drainage density. The drainage frequency value is 0.43 per km^2 exhibiting a positive correlation with drainage density. The drainage coarseness of the Shali River basin is 1.93 and is classified as a very uneven drainage structure. Due to undulating terrain, the amount of infiltration is very low. The elongation ratio of the Shali River basin is 0.46 that is signifying discreetly low relief with an elongated shape of the drainage pattern.

Mukherjee (2015) studied the ecological and socio-economic facilities of the Shali reservoir and stated that the Shali water reservoir is also known as the Gangdua dam which is situated on the Shali River. It was made for irrigation purposes. Nowadays the dam is famous as a picnic spot. This paper reveals that the reservoir has a major role in fish production. Annual fish production is about six tons per hectare. Various types of migratory birds are also found here during the winter season. It acts a prime role to maintain the groundwater level of this region. A major portion of this region is reliant on this reservoir for drinking water. About 70 families are engaged in fishing activities from Shali reservoir. During the peak season

(October to March) more than 2500 people's livelihood depends on tourism. Moreover, the reservoir has an important value for its existence and attractive sceneries.

Das and Gupta (2018) delineated GPZ in the Shali River basin only, using GIS and RS methods. The groundwater potential zones are delineated through different maps i.e., geology, hydro-geomorphology, slope, drainage, LULC map, and lineament using RS and GIS methods. The delineation of groundwater potential zones has been made by overlaying the thematic layers through weighted multi-influencing factors. From this process, five groundwater potential zones: excellent, very-good, good, moderate, and poor have been classified in the Shali River basin area. The study displays that around 28.70% of the total area falls under poor groundwater potentiality, 15.65% falls under moderate groundwater potentiality, 19.45% area falls under good groundwater potentiality, 11.20% falls under very good groundwater potentiality and 25% has excellent groundwater potentiality. This study will benefit developers and decision-makers to find appropriate places for the extraction of water.

Malik et al. (2019) analysed the annual variation of vegetation conditions in the Shali watershed by using a geospatial approach. To discover intra-annual vegetation dynamics NDVI and statistical investigations have been done here. In this study, NDVI has been computed for twelve consecutive months of 2014. In January, a high degree of NDVI was found along the Shali river due to river base flow going on and localised irrigation practices assisted villagers to cultivate lands. The water body showed very low NDVI in the winter season. During April NDVI showed medium due to the high concentration of vegetation. After April, forest cover areas showed high NDVI and during monsoon time (august) highest NDVI is found all over the area. Vegetation status for the months from Jan to May is similar. June month is considered a transition month. August to October months represent higher concentration. Novembers and December months comparatively do equal to pre-monsoons. here are two different forms of NDVI reflection i.e., during the monsoon season single peak represents natural vegetation and multiple peaks represent the agricultural field. The study signifies that vegetation status is heterogeneous. NDVI has been computed pursuing Rouse et al. (1974), NDVI = (NIRr- RED)/ (NIR+REDd) where RED is wavelengths surface reflectance in visible ($\lambda \sim 0.6$ µm) and NIRr is wavelengths surface reflectance of ($\lambda \sim 0.8$ μm) of the spectrum, respectively.

3.3 Chapter outline

This chapter comprises three segments. In the first segment, the main reasons behind the erection of the Shali reservoir have been discussed. In the second segment, the Shali reservoir's annual and seasonal water level has been analysed. Shali reservoir sediment level estimation has been performed before the water level analysis. In the third segment, a SWOT analysis of the Shali reservoir has been done (Figure 3.1).

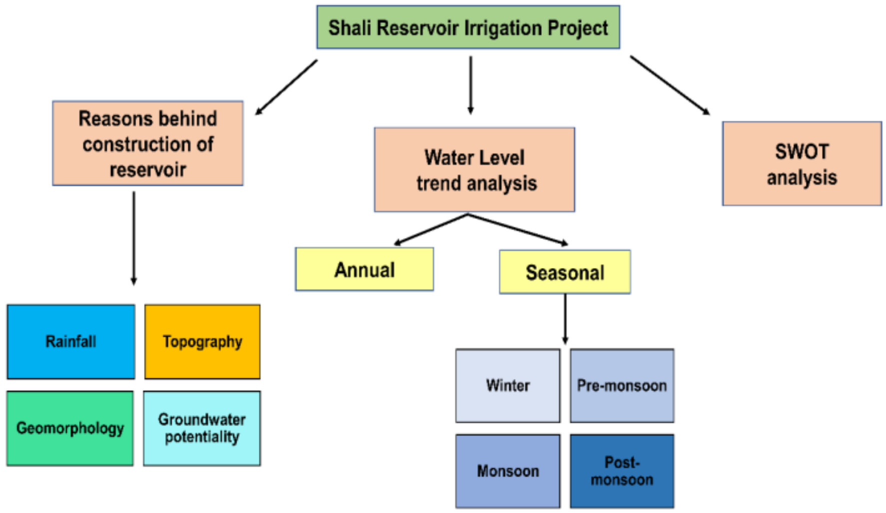

Figure 3.1 Chapter outline

3.4 Method

3.4.1 Mann Kendall (MK) trend analysis

It's a non-parametric test that is applied to determine trend detection of time series data like rainfall, temperature, etc. It analyzes the positive or negative trends of the given data. In the MK statistics 'β' is calculated using the following equations (3.1-3.2) given by H.B. Mann (1945) and M.G. Kendall (1975).

$$\beta = \sum_{i=1}^{p-1} \sum_{j=i+1}^{p} \operatorname{sgn}\left(P_{rj} - P_{ij}\right) \tag{3.1}$$

$$\operatorname{sgn}\left(P_{rj} - P_{ri}\right) = \begin{cases} +1, & > \left(P_{rj} - P_{ri}\right) \\ 0, & = \left(P_{rj} - P_{i}\right) \\ -1, & < \left(P_{rj} - P_{i}\right) \end{cases} \tag{3.2}$$

where, the P_{rj} and P_{ri} are values of consecutive data, and p represents time-series data counts. The positive 'β' value characterises high tendency and the negative value characterises low inclination.

Generally, more than 10 records are used in the MK statistics. The variance of the records has been calculated as follows in Eqs. 3.3-3.4.

$$Var(\beta) = \frac{p(p-1)(2p+5) - \sum_{i=1}^{m} tc_k(k)(k-1)(2k+5)}{18} \tag{3.3}$$

where the tc_k is the ties countable for the k^{th} specified sample.

The last step of the MK statistics is to calculate the standard deviation *Zc* given in the equation. Here, an increasing nature means a positive *Zc* value and a decreasing nature means a negative *Zc* value.

$$Zc = \begin{cases} \dfrac{\beta - 1}{\sqrt{Var(\beta)}}, & \beta > 0 \\ 0, & \beta = 0 \\ \dfrac{\beta + 1}{\sqrt{Var(\beta)}}, & \beta < 0 \end{cases} \tag{3.4}$$

3.4.2 Linear regression analysis

Statistical methods are very appropriate to recognise the association between dependent, variables and independent variables. The correlation coefficient can be calculated if the variables are continuous, Regression analysis describes the relationship and helps to estimate the dependency. From the best-known regression analysis Linear regression method has been applied in this paper. LR is used to identify linear relationships between variables. In this method, the dependent variable is treated as *Y* and the independent variable is treated as *X*, and the linear regression model defines the dependent variable with a straight line which is demarcated by this equation (Eq. 3.5):

$$Y = a + b \times X \tag{3.5}$$

where *a* is the *Y*-intersect of line, and *b* is slope. The statistical method helps to identify the value of *a* and *b* with the help of *X* and *Y*. the slope b from the regression line can be named as the regression coefficient. The value is maintained based on the independent variable (*X*). The unit of measurement is an important part of the analysis (Schneider et al., 2010).

Coefficient of determination (R-squared)

The coefficient of determination is used to measure the validity of a regression model; it can be calculated by the following equation (Eq. 3.6):

$$R^2 = \frac{\sum_{i=1}^{n} \left(y_i - \overline{y} \right)^2}{\sum_{i=1}^{n} \left(y_i - \overline{y} \right)^2} \tag{3.6}$$

R^2 is the fraction of the total variance. Where closer the regression model's projected values $\hat{y}_i$ sit to observed values y_i, the closer the coefficient of determination is to 1 and the more precise the regression model is. In this chapter R-squared value has been used to recognise the accurateness of the linear model.

3.4.3 Normalised Difference Water Index (NDWI)

The index uses Green and NIR bands of images of remote sensing. The NDWI can improve water information proficiently. Water bodies only reflect inside the visible segment of the electromagnetic spectrum. Waterbodies have higher reflectance on the blue spectrum (0.4 μm - 0.5 μm) than on the Green (0.5 μm - 0.6 μm) and Red (0.6 μm - 0.7 μm) spectrums. Clearwater is having maximum reflectance in the blue segment among the observable spectrums. So, water logically applies to blue. There is no reflection in NIR and beyond. The index was planned for maximizing the water reflectance to identify water bodies with green wavelengths and minimize the lower NIR reflectance through water features. The NDWI formula (Eq. 3.7) is as follows (Gao, 19961).

$$NDWI = \frac{(Green - NIR)}{(Green + NIR)} \tag{3.7}$$

The NDWI value ranges between -1 to +1, with values toward 1 considered as water bodies. A high positive value appears darker than a low positive value. Here, a high NDWI value means high water depth and a low NDWI value signifies low water depths.

3.5 Reasons behind the erection of Shali reservoir

According to literature reviews before the construction of the Shali reservoir, the Shali river was completely dried up during the winter and pre-monsoon season which affected the agricultural activities in the Shali River basin area. The main reasons behind the erection of the Shali reservoir are stated below.

3.5.1 Low amount of rainfall

The foremost reason behind the erection of the Shali reservoir was rainfall. The Shali River basin area gets the minimum amount of rainfall than the other parts of the Bankura district. The south and south-western part of Bankura gets a very high to high amount of rainfall than other parts. It gets around 1394 to 1425 mm of annual rainfall. Whereas, the upper portion of the district gets moderate to very low amounts of rainfall. The Shali River basin gets around 1339 to 1381 mm of annual rainfall which is very low comprising the other parts of the district (Rajeevan et al., 2008). Therefore, the Shali reservoir was made at the mouth of the Shali River to store the rainwater for irrigational usage (Figure 3.2) (IMD, 2021) (A1. 3.1).

3.5.2 Uneven topography

Uneven topography is another important factor behind the construction of the Shali reservoir. The average elevation of the Bankura district is ~225 m and the average slope is ~25%. Shali River basin comprises moderate to high topography. The elevation of the upper portion is higher than the lower portion in the Shali River basin and the landscape is undulating and the slope is also high in the category. So, due to the elevation and slope maximum amount of rainwater flows as surface runoff before the construction of the reservoir. Therefore, the Shali reservoir was made at the mouth of the Shali River to reduce the surface runoff (Figure 3.3).

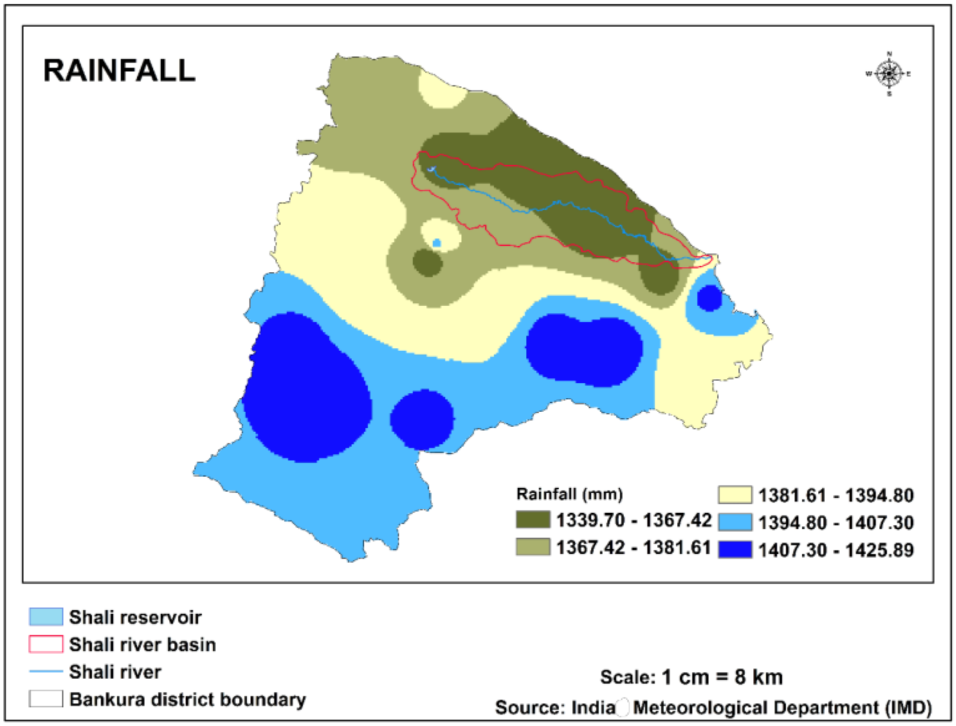

Figure 3.2 Shali River basin area gets less annual rainfall than adjoining areas (1980 - 2020)

3.5.3 Geomorphological reason

The geomorphological condition also plays a significant role in the construction of the Shali reservoir scheme. The Shali River runs from the north-west direction to the south-east direction. Bankura district falls under arid and semi-arid regions, therefore the district is mostly confined to pediplain, pediments and lateritic uplands and plains.

A very small part is under older alluvium. Pediments are gently sloping erosional rock surface., which is predominantly found in arid and semi-arid regions. Whereas flat rock surfaces are known as pediplain. It is formed by the joining of several pediments (Bhukosh, 2022). According to L.C. King, it is the last stage of landform evolution and the final result of the erosional process. The Bankura district is also covered with lateritic uplands and plains which have low water holding capacity. So, it was essential to construct a reservoir for irrigational usage (Figure 3.4).

3.5.4 Groundwater level potentiality

Goswami and Ghosal (2022) examined groundwater potential zones (GPZ) of the Bankura district using two MCDM techniques: AHP and MIF. They used ten parameters to identify GPZs, such as geology, groundwater yield, aquifer thickness, lineament, slope, drainage, net recharge, elevation, LULC and soil structure.

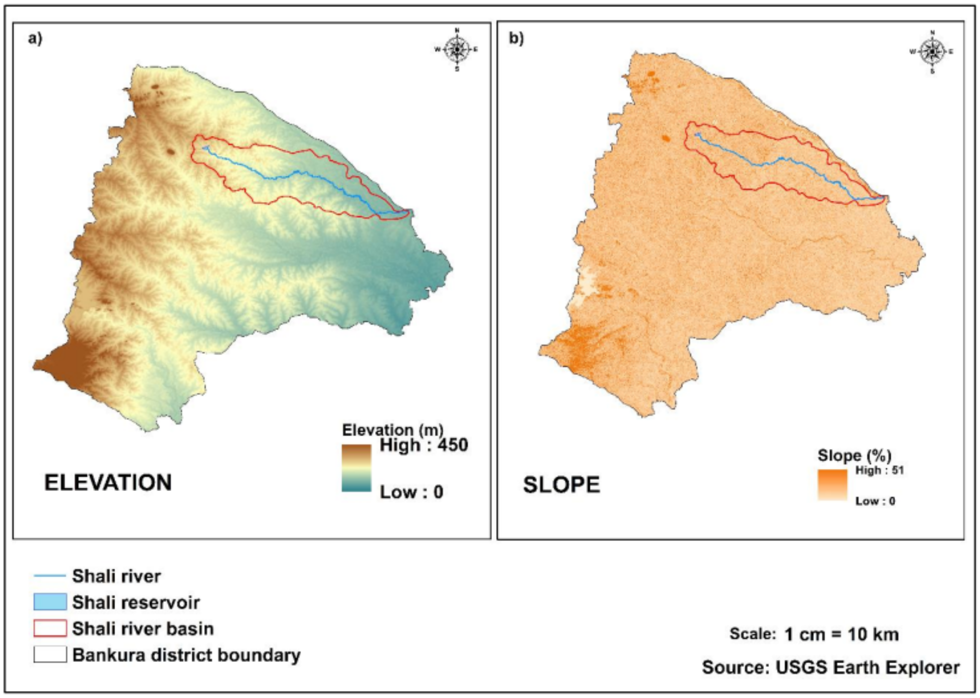

Figure 3.3 Shali River basin comprising moderate to high topography (elevation and slope) than adjoining areas

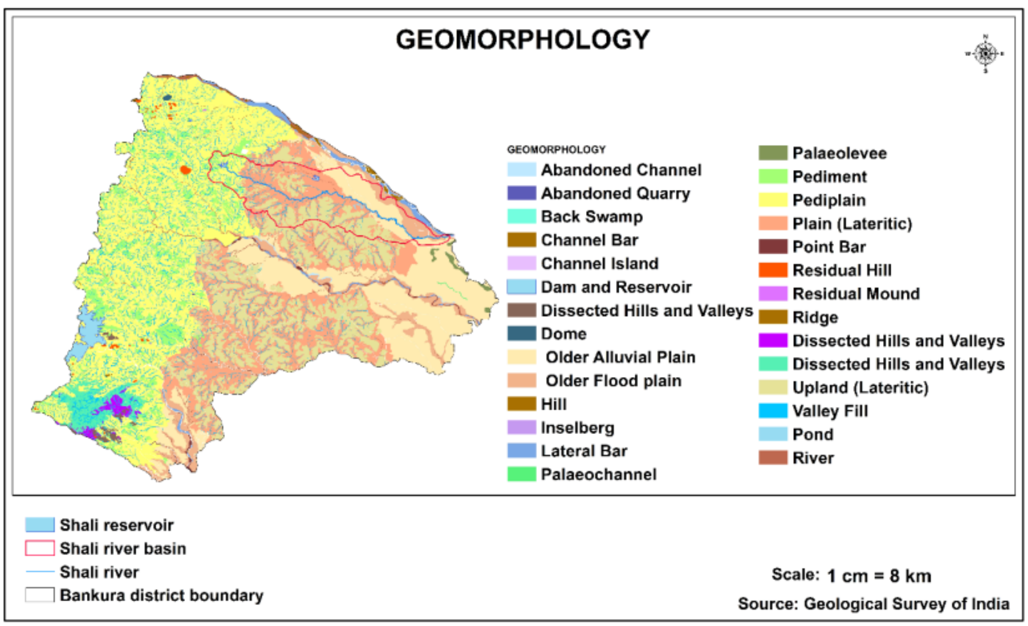

Figure 3.4 Geomorphology map of the Shali River basin with adjoining areas in Bankura

The study resulted that, around 64% of Bankura district was under medium to very low GPZ and around 36% was under very high to high GPZ. The Gangajalghati block of Shali River basin, where the Shali reservoir is situated was observed under medium to very low GPZ, but the Barjora block was in medium to high GPZ. Whereas, Sonamukhi block was under medium GPZ and Patrasayer block was under very high to high GPZ. Therefore, from the study of Goswami and Ghosal (2022), it can be said that the Shali River basin has medium GPZ which can be a reason behind the construction of the Shali reservoir.

3.6 Basic features of Shali reservoir

Attribute	Value
Name of the reservoir	Shali or Gangdua dam
River	Shali
Nearest city and district	Bankura
State	West Bengal
Basin	Shali river
Purpose of dam	Irrigation
Year of completion	1985
Operating & maintaining agency	Irrigation and Waterways Dept., GoWB
Dam as per Parliamentary Constituency	Bishnupur
Seismic zone	Zone III
Area of the reservoir (ha)	132.84
Perimeter of the reservoir (m)	13620
Length of the reservoir (m)	2308
Maximum height above foundation	12 meter
Length of Shali river (km)	80
Work started in 5-year plan	III plan
Completed in 5-year plan	IX
Project sanction status	Planning Commission
Approval year	1975

Source: I&WD, GoWB

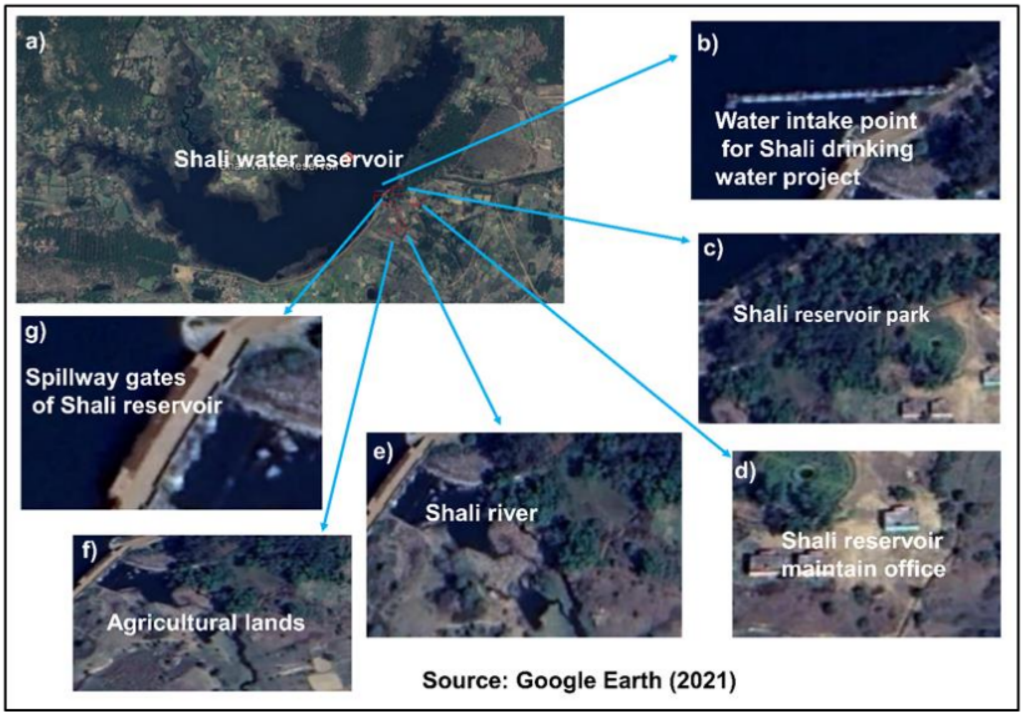

Figure 3.5 Satellite images of Shali reservoir and its adjacent areas

Figure 3.5a Shali reservoir (source field visit)

Figure 3.5b Water intake point of Shali drinking water project

Figure 3.5c Shali reservoir park

Figure 3.5d Shali reservoir camp office

Figure 3.5e Shali River

Figure 3. 5f Agricultural lands

Figure 3.5g Spillway gates of Shali reservoir

Figure 3.5a Gauged water level in pre-monsoon

Figure 3.5b Gauged water level in monsoon

Source: field visit (pre-monsoon date: 03.04.2021 and monsoon date: 25.07.2021)

Figure 3.6 Water level data collection of Shali reservoir from the reservoir camp office (field visit 27.12 2021)

3.7 Shali reservoir water level trend

The water level of the Shali reservoir totally depends on rainfall. Around 30 years' water level (WL) data of the Shali reservoir has been assembled from I&WD, GoWB. Prior water level trend analysis reservoir sedimentation analysis has been performed using an empirical method and the sediment layer has been subtracted from the water level gauge data. Reservoir sedimentation means the deposition of eroded soil particles carried by surface runoff and water channels into the reservoir. In the case of the Shali reservoir, no literature on sedimentation analysis has been found. The I&WD, GoWB is yet to maintain proper data regarding the sedimentation of the Shali reservoir. Therefore, in this research, empirical methods are used to estimate the sedimentation level of the Shali reservoir.

Here, two empirical methods have been applied to estimate the sediment level of the Shali reservoir: The revised universal soil loss equation (RUSLE) and Satellite remote sensing (SRS).

Method 1: Estimation of Shali reservoir sediment level using RUSLE

It is an empirical method that envisages soil loss in an area (Renard et al., 1997). Firstly, water channels have been demarcated which carry sediments in the reservoir. Based on the water channels carrying sediments towards the Shali reservoir, three watersheds are identified. It is assumed that eroded soil particles from these watersheds are carried by the water channels to the Shali reservoir (Figure 3.7). The soil loss estimation has been calculated using the following Eq. 3.8.

$$\text{Estimated soil loss} = R \times K \times LS \times C \times P \quad (3.8)$$

where, R = rainfall and runoff, K = erodibility of soil, LS = slope length and gradient, C = crop supervision, and P = support systems (agricultural direction, strip cropping, etc.)

Factors of RUSLE

R is the soil erosion rate depends on the intensity and duration of rainfall (Eq. 3.9).

$$R = \sum_{1}^{12} 1.735 \times 10^{(1.5\log_{10}(Pi/p) - 0.08188)} \quad (3.9)$$

K checks the vulnerability of soil particles caused by rainfall. It also measures the texture, structure, permeability, and organic properties of soil (Eq. 3.10).

$$K = 27.66 \times m^{1.14} \times 10^{-8} \times (12 - a) + 0.0043 \times (b - 2) + 0.0033 \times (c - 3) \quad (3.10)$$

m = silt in % + very fine sand in % × (100 – clay in %)
a = organic substance (%)
b = structure code
c = profile permeability code

LS is the soil loss depends on steepness and length of slope (Eq. 3.11).

$$LS = \left[\frac{Q_a M}{22.13}\right]^{y} \times (0.065 + 0.045 \times S_g + 0.0065 \times Sg^2) \quad (3.11)$$

where LS = topographical factor (slope length); Q_a = flow accumulation grid; S_g = Grid slope in %; M = grid size; y = dimensionless exponent that assumes value of 0.2-0.5.
C- it signifies crop management factors that are taken for soil loss prevention.
P measures the up and down slopes soil loss.

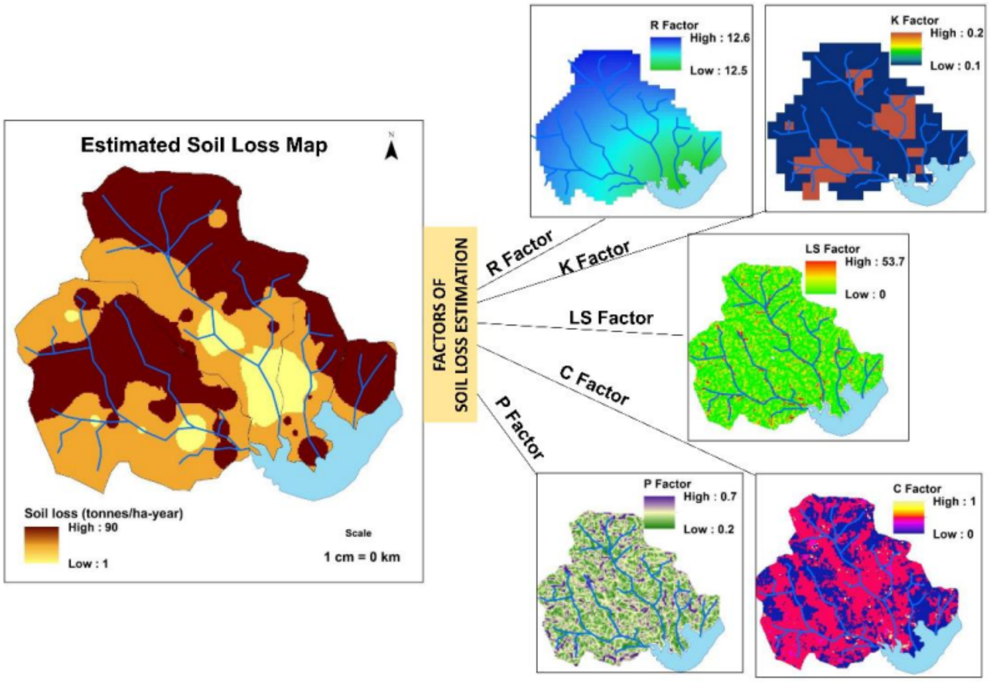

Figure 3.7 Soil loss estimation using RUSLE

Calculation of sediment level of Shali reservoir (RUSLE method)

Annual soil loss (derived from RUSLE) = 57490 tonnes in 1321 ha (watershed area)

Soil loss in 30 years (1991 – 2021) = 1724700 tonnes (total soil loss)

Total volume of soil loss =1954085.1 m^3

Reservoir area = 1130000 m^2

Reservoir water level = 12 m

Reservoir volume =13560000 m^3

Therefore, sediment height = 1.72 m

The study reveals that in the Shali reservoir, the sediment deposition height from 1991 to 2021 is aggravated around 1.72 m.

Method 2: Estimation of Shali reservoir sediment level using SRS

In this method, Landsat 4 and 8 images of the Shali reservoir are used from 1991 to 2021. Then NDWI is applied to separate water spread areas of the Shali reservoir. The satellite images used for this study are mostly taken from January because this time the percentage of atmospheric cloud was almost nil (Figure 3.8).

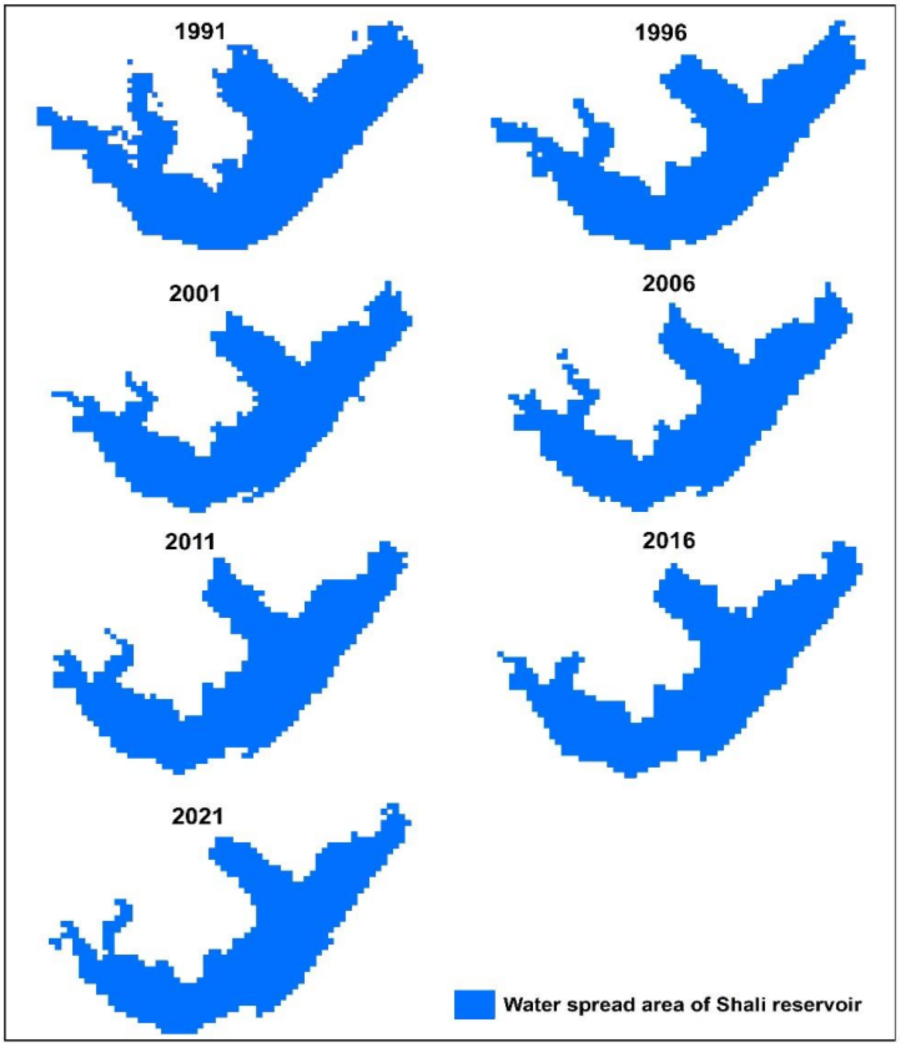

Figure 3.8 Temporal changes of water spread area of Shali reservoir.

To estimate the sedimentation level a trapezoidal formula (Eq. 3.12) has been used (Katiyer et al., 2006).

$$V = H(A_1 + A_2 + \sqrt{(A_1 \times A_2)})/3 \tag{3.12}$$

where V is volume between two levels; A_1 is water spread area at height 1; A_2 is water spread area at height 2 and H is difference between heights 1 and 2.

Here, the study reveals that from 1991 to 2021, around 1.12 m of sediment deposition occurred in the Shali reservoir (Figure 3.9) (A1. Ch 3.3).

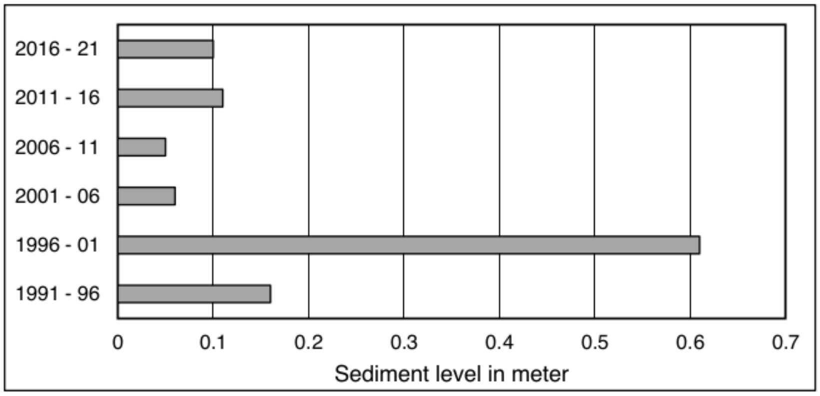

Figure 3.9 Temporal change in sediment level of Shali reservoir

The sediment aggradation height of the Shali reservoir has been found around 1.72 m in RUSLE and 1.12 m in the SRS method which proves that the estimation of the sediment layer has been performed accurately.

3.7.1 Annual water level trend

The WL trend analysis has been performed in two segments. In the first segment annual water level trend has been analysed. Whereas, in the second segment season wise trend analysis has been performed. MK trend method has been applied to identify the trend.

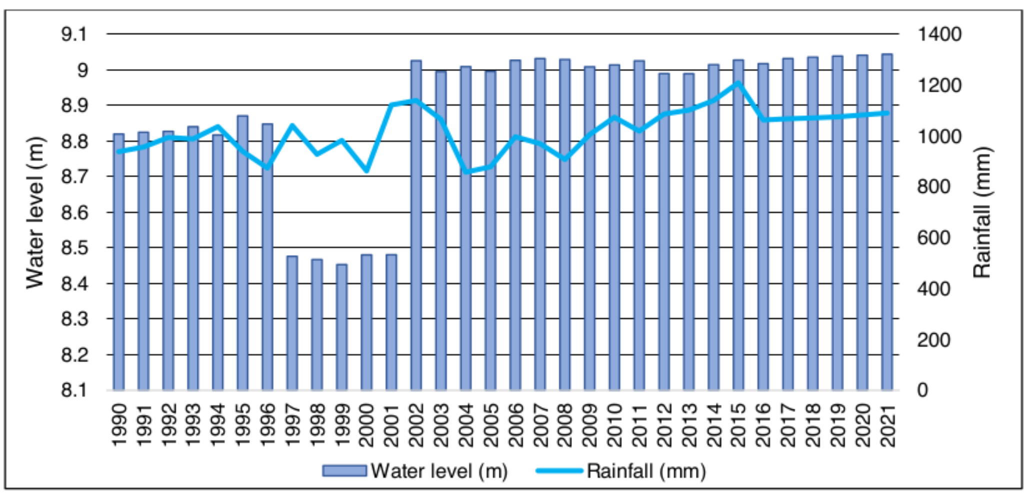

Figure 3.10 Annual water level and rainfall trend of Shali reservoir

The MK test z value of the annual water level trend is 4.93, which represents a highly positive trend. So, the WL of the Shali reservoir has been increased from 1990 to 2021. In 1991, the WL of the Shali reservoir was around 8.81 meters. In 2000, the WL decreased to around 8.48 meters. In 2010, the WL was increased to 9 meters, whereas in 2021 the WL increased to 9.04

meters. The nature of the WL of the Shali reservoir is fluctuating. The maximum rise in WL was observed in 2002 and the lowest was found in 1999. The WL of the Shali reservoir totally depends on rainfall. The Shali reservoir was installed with rain gauge, so annual rainfall trend analysis was also performed from 1990 to 2021. The MK Z value of rainfall is around 3.32 which signifies an increasing trend. Like water level data, the Shali reservoir area received the maximum amount of rainfall in 2021 and the minimum amount of rainfall in 1999 (Figure 3.10) (A1. Ch. 3.4).

3.7.2 Seasonal water level analysis

The Shali reservoir region experiences four distinct seasons such as winter (January – February), pre-monsoon (March–May), Monsoon (June–September) and Post-monsoon (October–December) (A1. Ch. 3.5). The area gets a very minimum quantity of rainfall (~50 mm average annually) in the winter season. Therefore, the amount of WL was reduced this time than the other seasons. The maximum and minimum WL during winter has been observed around 9.02 meters and 8.40 meters. the average WL is around 8.85 meters. In 1990 and 1992 - 2000 the WL was below average, whereas, in 1991, 1996 and 2002 – 2021 the WL was above average. The MK trend Z value of winter WL is around 1.57 which represents a very low increasing trend (Figure 3.11).

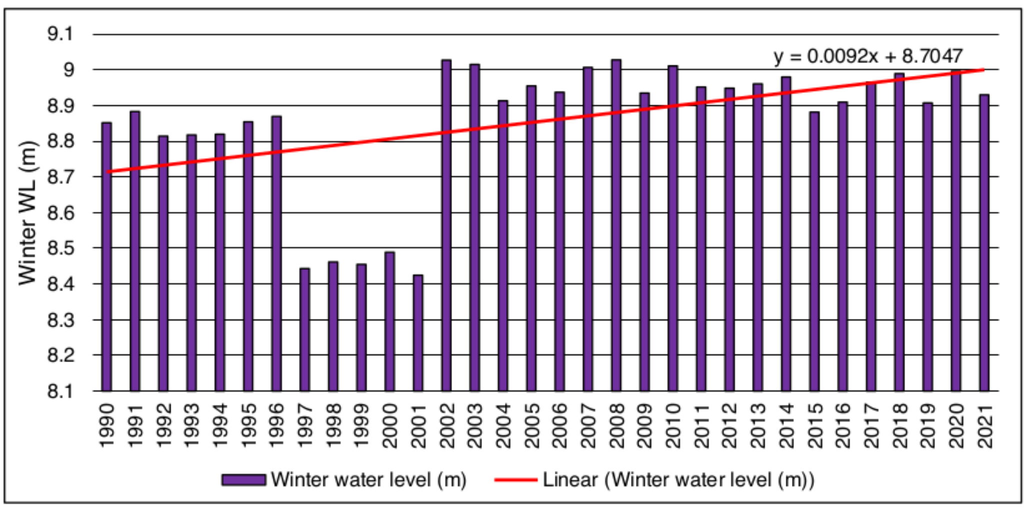

Figure 3.11 Winter water level trend of Shali reservoir

Table 3.1 Seasonal water level (WL) trend of Shali reservoir

Season	Average WL (m)	Highest WL (m)	Lowest WL (m)	MK test Z value
Winter	8.85	9.02	8.42	1.57
Pre-monsoon	8.83	8.98	8.37	1.50
Monsoon	8.91	9.07	8.48	2.71
Post-monsoon	8.89	9.06	8.91	1.96

In the pre-monsoon, the amount of rainfall has decreased to some extent. So, the amount of WL was reduced in pre-monsoon. The average WL in pre-monsoon is around 8.83 meters, maximum and minimum WL are around 8.98 and 8.37 meters. In 1997-2000 and 2001, the WL was below average but in 1990-1996 and 2002-2021 was above average WL. The MK trend Z value was around 1.50 which signifies positive change (Figure 3.12).

The Shali reservoir receives the maximum amount of rainfall during the monsoon season. Therefore, WL also increased in monsoon. The average WL during monsoon is around 8.91 meters. The maximum and minimum water level is around 9.07 and 8.48 meters, respectively. In 1992, 1997-2001 the WL was below average in monsoon whereas, in 1990, 1991, 1993, 1994, 1995, 1996 and 2002-2021 was above average WL observed. The MK trend analysis z value is around 2.71 in monsoon which represents a high increasing WL trend from 1990 to 2021 (Figure 3.13).

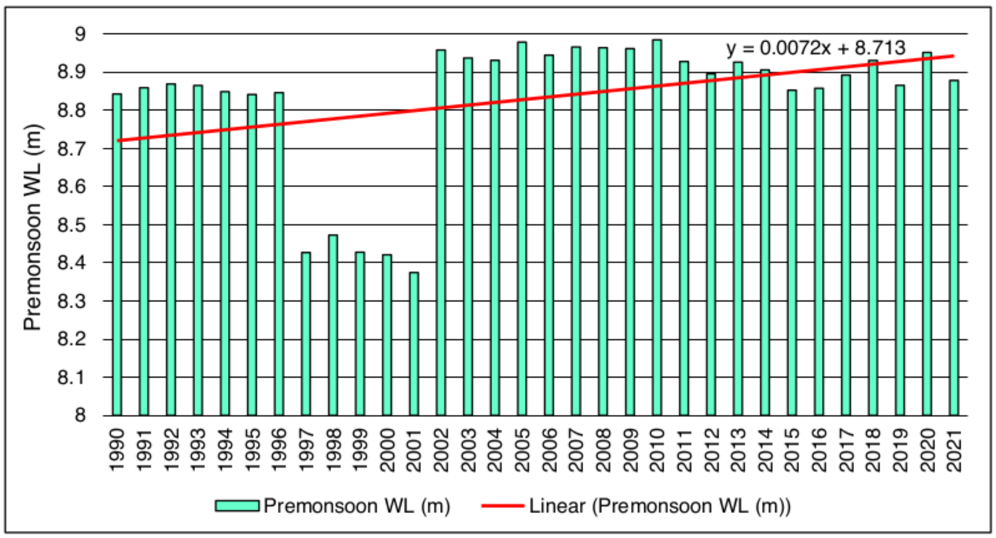

Figure 3.12 Pre-monsoon water level trend of Shali reservoir

During post-monsoon, the amount of rainfall starts to decrease, so the amount of WL was also reduced during post-monsoon. The average WL in post-monsoon is around 8.89 meters. The maximum and minimum WL are 9.06 and 8.91 meters. in 1992-1994 and 1997-2001, WL was below average during post-monsoon but in 1998, 1991, 1995, 1996 and 2002-2021 was above average WL during post-monsoon. The MK trend analysis z value of post-monsoon is 1.96 which signifies that the amount of water level has increased in the Shali reservoir during post-monsoon from 1990 to 2021 (Figure 3.14) (Table 3.1)

The Shali reservoir stores the rainfall and supplies the rainwater through the Shali River to the villages of the Shali River basin. Before construction of reservoir, the Shali River dried up during winter and pre-monsoon season. This situation affects agricultural production. The creation of the Shali reservoir helps to maintain the water flow in the Shali River throughout the year. A remote sensing index-based analysis has been performed to analyse the correlation between the reservoir and river water levels. Normalized difference water index (NDWI) has been applied to identify the water level.

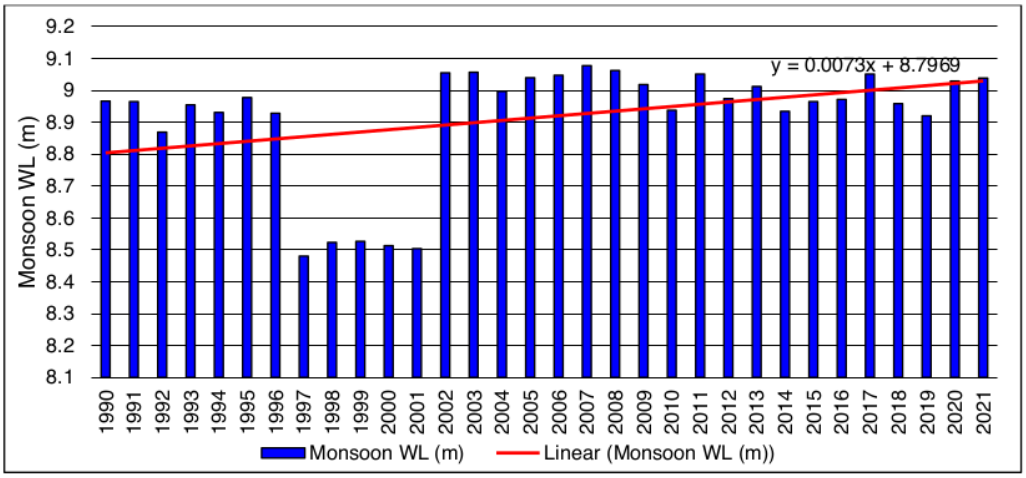

Figure 3.13 Monsoon water level of Shali reservoir

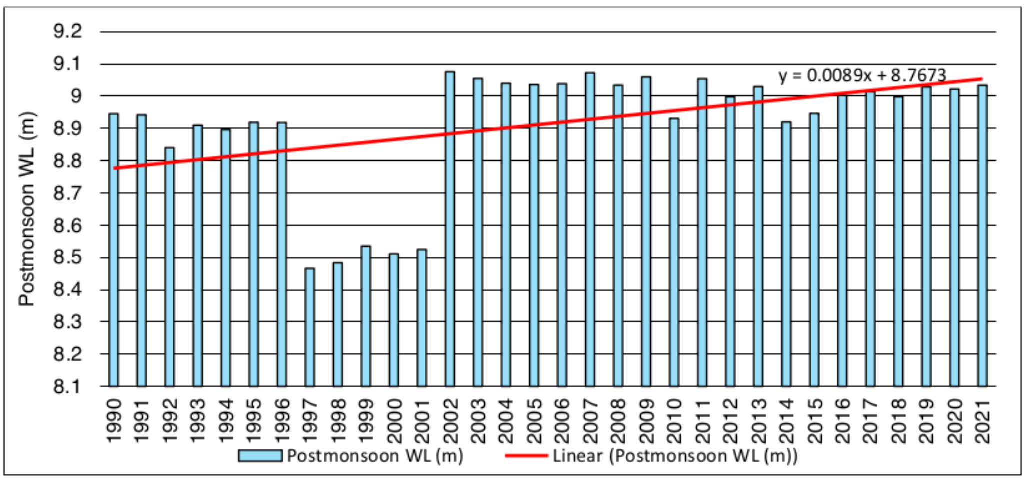

Figure 3.14 Post-monsoon water level of Shali reservoir

Monthly (1990-2021) Landsat 4 TM and 8 OLIi datasets (A1. Ch. 3.6) were used to collect NDWI values of the Shali reservoir and Shali River, 20 points have been taken along the Shali River to derive the NDWI values. Then yearly average value of NDWI for the Shali river has been calculated. Lastly, the linear regression method has been performed to identify the correlation between the reservoir and river water levels. The Shali River water level (Ri) depends on the reservoir water level (Re), so reservoir NDWI is considered as independent (*X*-axis) value and the Shali river NDWI value is considered as dependent (*Y*-axis) value (Figure 3.15). The R^2 value is 0.79 which signifies a positive correlation between the reservoir and river water levels. Figure 3.16 signifies that the water availability of Shali river totally depends on Shali reservoir (A1. Ch. 3.7).

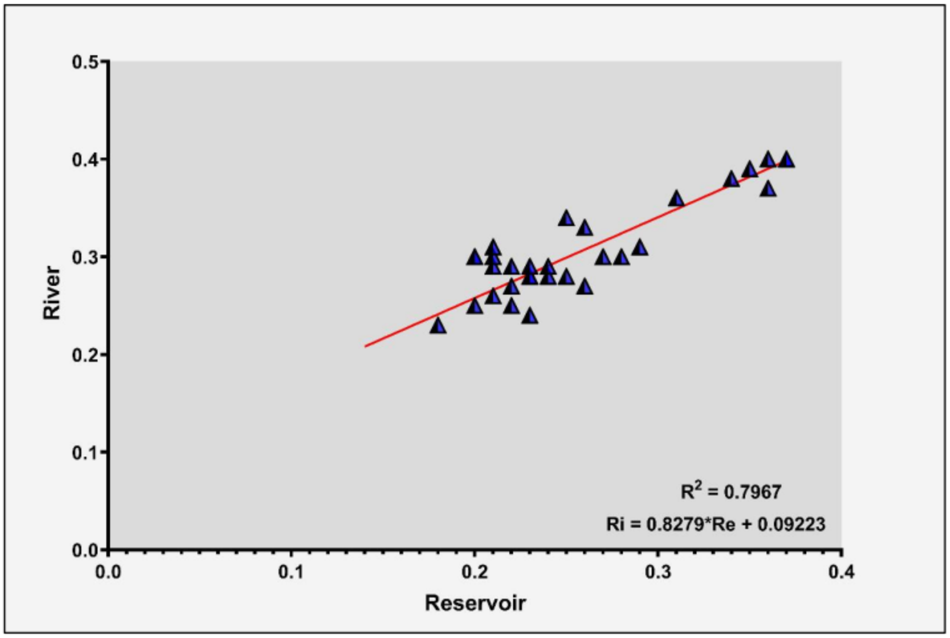

Figure 3.15 Correlation between Shali River and reservoir NDWI values

3.9 SWOT analysis of Shali reservoir

The SWOT (strength, weakness, opportunities, and threat) identifies fundamental strengths, weaknesses, opportunities, and threats leading to fact-based assessment, new outlooks, and novel ideas. Here SWOT analysis has been performed to recognise the strengths, weaknesses, opportunities, and threats of Shali reservoir. This analysis has been done by interviewing the reservoir maintenance officials and local people (Figure 3.16).

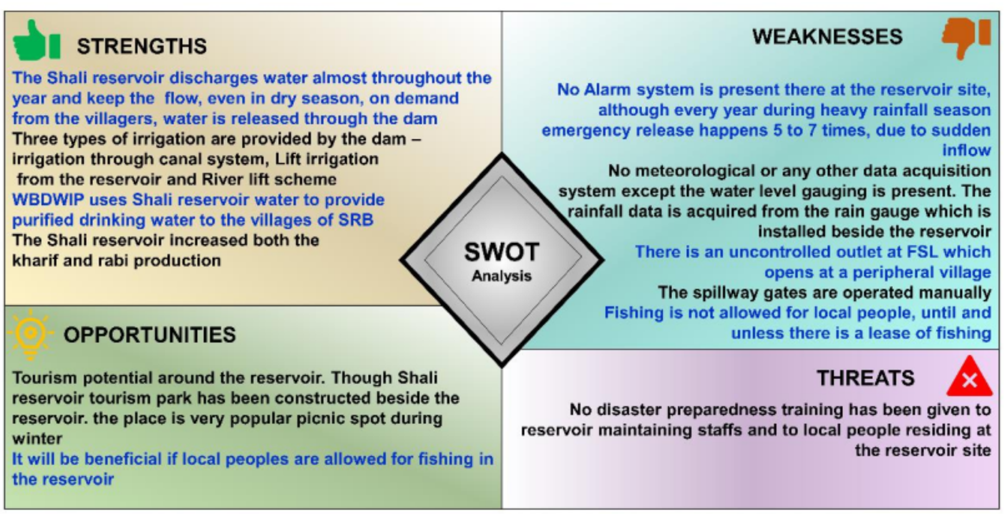

Figure 3.16 SWOT analysis of the Shali reservoir

3.10 Conclusions

The main objective behind the construction of the Shali reservoir was to deliver irrigational water throughout the year in the Shali River basin. The water level trend analysis discloses that the water level of the Shali reservoir has increased from 1990 to 2021. The seasonal water level trend analysis also depicts the same which signifies that in post-monsoon and winter seasons, the reservoir can provide an adequate amount of irrigational water for cultivation. The LR analysis has been applied to identify the correlation between the reservoir and river water levels. For this purpose, yearly NDWI values of the Shali reservoir and Shali River were extracted and the R^2 value displays a high-positive association between the reservoir and river.

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Transformations and future scenario of LULC

4.1 Introduction

Shali reservoir was constructed to convey water for irrigational usage in the Shali River basin area. The reservoir was constructed by the I&WD, GoWB. It was completed in 1985 and provides irrigational water through the Shali river. The previous chapter reveals that the Shali reservoir can provide irrigation water throughout the season. Therefore, RS and GIS procedures have been utilised to identify the temporal modifications of LULC after the construction of the Shali reservoir. LULC mapping has been carried out from 1986 to 2021, maintaining a five-year gap to perform a detailed study about the LULC change.

4.2 Concept of LULC

The land use and land cover (LULC) classifies, the topmost layer of the earth, LC specifies, natural and anthropogenic structures of the earth's surface, whereas LU signifies the anthropological actions on the land surface. Both the terms are interrelated, LU can transform the LC and the transformed LC can change the LU. Thus, LULC plays a valuable role in natural resource observation and conservation policies globally because of the unfavourable effects of LULC modifications nowadays. The changes in LULC influence physical parameters such as infiltration, groundwater recharge, surface runoff, land surface temperature, and air quality.

4.3 Definitions of LULC from various articles

LULC is a frequently used term in research, so the definition and meaning of LULC have to be understood for proper implication.

Anderson (1976) defined LU based on ground-related activities done by human beings, whereas, LC considers those attributes which cover the land surface like urbanised areas and vegetation cover.

Meyer and Turner (1992) described human employment as LU. Social scientists studied LU and physical scientists studied LC which covers the biotic and physical aspects of the land.

Lambin et al. (2000) outlined LU based on human purposes that signifies how and why humans are modifying the land and LC refers physical characteristics of lands.

Huang (2002) explained LU according to their usage: residential, commercial, manufacturing etc. whereas, LC refers to the actual attributes on land: water bodies, grasslands, soil cover etc.

Gregorio (2005) elucidated LU through the activities of people. Here, people modified a certain LC type for developmental purposes. While LC denotes physical attributes of the earth’s surface.

Roy and Giriraj (2008) explained LU based on their usage and activities, whereas LC means natural cover: forest, barren-lands, water-bodies etc.

Hasmadi (2009) clarified LU as what way people are modifying land resources and LC denotes physical condition of lands.

Longley (2010) simplified LU based on human occupancy and LC represents living and non-living attributes of earth surface.

Drummond and Loveland (2010) summarised LU according to land management measures taken by humans and LC refers status of physical features: barren-land, forest-covers, agricultural fields, lakes etc.

Verburg et al. (2011) referred to utilisation purposes of land as LU and LC refer to soil, vegetation etc.

Duhamel (2012) specified LU based on socio-economic causes: commercial, residential etc. whereas, LC describes the physical set-up of earth surface.

Huth et al. (2012) explained LU based on anthropogenic actions that modify land surface and LC describes vegetation cover, non-vegetated areas etc.

Sun and Schulz (2015) described people's engagement in the transformation of land as LU and the physical features mostly vegetation cover and types are considered as LC.

Ranjan et al. (2016) explained LU-based economic purposes that signify how people are using land for economic development and LC specifies physical attributes (forest-cover, man-made landscapes, soil etc).

Sreedhar et al. (2016) signified LU based on economical purposes and LC means existing natural attributes of earth surface.

Veeraswamy et al. (2017) referred to LU based on habitat usage, which means how people are using their habitat. while LC means the distribution of natural resources on earth.

Fritz et al. (2017) defined LU as how people are utilising observed physical attributes on land and LC means how physical attributes are utilised by people.

Pongratz et al. (2018) outlined LU based on chain of activities done by humans for economic development and LC denotes man-made structures, waterbodies, forest-cover, rocky surfaces etc.

Miheretu and Yimer (2018) defined LU that people modifying lands intentionally for economic development: settlement areas, agricultural land etc. and biophysical state of earth surface is considered as LC.

4.4 Literature review

The nature of LULC is multidisciplinary. The LULC assessment is very useful in natural resource management, wildlife habitat protection, agricultural land detection, crop health monitoring, urban expansion, damage delineation etc.

Reis (2008) analysed LULC change of Rize, North-East Turkey. They classified the study into three segments. In the first segment, the supervised classification method was applied to Landsat TM data sets (1976 and 2000). In the second segment, a pixel-by-pixel assessment was done to detect the LULC change from 1973 to 2002. In the third segment, the LULC changes were analysed with the topographic structures such as slope, and altitude.

The results showed a massive change in LULC, around 36% of agricultural lands were increased. Rapid urban growth was also observed. Whereas, pasture and forest areas decreased. They also mentioned that maximum LULC change occurred with the coastal areas because of having low slope value.

Mukherjee et al. (2010) examined the influence of the canal on LULC change in Punjab. The main objective was to identify the LULC modifications of Batla, Punjab because canal irrigation improved crop production. Landsat TM and IRS-1C datasets were incorporated into the study. They performed supervised classification with MLC. Studies revealed that without proper management water-logged areas were increased which increased the number of uncultivated lands. The study suggested the implementation of proper policies to enhance crop production.

Rehman et al. (2012) assessed the LULC of Delhi (North-West portion). The observed urban sprawl induced LULC changes in Delhi, so LULC change analysis of Delhi was very much needed to regulate the situation. LULC change analysis was performed from 1972 to 2003. They used the Aster image of 2003 and SOI toposheets of 1972 to detect modifications. The supervised classification method with MLC was applied for classifications. They classified the LULC maps into eight categories. The study showed a drastic change in LULC patterns, around 27% of agricultural land was decreased. Contrarily around 34% of the urban area was expanded. They mentioned rural-to-urban migration as the prime cause of this situation.

Zhao et al. (2012) examined LULC transformation in Lake Dianchi in China from 1974 to 2008. The study revealed that since 1974, LULC was changed greatly due to agricultural development. The development mainly occurred in adjoining areas of Lake Dianchi. Lastly, the dynamics of LULC change correlated with LULC policies and the economic development of China.

Pandian et al. (2014) mentioned that LULC assessment is very much important to understand the interaction between environment and human activities. They discovered the LULC change in the parts of the Coimbatore and Tirupur districts. They incorporated both satellite and toposheet data sets to detect LULC change from 2000 to 2009. The study revealed a major change in LULC patterns, agricultural lands were decreased extensively, whereas fallow lands and built-up areas were increased. The study observed the main reasons behind these modifications which are residential and industrial areas.

Rawat and Kumar (2015) observed LULC change in the Almora district, Uttarakhand. They studied LULC change from 1990 to 2010 and used Landsat Thematic Mapper (TM) data. Supervised classification was applied using an MLC classifier. They classified the LULC into five different classes: vegetation, water body, agricultural and waste-lands. Results indicated that during the study period forest covers and urbanised areas increased by ~4%. Meanwhile, water bodies, agricultural lands and barren lands decreased.

Singh et al. (2015) predicted and discovered LULC variations using the CA method in the highly urbanised city of Allahabad in India. For change detection, Landsat TM 1990 and 2000 data were used. The results showed rapid urbanisation occurred but the maximum part was under agricultural activities. Badlands and fallow lands decreased. They also mentioned that rural-to-urban migration was the main reason for built-up areas because the study area offers better education, business and job opportunities etc. CA model was used to replicate the LULC of 2020. The replicated result indicated that cultivable land will transform into fallow land, agricultural land and urbanised areas.

Gidey et al. (2017) projected and analysed future situations of LULC. They predicted the land use scenario of 2033 using CA and CA_Markov models. For the prediction analysis, the LULC data of 1984-1995, 1995–2005 and 1984–2015 datasets were used as baselines. Socio-economical and physical attributes were also used through Multi-Criteria Evolution (MCE) and fuzzy techniques to create change images. The predicted map of 2033 showed that forest lands 44%, bush lands 20%, urbanised regions 48% and greeneries 15% will be increased. Whereas, significant reductions will be noticed in water bodies, croplands, barren lands and floodplain areas respectively. Pearson correlation between historical land simulated LULC types showed a strong positive relationship. They also mentioned the study area will be benefited from the forest land but the reduction of water bodies can cause drought-like situations. This study will help to foster better decisions for sustainable development.

Rahman et al. (2017) detected temporal change in LULC and predicted LULC using the CA-ANN method of southwestern coastal Bangladesh from 1989 to 2015. Due to natural and anthropogenic reasons, the LULC pattern of Bangladesh's coastal region) was changed. change analysis revealed that around 21% of barren lands were decreased and the shrimp farms area increased ~25%, which indicated a foremost occupational alteration from farming to shrimp farms. Whereas, the amount of settlement areas decreased. The simulated map of 2028 also showed similar things. They discovered that varying LULC and occupational transformations from agriculture to prawn farming were correlated with each other. They also mentioned that internal migration was increased rapidly which should be regulated.

Gadrani et al. (2018) assessed the LULC change in Tbilisi areas from 1987 to 2016. Landsat-5 and 8 data sets were incorporated to detect changes. Digital image processing was applied to analyse the changes in LULC. The study observed a sharp rise in urbanised zones, around 13% of urbanised zones increased throughout the study period. They also suggested that decision-makers should apply proper management programmes to mitigate this situation. Guidigan et al. (2018) aimed to detect LULC changes and their impact in Benin Republic, West Africa. The study used a climate change initiative land cover product to detect the changes. Change analysis was performed from 2001 to 2013. A prediction analysis was also done to predict future LULC patterns for 2025 and 2037 respectively. The result showed a rapid increase in cropland.

Tantaei et al. (2019) monitored and predicted LULC alteration in Xinjiang-China (1990 to 2030). They used satellite images from 1990, 2000, 2005, 2010 and 2015 to conduct the study. They deployed OBIA (object-based) classification method to identify LULC changes. The CA-ANN process was applied to predict LULC for 2020, 2025 and 2030. The LULC change analysis discovered that forest cover, barren lands and water bodies were reduced whereas, croplands and urban lands were increased significantly. The prediction analysis showed that in 2030, forests and wetlands will be reduced drastically, while urban lands will be increased. Mohamed and Worku (2019) worked on LULC change in the Addis Ababa region of Ethiopia. They discovered the LULC change of the Addis Ababa region from 1984 to 2015 to detect the urban growth process. Due to the rapid increase of urbanised areas, greeneries and agricultural fields were reduced. They applied Shanonn Entropy Index and geospatial techniques to measure the pattern of urban expansion and urban growth rate as well. The study approved that urban growth has a negative impact on the study area. Therefore, the study emphasised a combined urban planning and management approach and quantify the urban intensity also.

Satya et al. (2020) simulated the future land use scenario of the Warangal city of Telangana. They applied Markov. Chain and CA to estimate future LULC in 2052. For this purpose LULC images from 2004, 2006 and 2018 were used. The predicted map revealed that the amount of built-up areas increased, while the agricultural lands decreased. They mentioned biophysical and socio-economic factors were responsible for this situation. Government initiatives should take place to control this situation.

Thonfeld et al. (2020) assessed LULC variations in the Kilambero catchment in Tanzania from 1974 to 2014 which is considered a notable place in East Africa. They assessed the LULC change in two parts, such as post-classification comparison and spectral Variation. detection. For LULC, the RF method was applied and for spectral change detection robust change vector analysis (RCVA) was applied. The results showed that around 1/4th of the catchment was not undergone any modification. Contrarily, 1/3rd showed both, spectral and LULC variations. The Kilombero is a floodplain area and a Ramsar-protected area. In the past decades, around 50% of the land was transformed into cultivated land. They also mentioned that rapid population growth was also detected which converted natural LC into anthropogenetic LU. They suggested regular LULC monitoring will help decision-makers to mitigate this problem.

Yatoo et al. (2020) monitored alterations of LULC in Ahmedabad city from 1976 to 2017. Future prediction analysis was also performed for 2027 using CA and ANN methods. They applied the Normalised Difference Vegetation Index (NDVI) and Normalised Difference Built-up Index (NDBI) to discover urban LULC changes. Results showed that around 156 km^2 of built-up areas were increased, whereas, urban vegetation and water bodies decreased. The predicted map showed that in 2027, the major portion of Ahmedabad city would cover by built-up areas.

Abbas et al. (2021) applied multitemporal RS datasets to detect modifications in LULC, from 1980 to 2020 in Greater Bay, China with a 10-year interval. They also predicted future LULC scenarios of 2030, 2040 and 2050 by using the CA-ANN approach. DEM, slope, population, road distance and city centre were used as parameters for the future prediction models. The study resulted that natural and socioeconomic issues were responsible for LULC change patterns. The prediction study showed that urban expansion will be increased and forest lands and croplands will be reduced.

Alam et al. (2021) studied spatial and chronological changes in LULC of the lower Ganga stretch from 1998 - 2018. They observed that floodplains were continually degraded and fragmented due to unsustainable LU. A supervised. classification. method. was. applied. to detect LULC changes. Change analysis revealed that from 1998 to 2018, the amount of agricultural fields and inland water-bodies were reduced significantly while, orchard, agricultural fallow, and bare lands were increased. In prediction analysis, they predicted the LULC for 2028 and 2038 respectively. The predicted result showed a continuously decreasing trend of agricultural land. The study suggested proper planning and management measures to mitigate the situation.

Frimpong and Molkenthin. (2021) traced the urban expansion of Kumasi Metropolis of Ghana using the RF method. They used Landsat (4-5 and 8) datasets from 1986 to 2015 to detect urban growth and also predicted the future LULC pattern for 2025. They applied change detection, urban land modelling, buffer analysis, density decay curve and correlation analysis to detect LULC changes. They also mentioned that RF classification produced better accuracy than another classifier. The result indicated that about 72% of urbanised zones were increased during the study phase. For prediction analysis, the Markov chain method was applied, and the predicted map showed that in 2025, the amount of built-up areas was increased to around 79%.

4.5 Data sources

Landsat satellite images have. been taken from. the USGS. Earth. Explorer. website (https://earthexplorer..usgs.gov/) to illustrate the periodical transformation in LULC. Images are taken from 1986 to 2021 and a five-year gap has been maintained. All the images are taken for the month of January because this time, cloud cover remains very low in this region. Both the Landsat 5 TM and Landsat 8 OLI data have been incorporated into this study. All the images are geometrically corrected with the WGS 1984 UTM Zone 45° N coordinate system (A1. Ch. 4.1).

4.6 Chapter outline

The entire study has been divided into five segments. In the first segment, LULC classifications are performed using supervised classification with the Random forest (RF) method from 1986 to 2021. In the second segment, change detection has performed from 1986 to 2006 and from 2006 to 2021. LULC change matrices are also developed. In the third segment, block-wise temporal LULC change and Block wise comparison of agricultural lands have been analysed. In the fourth segment, village-wise temporal changes in agricultural lands are shown. Lastly, in the fifth segment, the future scenario of LULC has been done employing the Cellular Automata (CA) approach. Here, the modules for LULC change evaluation (MOLUSCE), a QGIS plugin, has been used to simulate future LULC scenarios of 2031. The plugin requires some specific input data sets such as LULC maps for 2006 to 2021, DEM and transport networks of the study area (Figure 4.1).

4.7 Methods

4.7.1 Used Google Earth Engine (GEE) platform

GEE is a platform that helps users. in the scientific analysis. and visualization of geospatial datasets. GEE provides satellite imagery for geospatial analysis. It also has a data library for public usage that contains historical satellite images. Above 40 years of datasets are available in the public data archive. GEE also has an application programming interface and other tools to perform analysis of large datasets. The GEE code editor runs with a JavaScript application programming interface that requires a Google account. The GEE also provides an earth engine data catalogue (earth-engine/datasets/catalogue) which comprises a huge collection of Earth science raster datasets. The data catalogue includes the entire Earth-Resources Observation and Science (EROS) (USGS/NASA) Landsat data, Moderate Resolution Imaging Spectro-radiometer (MODIS) datasets, Sentinel datasets, National Agricultural Imagery (NAIP), Climate-Hazards Group InfraRed-Precipitation with Station-data (CHIRPS), digital. elevation. model. (DEM) data., sea surface temperature data etc. Users can import the datasets to perform various geospatial techniques (Figure 4.2) (Gorelick et al., 2017).

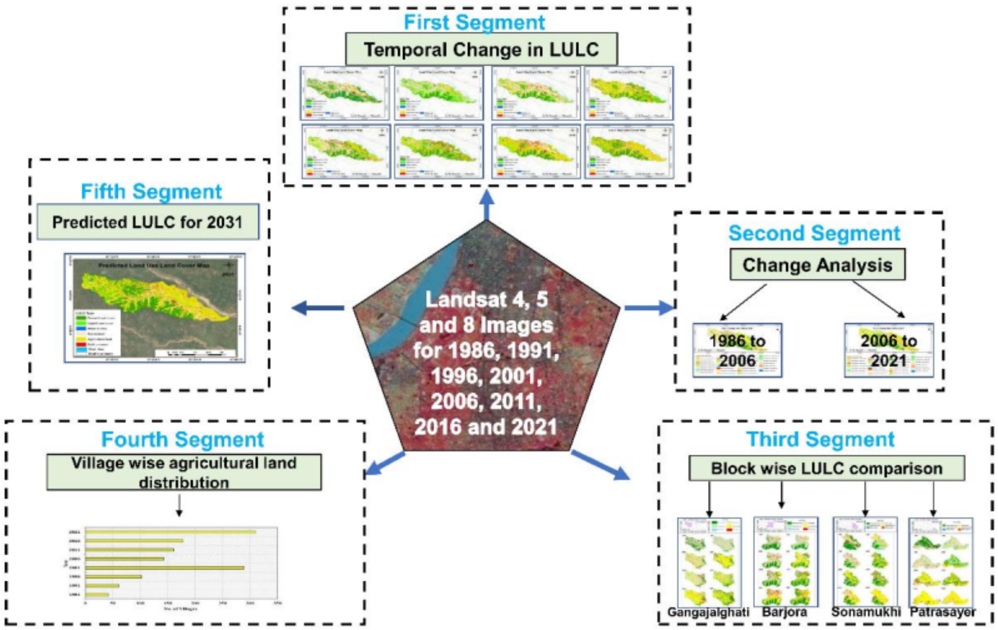

Figure. 4.1. Chapter layout

Figure 4.2 Elements of Google Earth Engine Code Editor

4.7.2 Random forest classifier

Breiman (2001) formulated the random classifier (RF) method. The RF classifier is a cluster of tree classifiers. Every tree classifier gives a unit vote based on training data sets to classify the extremely popular. datasets. An attribute selection measure is mandatory for the outline of the decision tree. There are many approaches available for the attribute selection measure but the Gini. Index. and information. gain. ratio. criterion. are the most popular method for the attribute selection measure (Rodreguez-Galieno et al., 2012; Pal, 2005; Belgieu and Drăgu, 2016).

The Gini Index possibly described in Eq. 4.1.

$$\sum \sum_{j\neq i} (f(C_i,T)/|T|)(f(C_j,T)/|T|) \qquad (4.1)$$

where, $f(C_i,T)/|T|$ is the possibility that the certain situation goes to class C_i.

Characteristics of random forest classifier

- It performs well on bulky data. bases.
- It. can. manage. thousands. of input. variables.
- It can predict the important variables for the classification.
- It calculates the proximity between the pair of cases that can be used in locating outliners.
- It is a comparatively lighter method than other tree ensemble methods.

4.7.3 Confusion matrix or error matrix

It is a quantitative method applied to measure the accuracy of remotely sensed image classification. It is a set of arrays (rows and columns) which signifies the error between the classified image and reference image in a matrix format (Campbell, 1987). It provides 3-types of accuracy such as producers. accuracy, users' accuracy and overall accuracy. Producer accuracy (Eq. 4.2) defines the corrected classified pixels, whereas users' accuracy defines (Eq. 4.3) the actual pixel category based on the ground. Lastly, the percentage of accurately classified pixels is considered as overall accuracy (Eq. 4.4).

$$\text{Producers' accuracy} = \frac{\text{Total number of correct pixels in a category}}{\text{Total number of pixels of that category derived from the reference data (i.e. row total)}} \times 100 \qquad (4.2)$$

$$\text{Users' accuracy} = \frac{\text{Total number of correct pixels in a category}}{\text{Total number of pixels of that category derived from the reference data (i.e. column total)}} \times 100 \qquad (4.3)$$

$$\text{Overall accuracy} = \frac{\text{Total number of corrected classified pixels}}{\text{Total number of pixels}} \times 100 \qquad (4.4)$$

4.7.4 Cellular Automata (CA)

CA is a gird-based model with compact space computation power. It's a distinct dynamic system where the neighbouring cells control the condition of every cell. It is a process that can pretend the chronological and spatial dynamics in two dimensions. The CA model has been applied in universal and regional activities equally. The global model is unable to effectively express a specific location because it assumes that the variables are equal, whereas in the local analysis, considering the communication strength of the cell, there is a mutual evaluation among the distinctive situations of cells within a neighbourhood. The communication power of the cell reduces with the rise in the distance between the cells (Mohamed & Worku, 2020). The CA model can be stated as addressed by (Eq. 4.5) (Muller & Middleton, 1994).

$$S_{t+i} \geq f\left(S_t, N\right) \tag{4.5}$$

where, S is a fixed, distinct position group of cells; N is the neighbouring cells; t and $t+i$ are distinctive moments, f is the cell conversion law of the regional space. In RS, the CA model has been incorporated to predict LULC classes (Lu et al., 2019).

4.8 LULC classification

The total span of the Shali River basin is around 727 km^2. with four blocks i.e. Gangajalghati, Barjora, Sonamukhi, and Patrasayer and 341 villages. It comprises six major types of LULC such as dense forest cover, light forest cover, water-bodies., barren lands., agricultural lands., and built-up. areas. The entire. classification. was performed using GEE cloud-based performance and the samples were trained by the random forest classifier method which is known as the most accurate remote sensing classifier. The LULC maps have been prepared from 1986 to 2021 by maintaining a five-year gap.

Table 4.1 Delineation of LULC types

LULC classes	Delineation
Dense forest cover	Land that is covered by natural forests covers like evergreen forests, deciduous forests, open shrubs etc.
Light forest cover	Land that is covered with grasslands.
Water bodies	Surface water bodies like lakes, ponds, reservoirs, tanks, canals, rivers etc.
Barren land	Exposed rocks, sandy areas, river banks etc
Agricultural land	Crops like paddy, wheat, orchards, plantations etc
Built up areas	Industrial and commercial areas, residential areas, roads etc.

4.8.1 LULC in 1986

In 1986, the Shali reservoir was completed. At that time, the Shali River basin was covered by dense forest areas. The basin has numerous protected forests such as Beliatore, Sonamukhi, Pastol, Gangabandh, Gangajalghati, etc. The varieties of forest types are open mixed jungle, fairly mixed jungle and dense mixed jungle. The north-western. and southern portions of the Shali River basin are masked through protected forest sal (Shorea robusta), eucalyptus (Eucalyptus globulus), akashmoni (Acacia auriculiformis), sonajhuri (Earleaf acacia), mahua (Madhuca longifolia), palash (Butea monosperma) and open shrubs, etc. In 1986, around 296 km^2 of the area of dense forest cover. Mainly, the southern segment of Shali River basin was covered with dense. forest. cover. Light forest cover or grasslands were found all over the basin. It covers only a 31 km^2 area. Water bodies covered only a 2.76 km^2 area. Except for forest cover, most of the land was under barren land, around 359 km^2 area was under barren land. Meanwhile, around 22 km^2 of land was used for agricultural land. Agricultural lands were mainly concentrated in the north-eastern portion of Shali River basin under Barjora and Sonamukhi blocks. The amount of built-up area was around 14 km^2. Only one cluster type of settlement was observed in the Sonamukhi block beside the Shali river (Figure 4.3).

4.8.2 LULC in 1991

In 1991, a rapid change was observed in LULC in the Shali River basin area. In 1991, the amount of dense forest cover was reduced to 104 km^2. Meanwhile, the amount of light forest cover was increased to 244 km^2. The density of forest cover was reduced which made them light forest covers. In 1986, the southern segment of Shali River basin was concentrated with dense forest cover but in 1991, these portions were turned into light forest cover. Although several new randomly placed light forest cover patches were detected in the basin. The amount of water bodies also increased to 9.62 km^2. Surprisingly, the amount of barren land was reduced to 294 km^2 and agricultural lands was increased to 50 km^2. The concentration of agricultural lands in the northern and north-eastern portions was increased. Along the shali river, agricultural lands were also observed. Therefore, after the creation of the Shali reservoir, in 1991, slight progress in agricultural activities was observed in the Shali River basin area. Built-up areas were also increased, with around 23 km^2 area under built-up areas. In 1986, only one compact settlement was observed but in 1991 several semi-compact settlement areas were observed (Figure 4.4).

4.8.3 LULC in 1996

In 1996, the status of forest cover was improved, around 120 km^2 of the area was under dense forest cover. A drastic change was observed in light forest cover, a huge amount of light forest cover was reduced from 1991 to 1996. About 122 km^2 area was covered by light forest cover. The edges of the dense forest cover turned into light forest cover. In 1991, the eastern portion of Shali River basin comprised light vegetation cover but in 1996 those places were replaced by barren lands.

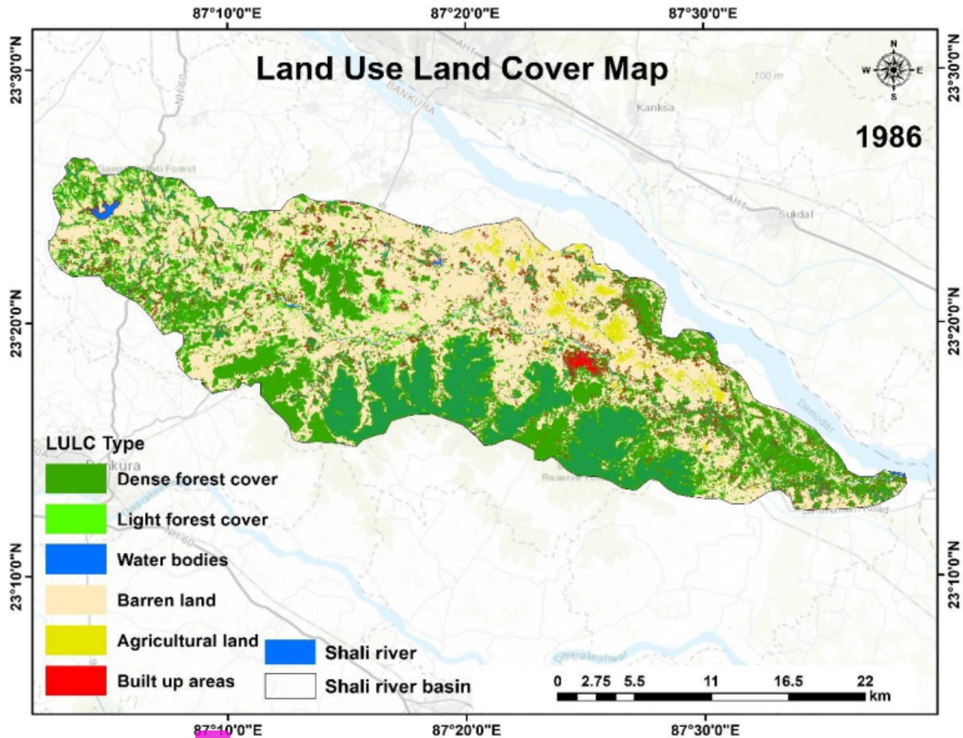

Figure 4.3 LULC map of Shali River basin in 1986

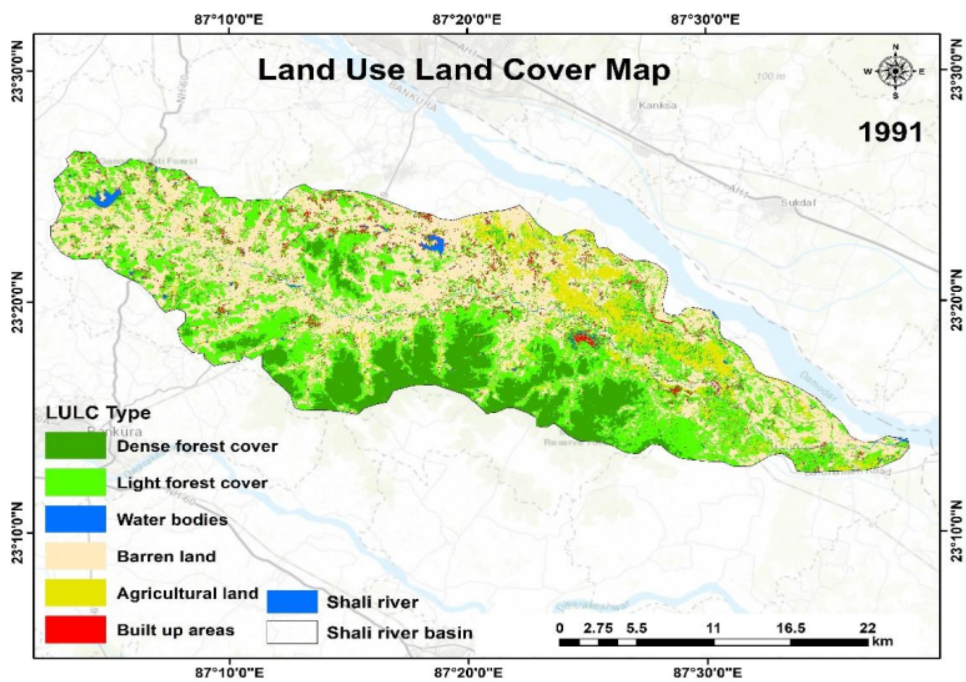

Figure. 4.4 LULC map of the Shali River basin in 1991

Therefore, during 1996, the amount of barren land also increased, around 363 km^2 of the area was under the barren-land category. While the amount of agricultural land increased. From 1986 to 1991, agricultural activities were concentrated only north and north-eastern portions of Shali River basin, but in 1996, the upper segment (western) of Shali River basin comprised more agricultural land than the eastern portion. Built-up areas also increased from 23 to 26 km^2. Several semi-compact types of settlements were observed in the northern portion of Shali River basin concentration of urban areas was more found in the lower portion than the upper segment of Shali River basin (Figure 4.5).

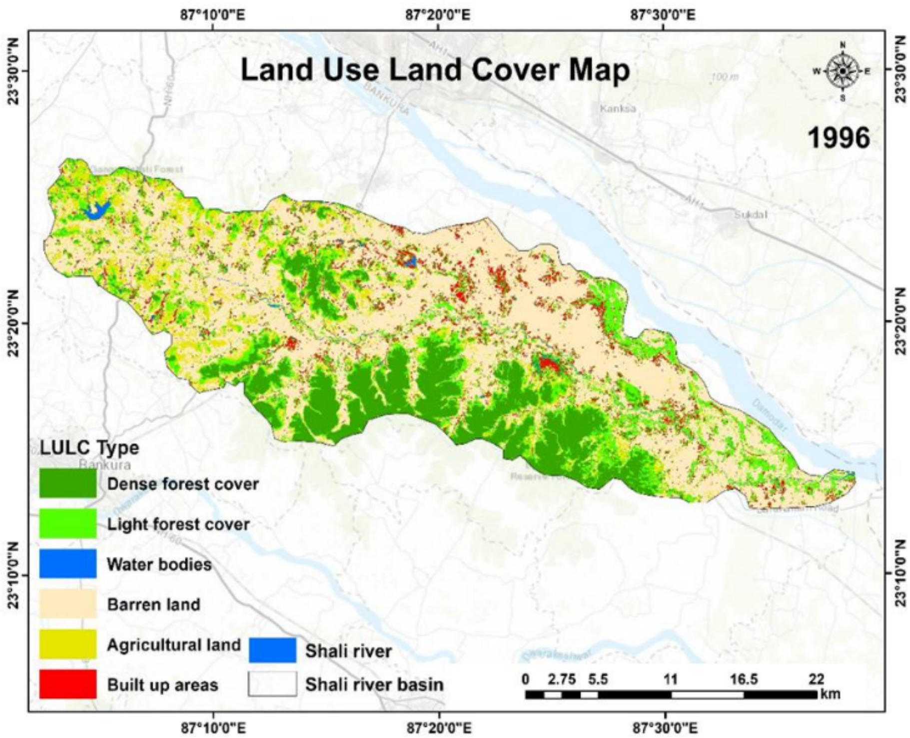

Figure 4.5 LULC map of Shali River basin in 1996

4.8.4 LULC in 2001

In 2001, a huge transformation was noticed in the LULC of the Shali River basin. The dense forest cover area was increased to 211 km^2 and the southern part of Shali River basin was covered with the dense forest cover. In the middle portion, a dense forest cover patch was observed. In 2001, only 37 km^2 of the area was under light forest cover. The lower portion of Shali River basin comprised light forest cover and some patches were also found in the northern portion of Shali River basin. Consequently, the amount of barren land was also reduced. In 2001, around 106 km^2 area was under the barren land category. Agricultural lands were replaced by barren lands. Rapid growth in agricultural land was noticed in 2001, around 349 km^2 area of Shali River basin was under agricultural land. Except for tiny patches in the western and northern portions, the Shali River basin was under agricultural land. Built-up areas also increased but not at the same rate as agricultural land. In 2001, around 28 km^2 of area was under the built-up category (Figure 4.6).

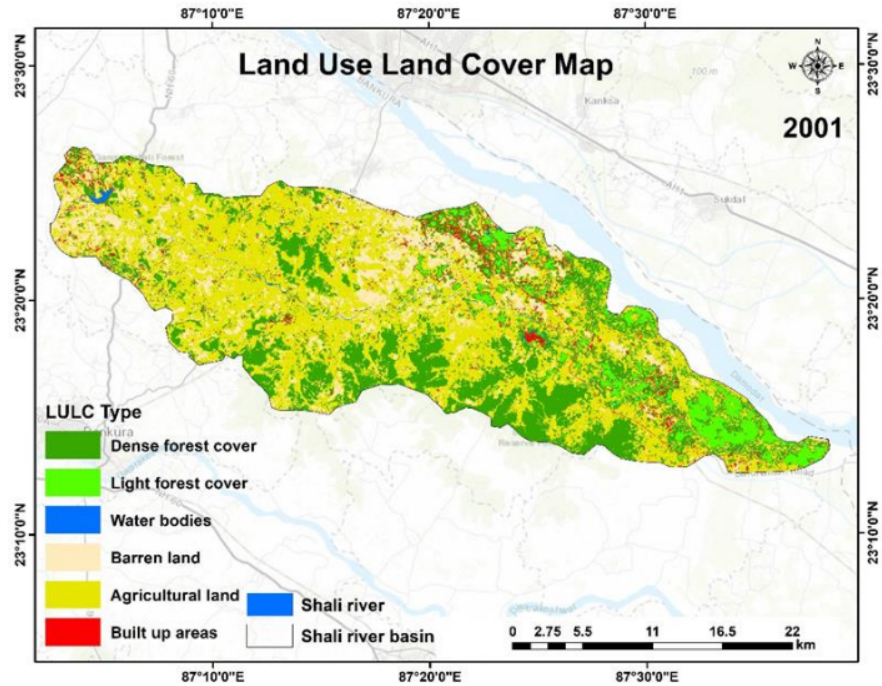

Figure 4.6 LULC map of Shali River basin in 2001

4.8.5 LULC in 2006

In 2006, forest cover transformation was observed again. The amount of dense forest cover was reduced to 189 km^2. Whereas, light forest cover was increased to 49 km^2. In 2006, patches of light forest cover were detected in the western portion of Shali River basin. The number of water bodies also increased. In 2006, again the barren lands increased to 265 km^2. which reduced the agricultural lands. Around 181 km^2 of the area was occupied by agricultural lands. Mainly, north and. north-eastern. portions of Shali River basin were under agricultural land and a few patches of agricultural land were also found in the upper portion of Shali River basin. Along, Shali river agricultural lands were also observed. The built-up area increased to 32 km^2. Scattered to semi-compact built-up patches were spotted in the northern portion of Shali River basin (Figure 4.7).

4.8.6 LULC in 2011

In 2011, growth in dense forest cover was observed, about 241 km^2 of the area was under dense forest cover. Except for the southern portion, many dense forest cover patches were found in the northern and eastern portions along with agricultural lands. The amount of light forest cover also increased to 62 km^2.

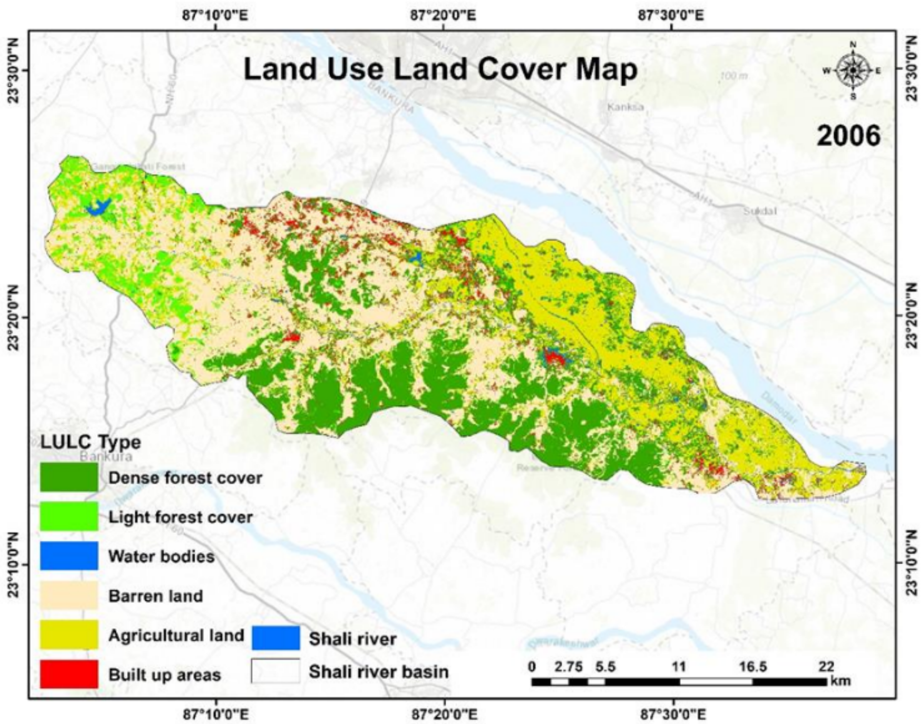

Figure 4.7 LULC map Shali River basin in 2006

Newley formed light forest cover patches was observed between dense forest cover in the southern portion of Shali River basin. Though, the light forest cover areas were mostly concentrated in the western part of Shali River basin. The number of water bodies decreased to 4 km^2. In 2011, a considerable reduction was noticed in the barren land. The amount of barren land was reduced to 137 km^2. The barren lands were only visible in the few spots of the upper, middle and eastern portions of Shali River basin. Meanwhile, a huge portion of Shali River basin was comprised of agricultural land, and around 244 km^2 area was under agricultural land. Dense agricultural lands were observed in the northern and eastern portions of Shali River basin and medium-dense agricultural land was found in upper portion of Shali River basin. Alongside the river agricultural lands were also spotted. In the built-up area segment, several compact settlement patches were found throughout the basin, maximum found in the northern portion and eastern portion, around 37 km^2 of land was observed under the built-up area category (Figure 4.8).

4.8.7 LULC in 2016

In 2016, the amount of dense forest cover was reduced to 118 km^2. Agricultural lands and barren lands were replaced by dense forest covers. During 2016, the dense forest covers were transformed into light forest covers and the amount of light forest cover was increased, around 66 km^2 area was under the light forest cover region (Figure 4.9).

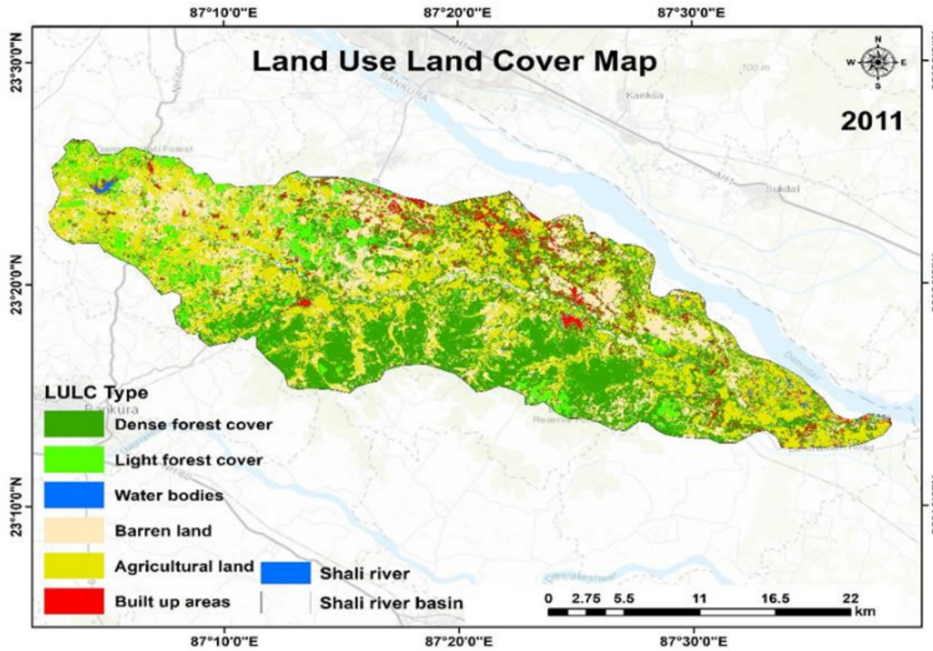

Figure 4.8 LULC map of Shali River basin in 2011

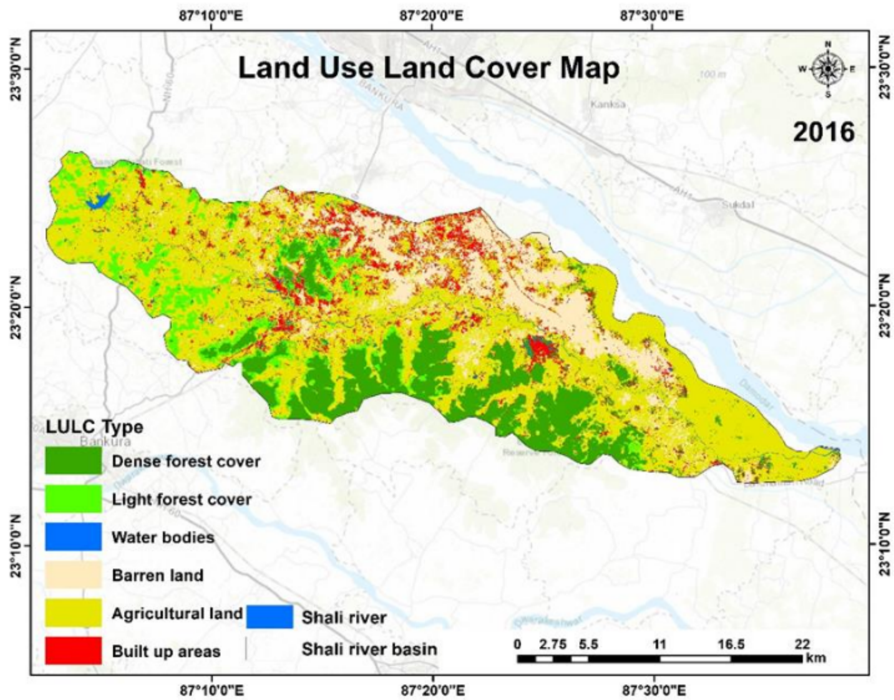

Figure 4.9 LULC map of Shali River basin in 2016

The upper portion of Shali River basin was concentrated with light forest cover. The proportion of waterbodies increased slightly. Barrenlands were reduced to 110 km^2 in 2011. The barren lands were only visible in a few spots of the upper, middle and eastern portions but in 2016 barren lands were assembled in the middle and northern portions of Shali River basin. Agricultural land increased, around 386 km^2 area was under agricultural land. Except for the northern portion dense agricultural lands were observed throughout the Shali River basin. In. built-up area category, the amount of built-up area also increased ~39 km^2 as was observed under the built-up category. In 2016, very prominent built-up patches were noticed all over the basin. Mostly, the northern portion of Shali River basin was occupied by built-up areas. Along the Shali riverside several newly formed built-up patches were observed.

4.8.8 LULC in 2021

In 2021, again the growth in dense forest cover was observed, around 207 km^2 area was under dense forest cover. In 2016, the dense forest cover areas were transformed into light forest cover areas but in 2021, those areas were turned into dense forest areas again. This time the upper portion of Shali River basin was also covered up with dense forest cover. Consequently, an abrupt loss in light forest cover was observed. Only 12 km^2 area was under light forest cover. Water bodies were also reduced by 3.41 km^2. meanwhile, a huge amount of barren land was reduced, ~58 km^2 area were found under the barren land category. Very few patches of barren land were found along the Shali riverside and the middle portion of Shali River basin. In 2021, barren lands were transformed into agricultural lands. The proportion of agricultural land increased, around 403 km^2 area was found under the agricultural land category. Along the agricultural land, built-up areas also increased, about 42 km^2 areas were found under the built-up category. North, north-eastern and eastern portions of Shali River basin were comprised of built-up areas. The lower part of Shali River basin was concentrated with maximum built-up areas than the upper portion. Shali river-side linear settlement patterns were also observed in the Shali River basin (Figure 4.10).

The temporal variations of LULC of the Shali River basin show that after the creation of the Shali reservoir agricultural activities have been intensified here. Positive growth in agricultural land from 1986 to 2021 has been observed. In 1986, the construction of the Shali reservoir was completed. Therefore, only 3% of the land was under agricultural activities. In 1991, the agricultural land increased to 7%. In 1996, around 12% area was under agricultural land. Whereas, massive growth in agricultural land was noticed in 2001, around 46% of the land was under agricultural land. In 2006, the proportion of agricultural land declined, around 24% of the land was found under agricultural land. Then, in 2011, the amount of agricultural land increased again, around 33% of the land was enclosed by agricultural lands. Whereas, in 2016 rapid growth was observed, around 53% of the land was agricultural land. Finally, in 2021, a slight growth in agricultural land has been identified, around 55% of the land is agricultural land. So, the Shali reservoir has enhanced the agricultural productivity of this region. The growth of agricultural land was not the same from 1986 to 2021. It fluctuates because the water level of the reservoir was not the same it varies according to rainfall (Figure 4.11) (A1. Ch. 4.2).

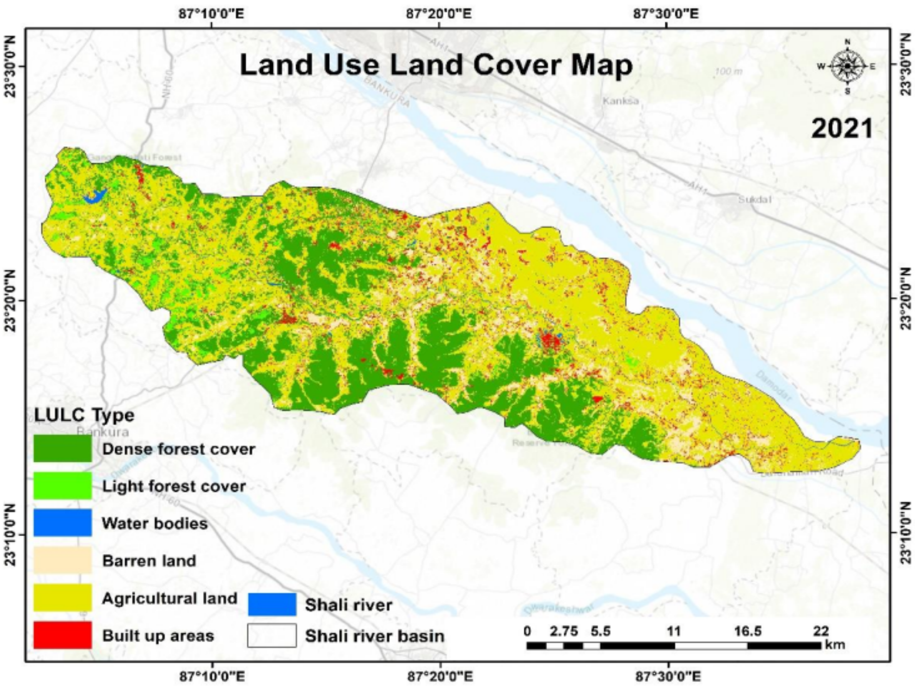

Figure 4.10 LULC map of Shali River basin in 2021

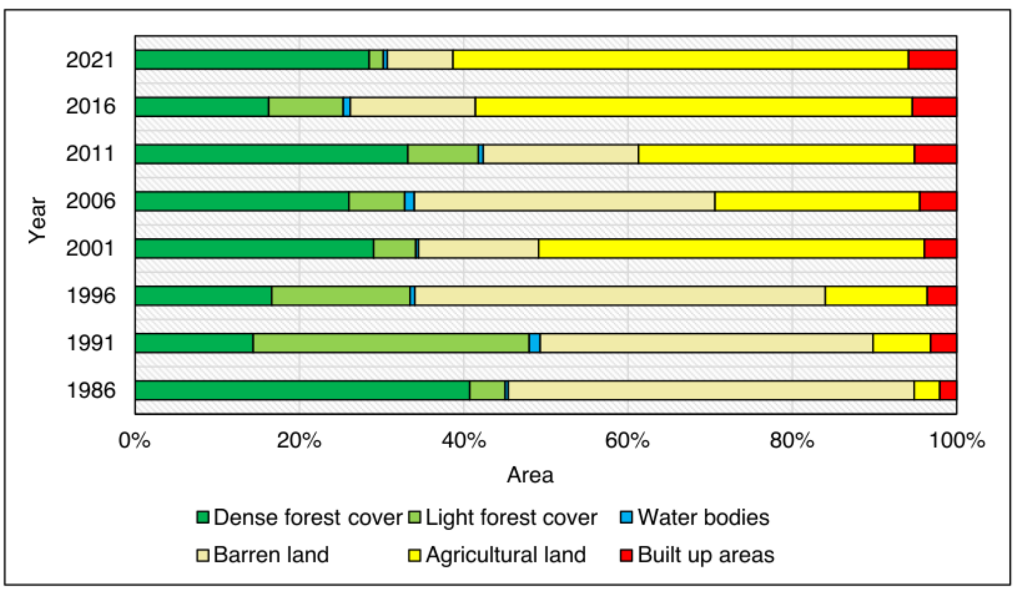

Figure 4.11 Temporal variation in LULC

4.9 Accuracy Assessment

In remote sensing, an accuracy assessment has been performed to validate the classification with some reliable data sources. In this study, around 50 points have been taken from the vegetation cover classification. Google Earth has been used to validate these points. Here, Cohen Kappa statistic measures have been used to find the inter-reliability between the variables. The Kappa statistics vary from 0-1, where, 0 = agreement corresponding to possibility, 0.13-0.201 = insignificant agreement, 0.211-0.401 = reasonable agreement, 0.411-0.60 = modest agreement, 0.611-0.801 = considerable agreement, 0.811-0.999 = near-absolute agreement, 10 = absolute agreement (According to Cohen Kappa, 1960).

Here, all the Kappa coefficient values lie between the 0.81 to 0.99 category, which indicates near absolute agreement corresponding to Cohen Kappa statistics.

Table 4.2 Accuracy assessment of LULC classification

LULC Classes	1986		1991		1996		2001		2006		2011		2016		2021	
	PA (%)	UA	PA (%)	UA	PA (%)	UA	PA (%)	UA	PA (%)	UA	PA (%)	UA	PA (%)	UA	PA (%)	UA
Dense forest cover	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Light forest cover	96	95	97	98	96	97	95	98	97	100	100	100	100	100	100	100
Water bodies	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Barren land	89	90	92	91	94	93	94	95	90	89	91	92	94	96	95	94
Agricultural land	90	88	91	93	95	93	98	96	93	91	90	91	94	95	92	93
Built up areas	85	87	86	88	87	81	83	81	79	86	87	85	89	90	87	88
Overall accuracy (%)	88		91		94		96		95		97		98		98	
Kappa coefficient	0.91		0.93		0.93		0.94		0.96		0.95		0.97		0.97	

4.10 LULC change analysis

Shali reservoir plays a significant role in transformation in LULC of Shali River basin. Here, change assessment is performed in. two segments: LULC changes from 1986 to 2006 and 2006 to 2021 (A1. Ch. 4.3).

4.10.1 LULC changes from 1986 to 2006

In the first segment, a 20-year of change analysis has been performed. Figure 12 shows the LULC change map from 1986 to 2006. Here, dark colours show the unchanged LULC types and light colours show the changed LULC types. This analysis also shows the transformation of LULC, for example, dense forest covers are transformed into agricultural lands, etc. The results reveal that from 1986 to 2006, around 14% of dense forest cover has been reduced, while around 2% of light forest cover increased. A very minimum percentage (~1%) of water bodies increased. In the barren land category, ~12% of the barren-land is reduced. Meanwhile, rapid growth in the agricultural land categories has been observed; around 21% of agricultural land has increased from 1986 to 2006 in the Shali River basin. Along with agricultural land, built-up areas have also increased, around 2% of the land increased in the built-up areas category (Figures 4.12-4.13 and Table 4.3).

A LULC change matrix has also been performed to give clarity on the modifications in LULC from 1986 to 2006. It reveals that a huge transformation occurred in LULC from 1986 to 2006, around 56.7 km^2 of dense forest cover are transformed into agricultural land, and around 7 km^2 of light forest cover area changed into agricultural land. In the barren land category, around 92 km^2 is converted into agricultural land.

Table 4.3 Change matrix from 1986 to 2006 (in km^2)

LULC types	Dense forest cover	Light forest cover	Water bodies	Barren land	Agricultural land	Built-up areas	Total 2006
Dense forest cover	**147.38**	2.87	0.05	31.30	8.22	0	189.18
Light forest cover	24.72	**3.65**	0.19	15.50	1.39	0	49.41
Water bodies	0.94	0.02	**1.98**	5.17	0.05	0	8.57
Barren land	55.19	15.55	0.36	**196.41**	0.88	0	265.99
Agricultural land	56.70	7.85	0.05	96.95	**11.89**	0	181.25
Built-up areas	11.17	1.41	0.10	13.83	0.37	**14.82**	32.6
Total 1986	296.14	31.35	2.73	359.12	22.77	14.82	727.00

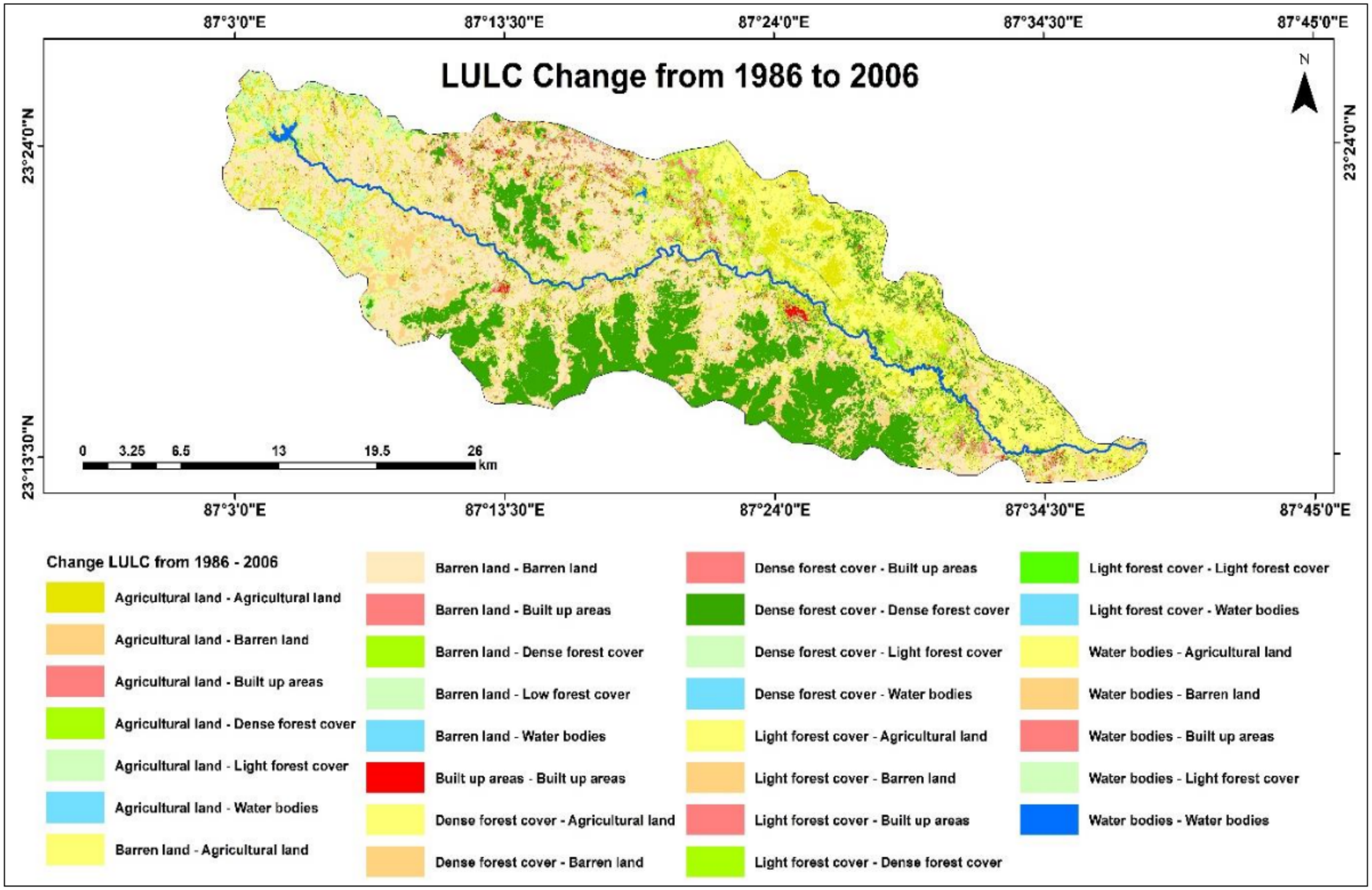

Figure 4.12 LULC changes from 1986 to 2006

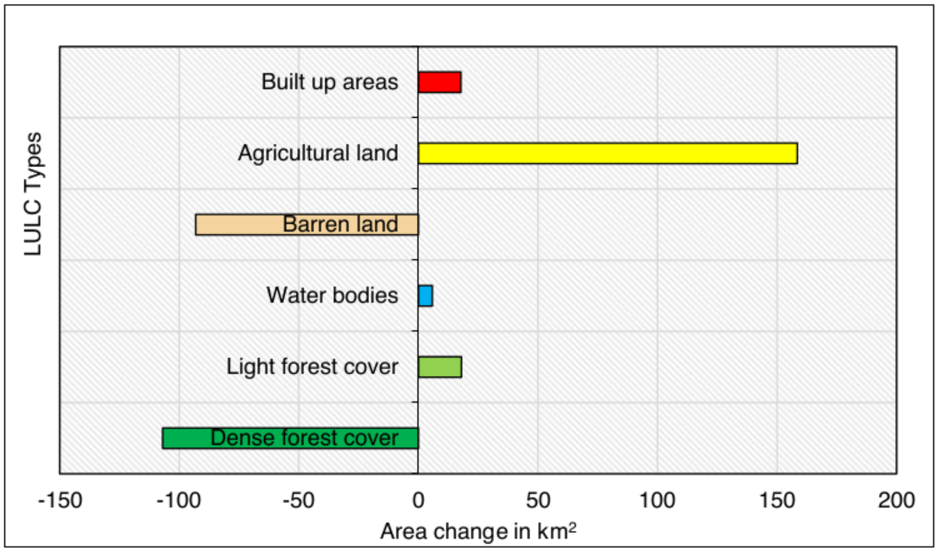

Figure 4.13 Area change in LULC from 1986 to 2006

4.10.2 LULC changes from 2006 to 2021

In the second segment of LULC change analysis 15-year change, analysis has been performed. In this segment, dense forest cover, built-up and agricultural lands are increased. Within 2006 and 2021, around 2% of dense vegetation areas are increased whereas, 5% of light vegetation cover decreased. A significant change in barren land has also been observed, around 28% of barren lands are reduced. Agricultural development also occurred in this segment, around 30% of agricultural land has increased. Long agricultural land and built-up areas are also increased.

In the second segment of change classification (2006 to 2021), positive changes in agricultural land and built-up areas are observed. In this segment, around 53 km^2 of dense forest cover area has been converted into agricultural land and around 21 km^2 of light forest area is changed into agricultural land. A massive transformation in the barren land category has been observed, with around 169 km^2 converted into agricultural land (Figures 4.14-4.15 and Table 4.4). Therefore, it can be said that the maximum amount of modifications in LULC happened between 2006 to 2021. The amount of agricultural land increased from 1986 to 2006 but the growth rate is lower than that from 2006 to 2021.

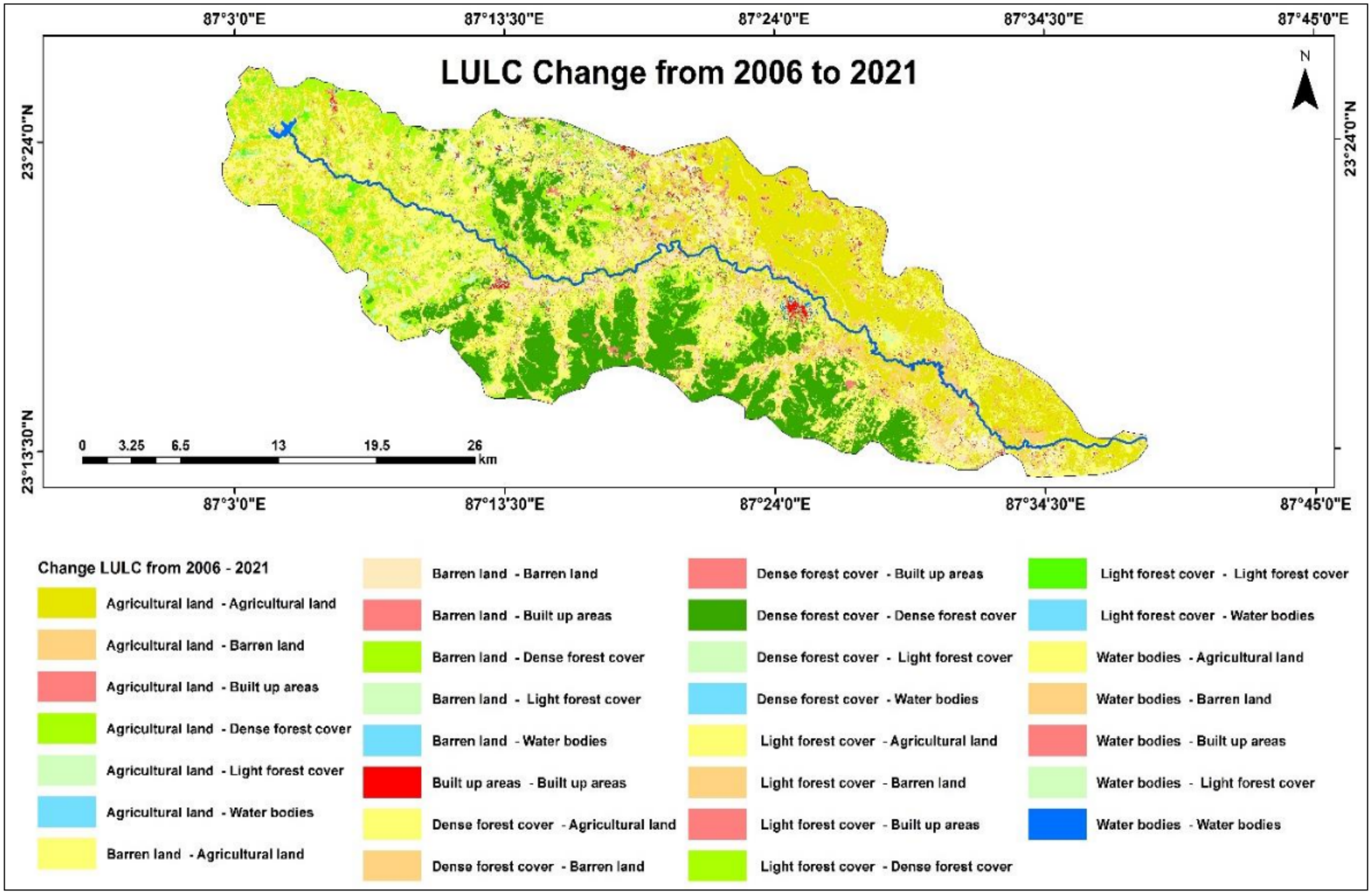

Figure 4.14 LULC changes from 2006 to 2021

Table 4.4 Change matrix from 2006 to 2021 (in km^2)

LULC types	Dense forest cover	Light forest cover	Water bodies	Barren land	Agricultural land	Built up areas	Total 2021
Dense forest cover	**117.63**	21.03	0.96	44.12	14.01	0	207.2
Light forest cover	1.58	**4.43**	0.02	4.88	1.46	0	12.59
Water bodies	0.21	0.24	**2.15**	0.17	0.50	0	3.41
Barren land	8.65	1.57	0.48	**35.73**	18.85	0	58.2
Agricultural land	53.77	20.16	4.55	169.63	**140.80**	0	403.09
Built up areas	7.23	1.92	0.37	12.30	5.64	**32.6**	42.51
Total 2006	189.18	49.41	8.57	265.99	181.25	32.6	727.00

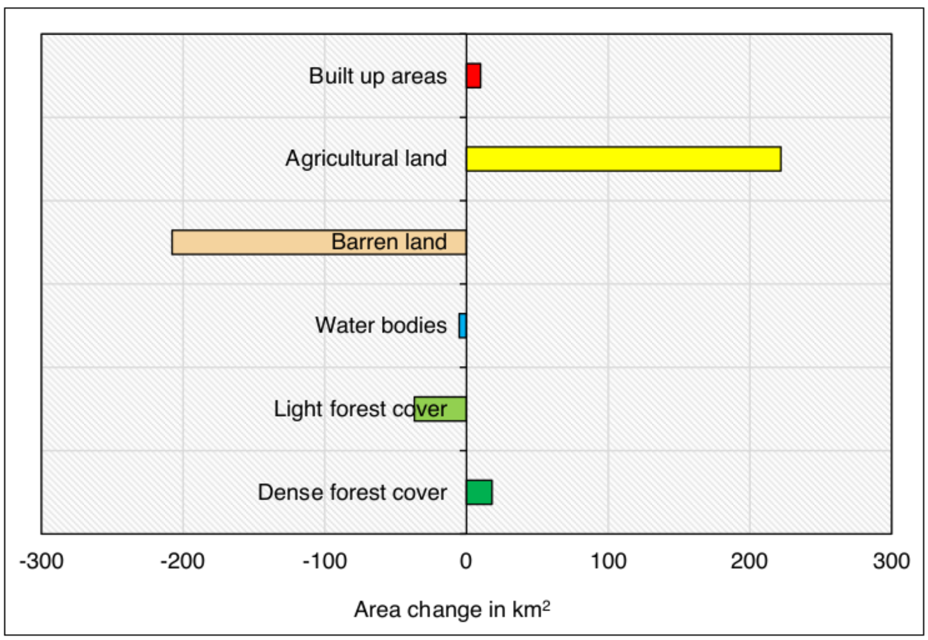

Figure 4.15 Area change in LULC from 2006 to 2021

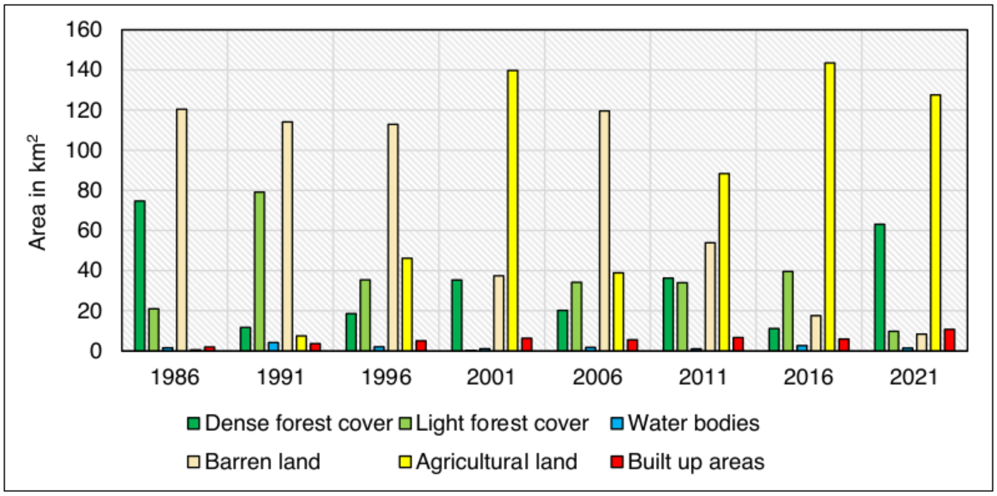

Figure 4.16 Area-wise temporal modification in LULC of the Gangajalghati block

4.11 Block-wise LULC pattern

The Shali River basin consists of four blocks such as Gangajalghati, Barjora, Sonamukhi and Patrasayer. Here, block-wise LULC comparison has also been performed to detect which blocks have the maximum amount of agricultural land (A1. Ch. 4.4). The sequential LULC map of Gangajalghati shows that from 1986 to 2006, a negative change was observed in the dense forest cover category, around 54 km^2 of dense forest cover was reduced from 1986 to 2006. Although from 2006 to 2021, a positive change in dense forest cover was noticed, around 42 km^2 of dense forest cover area was increased. In the light forest cover category, ~13 km^2 area was increased from 1986 to 2006 but from 2006 to 2021 a massive reduction was observed and ~24 km^2 of light forest cover area was reduced. An immense transformation was detected in the barren land category, from 1986 to 2006, only 0.8 km^2 of barren land was reduced but from 2006 to 2021 about 111 km^2 of barren land was decreased. Agricultural land increased from 1986 to 2021, from 1986 to 2006, around 38 km^2 and from 2006 to 2021 around 92 km^2 agricultural lands increased. Built-up areas also increased, around 8 km^2 built-up area was increased throughout the study period (Figures 4.16-4.17).

4.11.2 Barjora Block

In 1986, around 96 km^2 area of Barjora block was under dense forest cover but in 2006, the amount of dense forest cover was around 84 km^2. Whereas between 2006 and 2021 a positive change in dense forest cover was observed, and around 6 km^2 area was increased. Consequently, the amount of light forest cover increased by around 0.9 km^2 from 1986 to 2006 but from 2006 to 2021, around 6 km^2 of light forest cover was reduced. A negative change in barren land was noticed throughout the study period.

4.11.1 Gangajalghati block

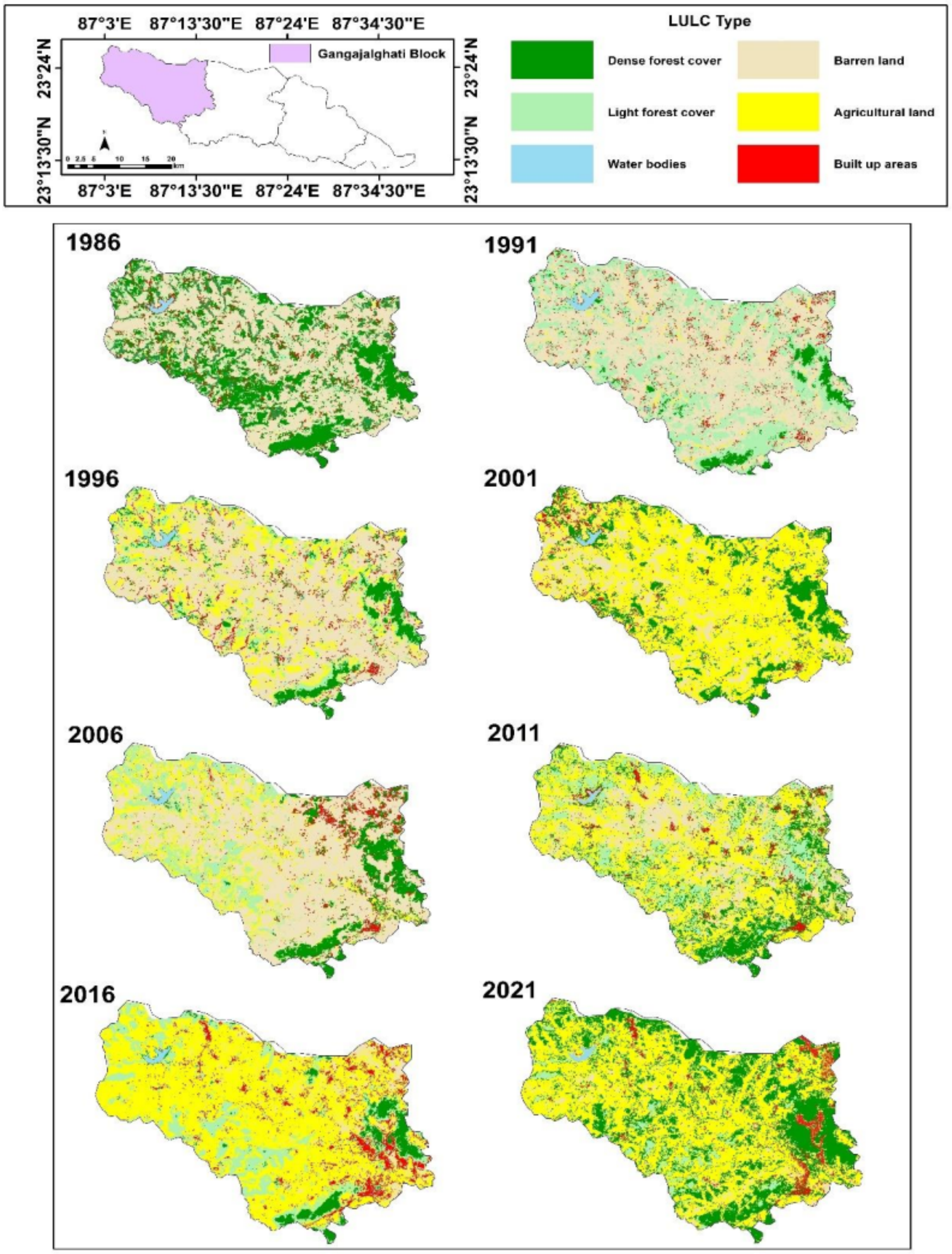

Figure 4.17 Temporal variation of LULC in Gangajalghati block

From 1986 to 2006 around 28 km^2 of barren land was reduced, while from 2006 to 2021 the amount of reduction of barren land increased, and around 73 km^2 of barren land was reduced. Positive growth in agricultural land was noticed from 1986 to 2021 in the Barjora block. From 1986 to 2006 around 33 km^2 of agricultural land was increased. Whereas, from 2006 to 2021, an enormous change in the agricultural land was observed, around 66 km^2 of area was increased in the agricultural land category. In the category of built-up area, positive change was also noticed, around 13 km^2 of built-up area increased from 1986-2021 in Barjora block (Figures 4.18-4.19).

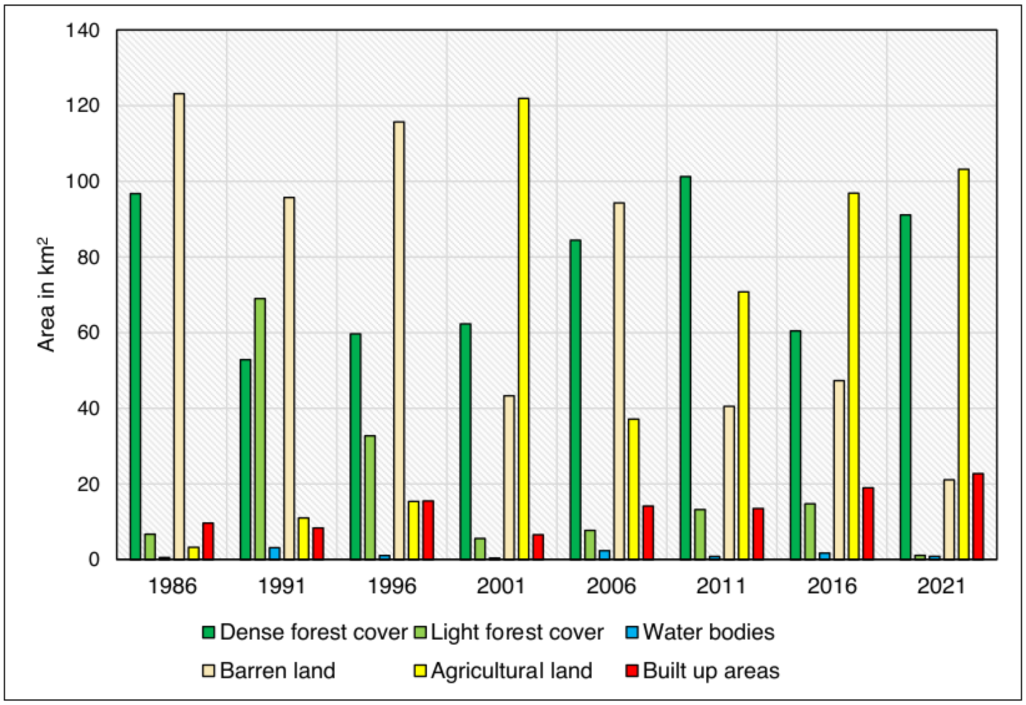

Figure 4.18 Area-wise temporal modification in LULC of Barjora block

4.11.3 Sonamukhi block

In the Sonamukhi block, a reduction in dense forest cover has been noticed throughout the study period. In 1986, around 94 km^2 area of Sonamukhi block was under the dense forest cover category, while in 2006, amount of dense forest cover was reduced to 66 km^2. That revealed that around 27 km^2 of dense forest cover was reduced from 1986 to 2006. The rate of dense forest cover loss increased from 2006 to 2021, around 34 km^2 of dense forest cover loss was observed in the Sonamukhi block. In the light forest category, around 2 km^2 of forest cover was increased between 1986 and 2006 but, from 2006 to 2021 around 4 km^2 of light forest cover was reduced. In the Sonamukhi block, the maximum proportion of barren land was reduced from 1986 to 2006, around 48 km^2 of land was reduced that time. While from 2006 to 2021, only 8 km^2 of barren land was reduced.

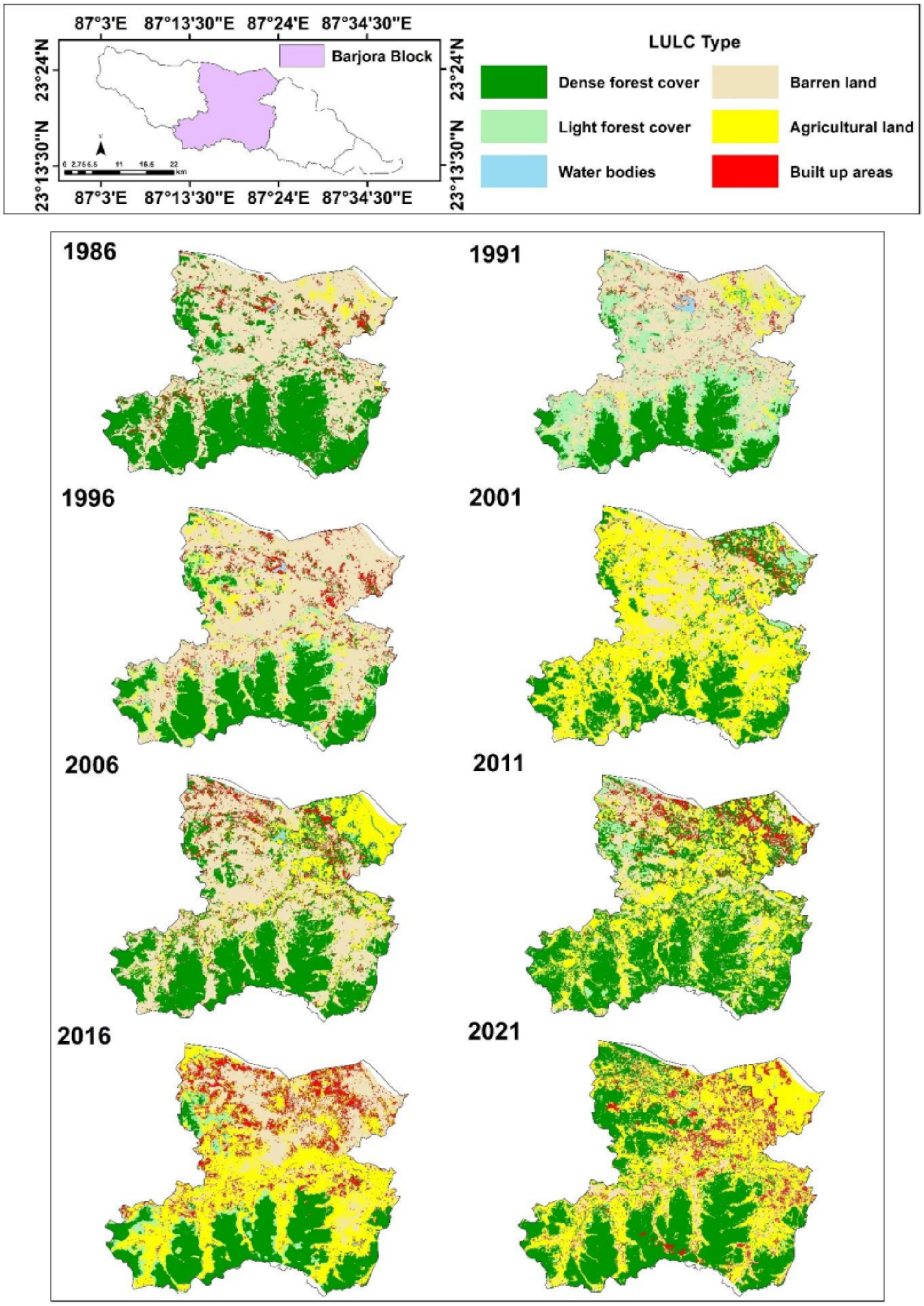

Figure 4.19 Temporal variation of LULC in Barjora block

The temporal modifications in LULC of the Sonamukhi block revealed that agricultural land has had positive change throughout the study period. A very high positive change in agricultural land was noticed from 1986 to 2006, around 65 km^2 of agricultural land was increased. But from 2006 to 2021 the agricultural land increased but not as much as from 1986 to 2006. Around 39 km^2 of agricultural land was increased from 2006 to 2021. In the Sonamukhi block, a positive change in built-up area was recognised throughout the investigation, around 10 km^2 of built-up area was increased from 1986 - 2021 (Figures 4.20-4.21).

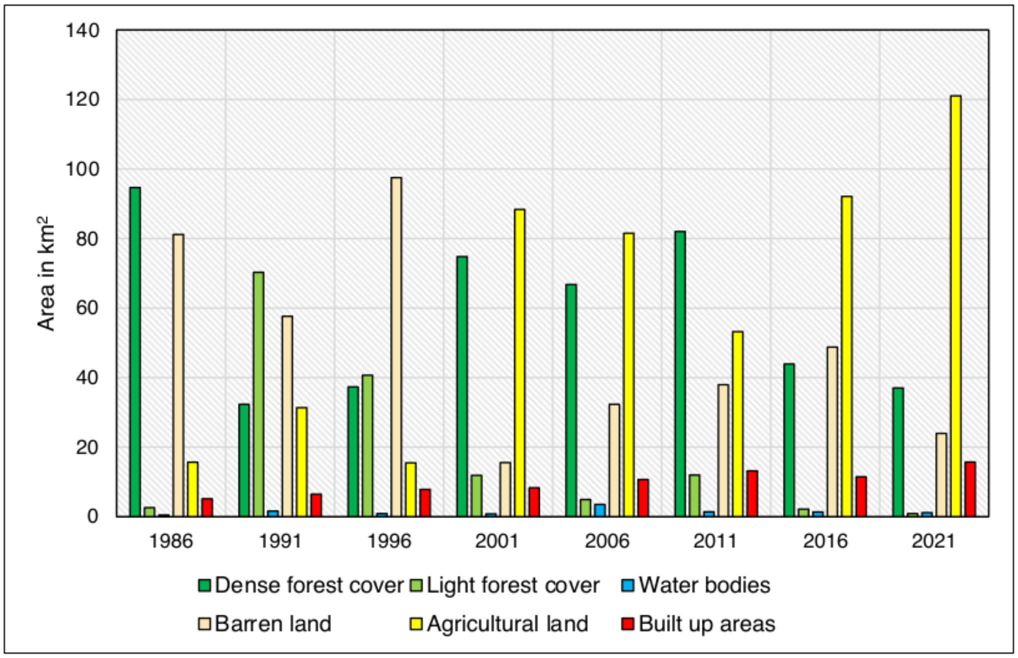

Figure 4.20 Area-wise temporal modification in LULC of Sonamukhi block

4.11.4 Patrasayer block

In 1986, around 26 km^2 area of Patrasayer block was under the dense forest cover category, but in 2006 it was reduced to 5.17 km^2, and around 21 km^2 of dense forest cover was reduced from 1986 to 2006. After 2006, again negative change in the dense forest cover category was observed. About 5 km^2 of dense forest cover area was reduced from 2006 - 2021. In the Patrasayer block light forest cover also declined. In the barren land category, around 10 km^2 of land was reduced from 1986 to 2021. While, positive change in agricultural land was observed, around 25 km^2 and 13 km^2 of agricultural land increased from 1986 to 2006 and 2006 to 2021. In the built-up area category, a positive change was observed, around 4 km^2 of land was increased in the built-up category during the study period (Figures 4.22-4.23).

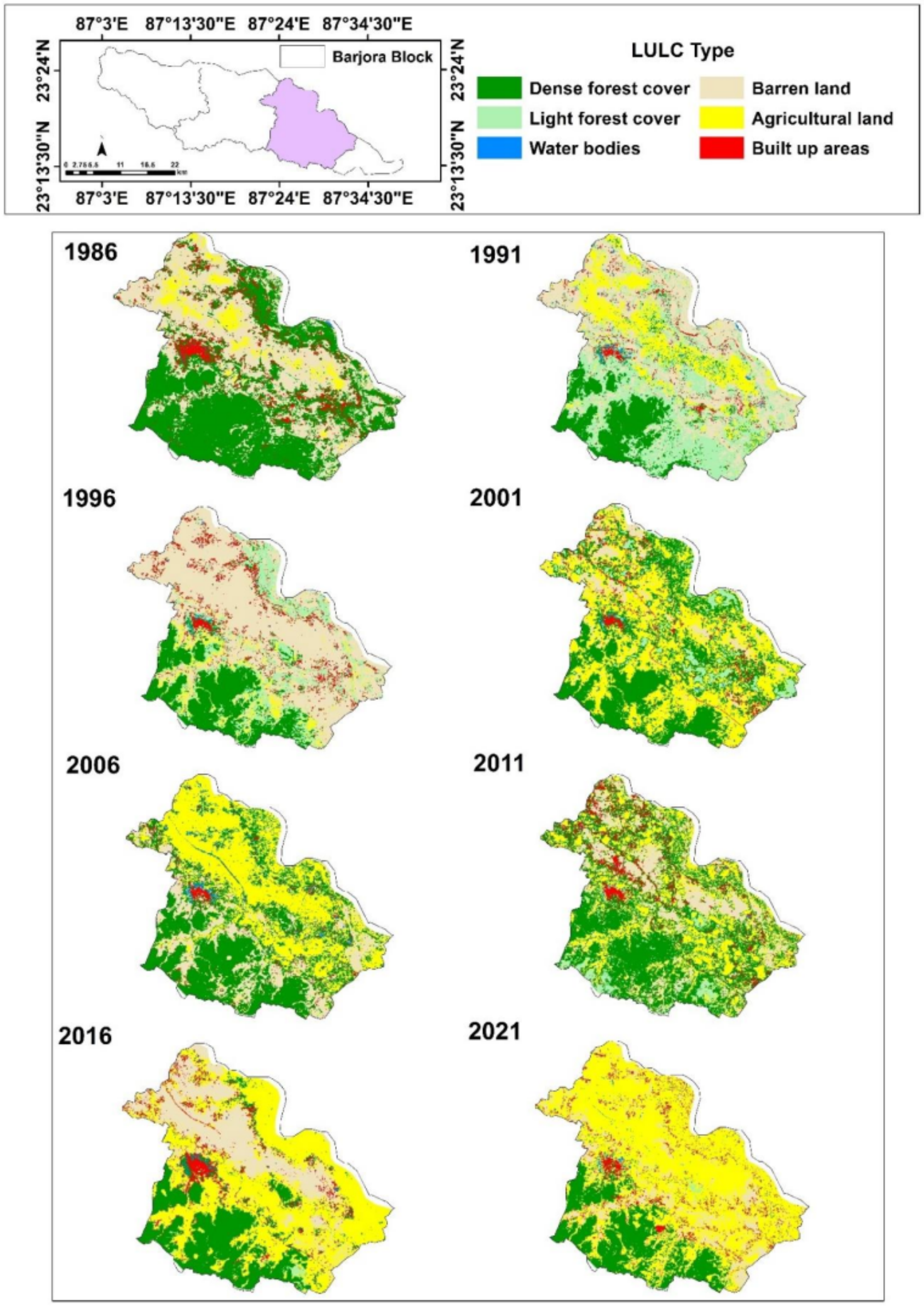

Figure 4.21 Temporal. variation. of LULC in Sonamukhi block

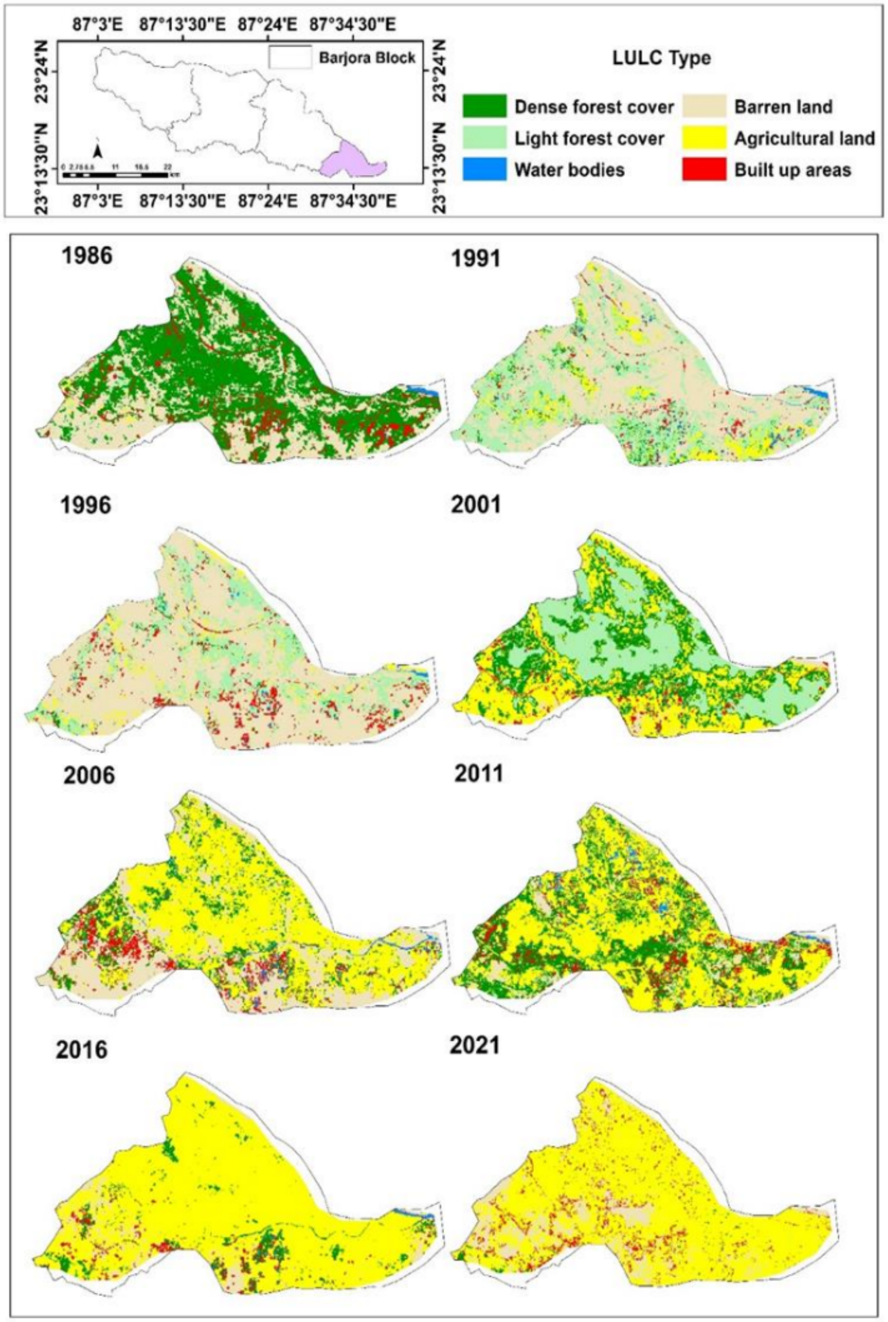

Figure 4.22 Temporal variation of LULC in Patrasayer block

4.12 Block-wise comparison in agricultural land

Block-wise temporal changes in LULC show that after the creation of the Shali reservoir, agricultural development has taken place in all blocks of the Shali River basin, although the growth rate is not equal (A1. Ch. 4.6). A comparison has been done to discover which block has the maximum amount of agricultural land. In 1986, Sonamukhi block (around 73%) had the highest number of agricultural land.

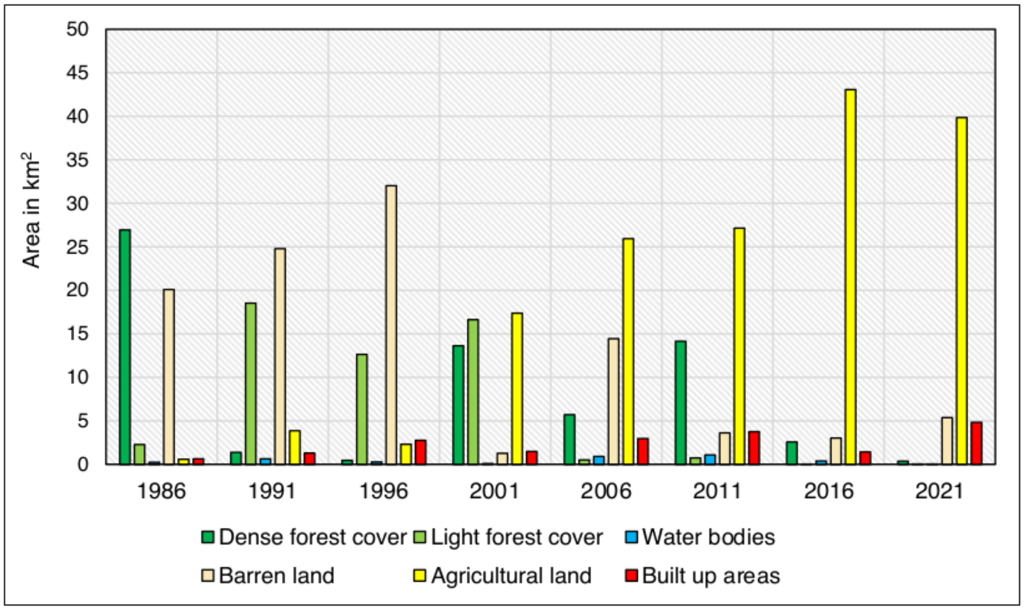

Figure 4.23 Area-wise temporal modification in LULC of Patrasayer block

In 1991, Sonamukhi had the highest number of agricultural land, around 63% of the land was agricultural land and Gangajalghati had the minimum amount of agricultural land. Barjora block was in the second position, around 22% of the land was agricultural land. In 1996, around 61% area of Gangajghati was under agricultural land, whereas Barjora, Sonamukhi and Patrasayer blocks have around 21%, 14% and 3% land under agricultural activities.

In 2001, Gangajalghati was in the first position, around 37% was under agricultural land. Barjora was in second position with around 33%, Sonamukhi was in third position with around 24% and Patrasayer was in fourth position with around 4% of land under agricultural land. In 2006, the amount of agricultural land increased in the Sonamukhi block, around 46% of the land was under agricultural activities. Gangajalghati and Barjora blocks had the minimum proportion of agricultural land than Patrsayer and Sonamukhi blocks.

Again in 2011, Gangajalghati block showed the maximum amount of agricultural land than the other blocks, around 35% of the land was under the agricultural land category. This time the agricultural land also increased in the Barjora block, around 30% of the land was found under agricultural activities. Whereas, Sonamukhi was 23% and Patrasayer had 11% of land under the agricultural land category.

In 2016, the proportion of agricultural land increased in the Gangajalghati block, around 37% of the land was under the agricultural category. Agricultural growth also occurred in

Sonamukhi, around 25% of the land was observed. In 2016, Barjora block had around 25% agricultural land and Patrasayer block in the fourth position. In 2021, the amount of agricultural land was reduced in the Gangajalghati block, around 31% of the land was under this category. In 2021, Barjora block was in second position with 28% agricultural land. While Patrasayer block has a minimum amount of agricultural land than other blocks respectively (Figure 5.24).

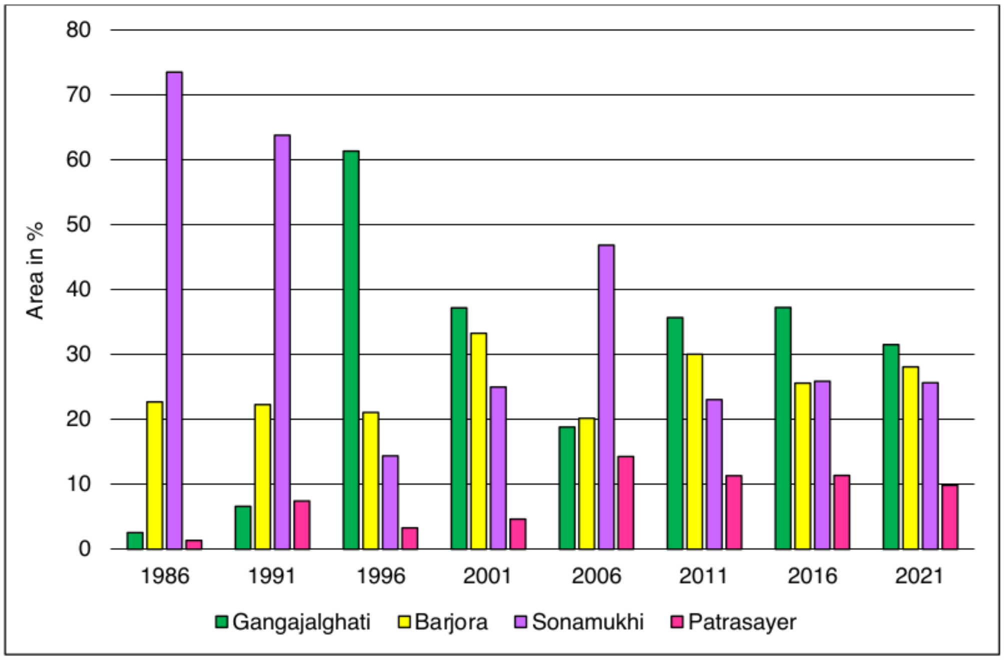

Figure 4.24 Block-wise comparison in agricultural land

4.13 Village-wise agricultural land

The Shali River basin is formed with 341 villages, where Gangajalghati block has 91 villages, Barjora block has 125 villages, Sonamukhi block has 97 villages and Patrasayer block has 28 villages. In 1986, the agricultural land was limited to 42 villages. These villages were observed majorly in Sonamukhi and Patrasayer blocks. In 1991, a minor positive change was noticed, around 61 villages came under agricultural activities. The maximum number of villages were concentrated in the Sonamkhi, Barjora and Patrasayer blocks. In 1996, about 103 villages were included in the agricultural activities, the maximum number of villages of Gangajalghati block was under agricultural activities. In 2001, a massive positive change was observed, around 289 villages of the Shali River basin came under agricultural activities. In 2006, the amount of agricultural land was reduced, only 143 villages have agricultural land. In 2011, a positive change was observed, 161 villages were included in agricultural activities. The number of villages increased in 2016 also, and around 178 villages were involved in agricultural activities. In 2021, a huge transformation in LULC was observed, the amount of agricultural land was increased, and around 310 villages of the Shali River basin were engaged in agricultural activities (Figure 4.25).

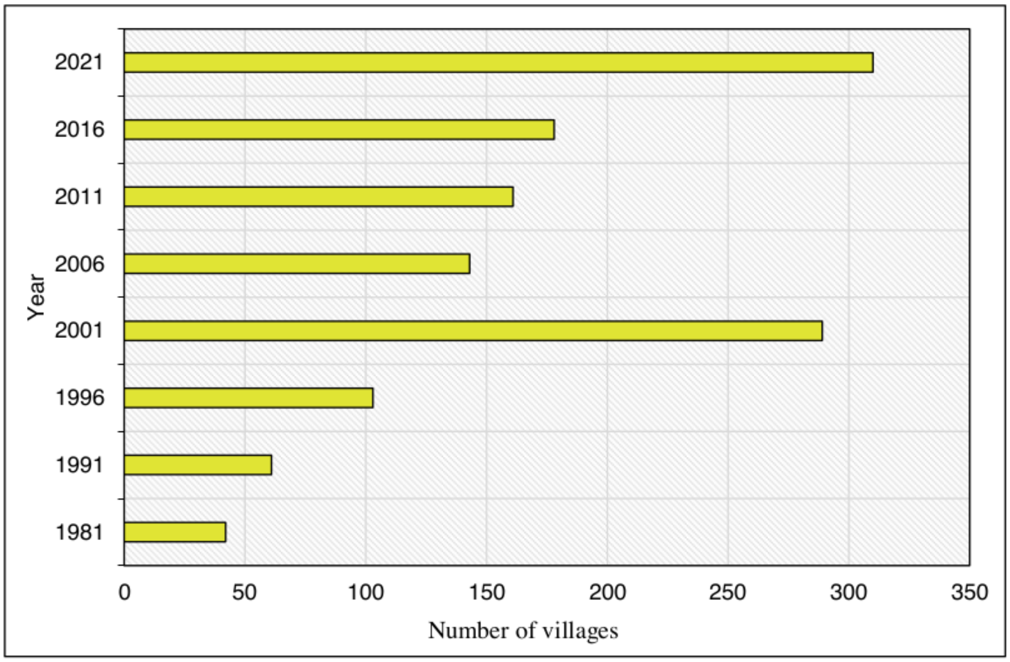

Figure 4.25 Temporal change in the village-wise distribution of agricultural land

Table 4.5 Village names with and without agricultural activities (2021)

Type	Village Names
Engaged in agricultural activities	Chhotalalpur, Kelai, Raajamela, Balekhun, Sedara, Laxmanpur, Baradihi Bararampur, Sagariyaa, Nutongram, Khajuriya, Jamsala, Chhotalacchipur, Naadihi, Bamondihi, Chholabaid, Haribhaga. Shuabasa, Keshiyara, Itadagra, Mallikidihi, Garjariya, Ukhradihi, Jam Bedya, Shirsha, Taljhitka, Lakhyara, Ekchala, Ranganathpur, Aamjor, Machparuliya, Gobindodham, Mauutara, Thamkanra, Ranabahal, Selere, Konara, Bhairobpore, Mande, Chhotakumira, Kenduadihi, Nabagram, Kotmadanmohanpur, Kapishtha, Nischintopore, Saltara, Shalbediyaa, Madhobpur, Kalapur, Ramanagar, Suara, Radhashyampore, Sankara, Brabhmanara, Chardighi, Khopaganj, Bira, Baalijora, Gopalpore, Jamberiya, Biringi, Malkonara, Borojuri, Danduliya, Ramkonali, Kendiyabari, Arba, Asanchuya, Arjunpur, Biharjuriya, Horekrsinopure, Gobordhanpore, Piraboni, Hare Krishnopore, Gobordhanpore, Piraboni, Arjunpur, Radhakrishnopore, Gopinathpore, Tentuliyadaga Simlanagar, Batlapara, Menjuya, Abirampore, Srirampur, Tiylasuli, Bhalukapahari, Bayermara, Raniara, Arbetal, Saharjora, Muktatar,

	Beleshola, Chak Keshya, Shitla, Monoharbati, Kanchanpur, Pabayan, Dakaisini, Khanrari, Uara, Deucha, Dejuri, Hatashuriya, Mondarboni, Dewangarya, Sorali, Madnahati, Numuigariya, Gururband, Katalpukur, Radhabalabhpore, Arjoni, Metiya Narayanpore, Mohidara, Krishnaboti, Nakona, Payermohan, Radhanagar, Sushuniya, Shahebdi, Bisanpur, Ashuriyamadabpur, Talanjuri, Kantabad, Harirampur,Belianarayonpore, Harekrishnopore, Dadimukhai, Gopakande, Puruniya, Sangrampore, Laxminarayanpore, Bahora Khulia, Gangadhorpur, Kalpai, Banshal, Dharampur, Dhwajamonipur, Phulberrya, Damodorpur, Dagarpara, Nutongram, Bahadurpore, Madhobpore, Olatara, Kanchchala, Samontomara, Daboni, Chala, Kalberiya, Namaghansara, Kuria, Bolorampore, Maalkuria, Ekairiya, Majuddagara, Siragara, Gadardi, Gadordihi, Radharamanpur, Birshinghapore, Jhoriya, Lalbajaar, Telaanda, Gobindopur, Sirsa, Palsana, Jaykrishnapur, Sargabaati, Harishpore, Gopinatpore, Shamdashpore, Amthiya, Gosahinpore, Belu, Saldaanga, Jaganathpur, Purusotampur, Asanshola, Muktopur, Kadma, Bandharkeda, Krishnapur, Benachapara, Mathuaberia, Bhairobdaga, Bhairobpore, Rautora, Barkuro, Kantabeshe, Nityanandapur, Gangabandh, Saulia ,Khidirpur, Radhakrishnapur, Belut, Dulai, Patanpolasi, Manusmari, Banksimla, Belegariya, Pashchimdubrajpore, Krishnanagar, Belut, Horishchandrapore, Radharomonpur, Ulaye, Peerbera, Prayagpore, Paschim Nandapur, Basunandopore, Sitaljar, Kubirbadh, Dubrajahati, Shibdaga, Kumardaga, Jaypur, Katania, Birshingpore, Paschimpotrohati, Rupol, Karjaboni, Palashere, Aliganj, Baikunthopore, Rupat Ganj, Jamboni, Patjor, Parbotiya, Bahuliya, Salchaturiya, Shyamsundarpur, Hamirahati, Basumara, Rampur, Khausa, Bashumera, Jasra, Patshol, Ratnopore, Mathuraboti, Bhulai, Keseshal, Khayrakura, Churamonipore, Kalyanpore, Bedomusal, Daxhinasal, Indakota, Amghatal, Sapuradighi, Sonamuhi, Kshertamohanpur, Shalda, Siltiya, Raitara, Shaahebganj, Maheshpur, Madanamohonpur, Galtor, Chaitanpore, Khuldanga, Amshal, Nanchanhati, Purbopatrohati, Bhalukan, Jaga Mohanpur, Shonadipa, Bonparuliya, Bnashe, Rajada, Junasara, Naaruala, Nischinapur, Ramchandrapur, Kunda Pushkarini, Kashipur, Kuchiagopalpur, Baharpur, Dhan Simla, Rampur, Machdoba, Karachmani, Chakdhoyakure, Bishnubati, Rampur, Jaljiala, Asanboni, Nahela, Parashiya, Dhagariya, Chapaboni, Hamirpore, Anandapur, Kendagare, Lalpore, Muktopore, Khoshalpore, Khamardihi, Hadal, Ramnagor, Dhamasha, Sonatikiri, Bolorampur, Teleshanra, Paruliya, Kesabpore, Brindabonpore, Vanda, Dayalpore, Chak Patrasayer, Panch Para.
Not engaged in agricultural activities	Koch Kunda, Manjmura, Ramchandrapur, Gobindapur, Kalla, Basu Chandanpur, Sonagara, Naboshan, Chander, Murakota, Patashpore, Bhaborkhola, Jemua, Chandaiyabat, Paschimbrindabonpore, Shaluka,

	Kushma, Birndabanpur, Dhabani Gobindapur, Kantabani, Bankurardanga, Maldanga, Mathuradanga, Rajmadhabpur, Radhakantapur, Srikrishnapur, Bara Narayanpur, Tiura, Kendua, Rampur, Ranibandh, Mamudpur.

4.14 Future prediction of LULC

A prediction analysis has been conducted to forecast the future LULC pattern of the Shali River basin area. This prediction has been executed using the CA and ANN respectively which is done by the MOLUSCE plugin in QGIS software. It is a beneficial plugin to discover future LULC patterns. This plugin includes three procedures such as ANN, CA, and validation.

The first step is the computation of the transition probabilities of the LULC maps by employing ANN. The 2nd step is the calculation of transition potential maps and the 3rd step is the application of CA to predict future LULC. The prediction study is based on two types of variables: dependent and independent. LULC maps are considered independent variables, whereas slope, elevation, commercial area, residential area, educational institutions, distance to road, distance to water bodies, etc. are considered dependent variables. The Euclidean distance function of ArcMap software has been incorporated to compute the distance between road and water bodies. Slopes and elevations have been derived from SRTM DEM data.

In the simulation modelling process, after opening the MOLUSCE plugin, the first step is to input dependent and independent variables to estimate conversion matrices and varying probabilities. In the second step, the ANN model has been applied to simulate the potential transition of LULC with 500 maximum iterations. The third step is the use of the CA model to predict LULC and the final step is the validation of the predicted map.

In this study, the MOLUSCE plugin is applied to simulate LULCc off 2031. Here, the LULC maps of 2006 and 2021 are considered independent input variables, whereas slope, elevation and distance to the road are considered dependent variables. Slope means the steepness of land, which can be measured in both degree and percentage. Elevation implies the height of a place from sea level and the distance to the road indicates areas close to the main road. Before the prediction of 2031, the LULC map validation process ensued between the 2021 actual map and the predicted map (Figure 4.26).

The validation result shows around 99% correctness and an overall kappa value of 0.98, which proves good accuracy. After that simulated map has been generated for 2031. The simulated map of 2031 is also classified into six different classes such as dense forest cover, light forest cover, water bodies, barren land, agricultural land, and built-up areas.

According to the 2031 simulation study, dense forest covers occupy about 198 km^2. area, around 8 km^2 area is under light forest cover, agricultural land occupies about 422 km^2 area, about 35 km^2 area is covered with barren land and 58 km^2 area is covered by built-up area (Figures 4.27 & 4.28).

Change analysis has been made from 2021 to 2031. The result shows positive changes in agricultural lands and built-up areas. From 2021 to 2031, around 19% of agricultural land

and 15% of built-up areas have been increased. Whereas, around 8%, 4% and 22% of dense forest cover, light forest cover, and barren lands decreased (Figure 4.29) (A1. Ch. 4.5).

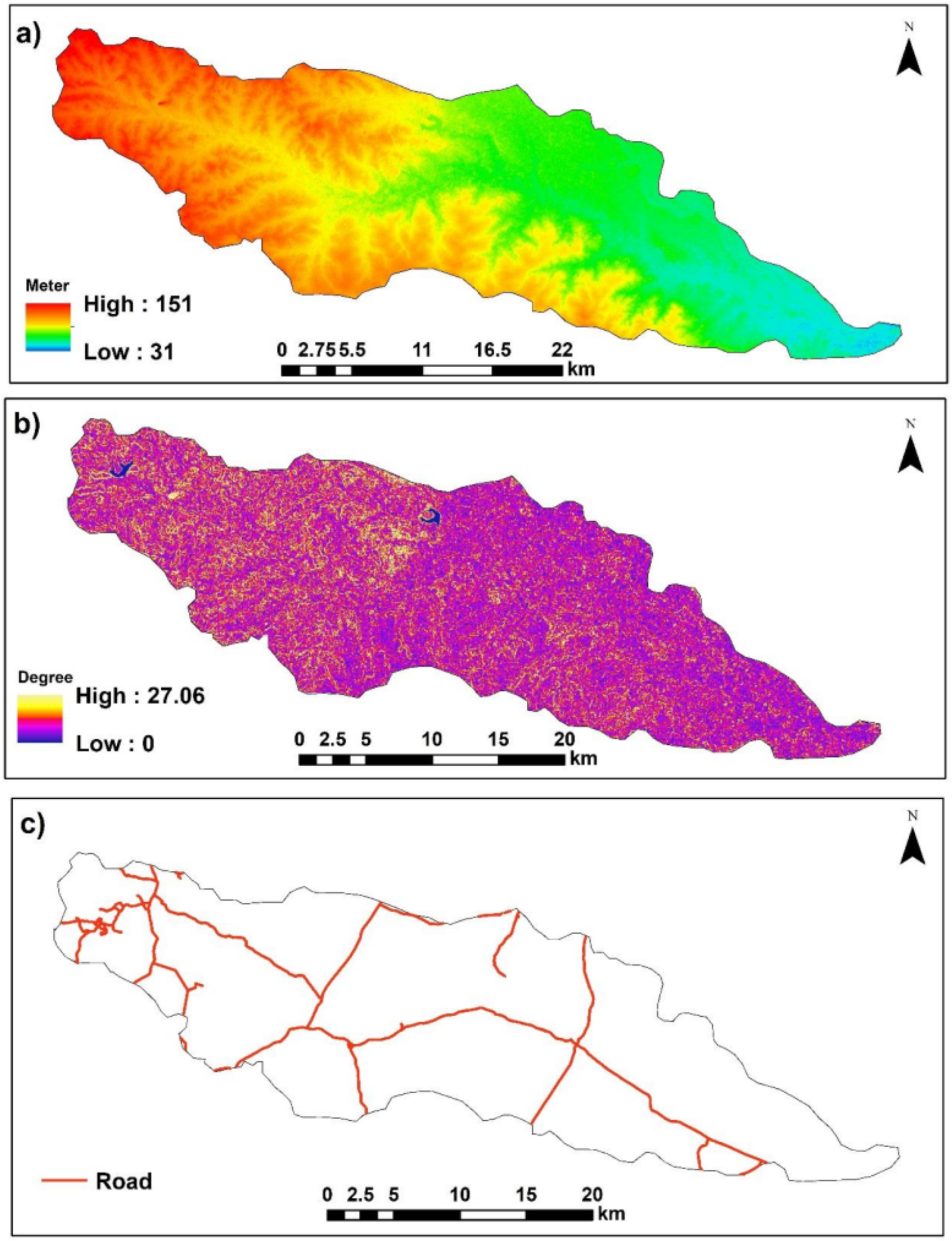

Figure 4.26 Input parameters for prediction analysis

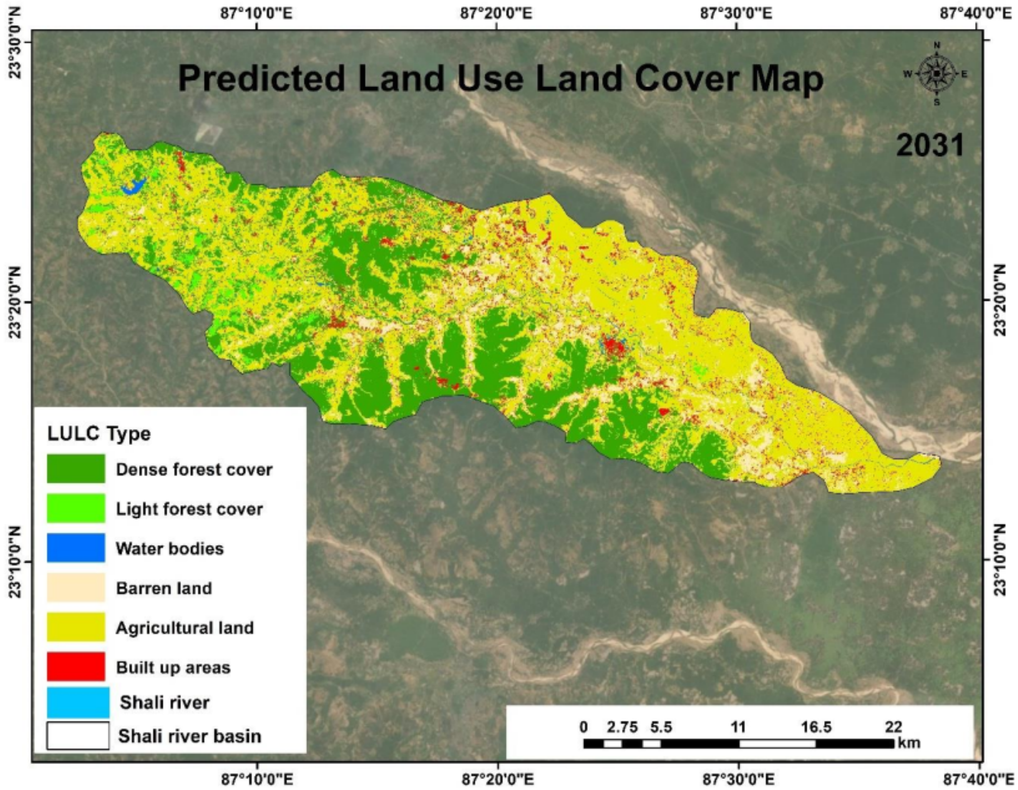

Figure 4.27 Predicted LULC map of 2031

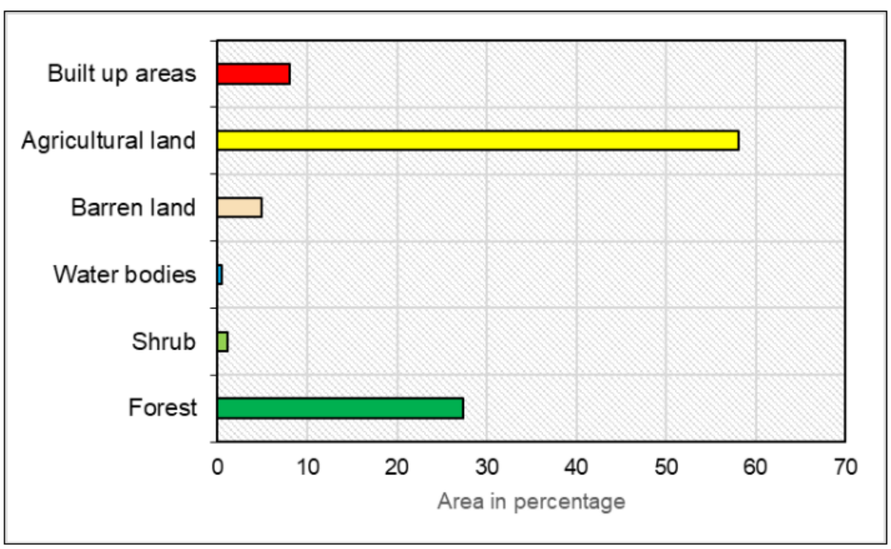

Figure 4.28 Areal coverage of LULC 2031

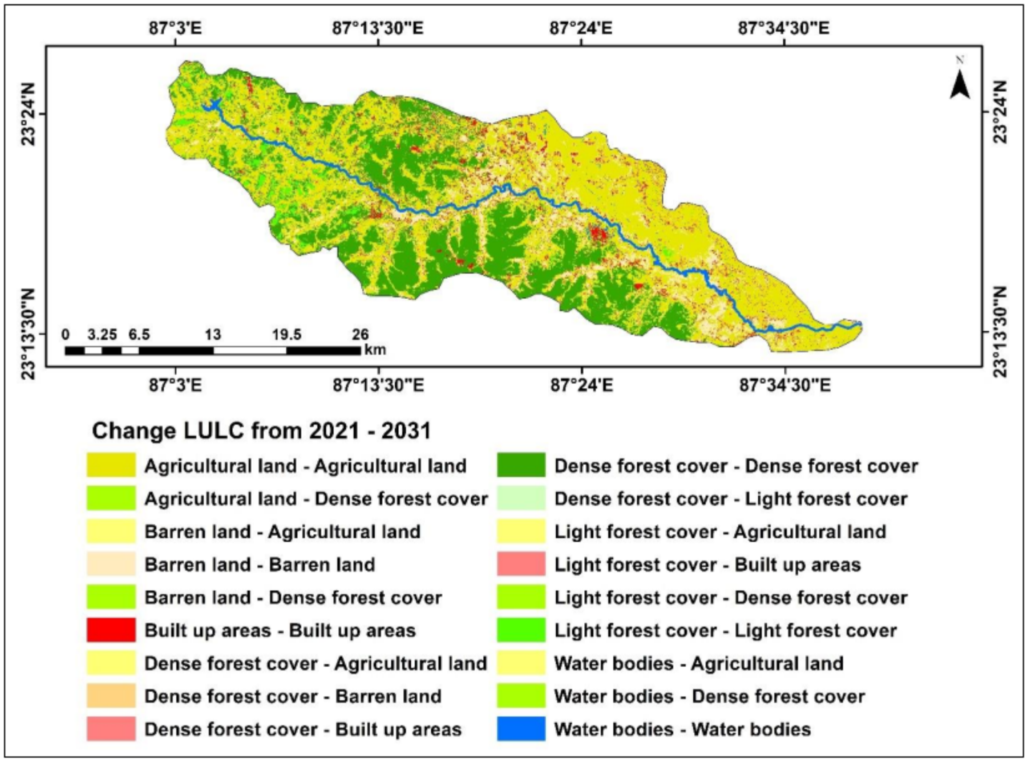

Figure 4.29 LULC change map from 2021 to 2031

4.15 Conclusion

The purpose of this chapter is to identify the chronological changes in the LULC pattern after the creation of the Shali reservoir. The chapter is organised into five segments i.e., year-wise LULC classification from 1986 to 2021, maintaining a five-year gap, change analysis: 1986 to 2006 and 2006 to 2021, block-wise LULC classification, and comparison, village-wise agricultural land distribution and lastly future LULC prediction of 2031.

The LULC classification results reveal that after the creation of the Shali reservoir, changes in LULC patterns are observed. From 1986 to 2021, around 52% of agricultural lands increased in Shali River basin.

In the change analysis segment, the result shows that the maximum amount of LULC transformations occurs from 2006 to 2021. A huge number of forest areas and barren lands are transformed into agricultural land. This indicates that the Shali reservoir accelerated agricultural growth. Along the agricultural development, built-up areas are increased. According to census 2011 data, after the creation of the Shali reservoir, the number of agricultural labourers increased which reduce rural-to-urban migration.

The Shali River basin consists of four blocks: Gangajalghati, Barjora, Sonamukhi and Patrasayer. The block-wise agricultural land comparison shows that from 1986 to 2021 around 29% of agricultural land has been increased in Gangajalghati block. In Barjora block, around 5% of agricultural land has been increased. Whereas, around 47% of agricultural land has decreased and 8% has increased. Though the soil type of Patrasayer is alluvial and the slope is gentle, which can help to enhance agricultural productivity and the upper portion of basinn is part of the Chotonagpurr plateau, which has undulating terrain and a high slope. But due to the nearness of the Shali reservoir and Shali river, it gets an ample amount of irrigation water than the other blocks. The study also depicts that in 1986, agricultural activities were concentrated within 42 villages, but in 2021, around 300 villages are engaged in agricultural activities.

The predicted LULC map of 2031 also depicts the same. the amount of agricultural land will be increased by 57%. therefore, it has been proved that the Shali reservoir plays a vital role in agricultural development in the Shali River basin area.

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Identification of suitable irrigation lands

5.1 Introduction

Irrigation is an artificial method that provides water as a crop requirement to support farmers. It draws water from rivers, canals, reservoirs, tanks etc. and diverts to the fields (Debnath and Adamala, 2020). In India, irrigation patterns are classified as ground and surface water irrigation. The selection of irrigation schemes depends on many aspects: soil properties (physical & chemical), rainfall, soil texture, landscape etc. In India, based on Cultivable Command Area (CCA) three types of irrigation systems are observed, minor, medium, and major irrigation systems (Asawa, 2005). Shali reservoir is a medium irrigation scheme, that provides irrigation water through the Shali river in the villages of the Shali River basin area. Shali reservoir area receives about 70-90% rainfall during the monsoon. In this study, the previous chapter (Chapter 4: Transformations and future scenario of LULC) shows that after the creation of the Shali reservoir agricultural lands has increased throughout the Shali River basin. Thus, AHP (Analytical Hierarchy Process) has been incorporated to identify suitable irrigation lands among the agricultural lands of Shali River basin. Based on literature reviews 12 factors have been selected as criteria for AHP such as topography (elevation, slope), climatic (rainfall), soil group, silt sand, clay (soil textures), soil properties (nitrogen, pH, organic carbon), LULC, river to agricultural field distance. An irrigation suitability map has been prepared to apply overlay analysis.

5.2 Literature reviews

Currently, several GIS application-based works are going on irrigation, AHP in one of them. This process can provide suitable irrigation land, which is beneficial for agricultural workers. The foremost aim is to delineate irrigation suitable lands under the Shali reservoir scheme using the AHP method. Previously, several works are published on irrigation suitability, Bozdağ et al. (2016) joined GIS and AHP to determine the suitable lands for irrigation in Cihanbeyli county of Turkey. They used soil, climate, topography, and groundwater as criteria. The study revealed that around 7% land of Cihanbeyli is highly suitable for irrigation. Worqlul et al. (2017) evaluated irrigation-suitable lands using groundwater in Ethiopia. They used a multi-criteria evaluation technique to identify suitable lands. The study includes physical, climatic and market access features as parameters. The results showed that around 6 million ha of land in Ethiopia is suitable for irrigation. Mandal et al. (2018) applied weighted overlay analysis to discover the potential irrigation suitable land of the Kansai watershed Purulia district, West Bengal. Soil type, LULC, slope, and distance from the water supply are used to identify the potential irrigation suitability lands. The study revealed that about 68% land of the Kansai basin was highly suitable for irrigation. Birhanu et al. (2019) applied weighted overlay analysis on the Dima River basin, Ethiopia to identify suitable irrigated lands for tomato and potato production. The suitable sites for potential surface irrigation were based on slope, soil type, depth of soil and closeness to the water source. Results suggested that about 60% of land in the Dima River basin is extremely suitable for irrigation. Worqlul et al. (2019) estimated potential lands for irrigation and studied the influence of climate change on the land suitability of Ghana. They incorporated the multi-criteria decision-making analysis (MCDA) technique to analyse the suitability of land. Climate data, slope, soil, and groundwater data were considered parameters of the suitability analysis. The analysis indicated that about 10% area of Ghana is appropriate for irrigation. Due to climate change about 9% of the land will be affected. Neissi et al. (2019) applied a GIS-based AHP to recognize suitable places for different irrigation schemes in Izeh of Iran. They considered three types of irrigation patterns: pressurised, gravitation, low-compression irrigation system and climate, topography, system cost and skilled labour were used as input parameters. The study revealed that low-compression, drip and surface irrigation patterns were appropriate irrigation types for Izeh plain.

Li and Chen (2020) assessed potentially suitable land for irrigation by using groundwater data and the AHP technique of the Xinjiang River basin. They used rainfall, evaporation, land use, soil classification and groundwater data as parameters for suitability analysis. The study showed about 45% of highly suitable land was available in the Xinjiang River basin and the available groundwater was not enough for irrigation. Tashome and Holefom (2020) identified potentially appropriate land in the Gumara watershed of the Nile Basin for surface irrigation. They selected six parameters and applied the AHP technique. The selected six parameters were proximity, slope, land use, climate etc. the results displayed that about 19% of the Gumara was highly appropriate for irrigation. Balew et al. (2021) mentioned that irrigation acts a fundamental role in boosting agricultural productivity in Ethiopia. They applied the AHP technique in the Rib-Gumara watershed of Ethiopia and selected climate, slope, topography, and distance to the water body as different criteria for AHP analysis. The study resulted that about 27% of the land is highly suitable for irrigation and suggested that Government should enhance the irrigation schemes of this region. Gonfa et al. (2021) measured suitable irrigated areas in Becho plain, Upper Ethiopia using AHP for surface irrigation. They selected four parameters: slope, LULC, soil and SWAT (soil and water assessment tool) model was also applied to analyse the availability of surface water. The outcomes disclosed that around 70% of the land is appropriate for irrigation.

All literature reviews state that land suitability analysis is crucial to enhance agricultural production in present times. The combination of the AHP and GIS is the best method to identify suitable lands. AHP is used in multi-criteria decision-making analysis to solve multifaceted decision-making procedures, that comprise multiple features. It is a hierarchical process that compares all the criteria and makes an overall weightage for each criterion. In land-suitability analysis, the amalgamation of AHP and GIS is setting a new trend which creates suitability maps accurately (Bozdağ et al. 2016).

Currently, numerous studies have been accomplished using AHP: solid waste management, groundwater potential zone, flood-affected areas, landslide mapping, land suitability etc. (Table 5.1).

Table 5.1 AHP based on different kinds of suitability analysis

Suitability form/ category	Parameters	Similar study performed by
Agricultural land use	Soil group, LULC, soil depth, erosion rate, slope, aspect, elevation	(Akenci et al., 2013)
Educational land use	Urban texture, physical properties, road width, population density, capacity of educational centres	(Javadian et al., 2011)
Coastal tourism sites	Distance to road, market, museum, recreation, resort, residential area, slope, land use and distance to coastal zone	(Liaghat et al., 2013)
Urban services planning	slope, LULC, altitude, urban existing amenities	(Perry et al., 2018)
Hill shade development	Road, elevation, slope, aspect, agricultural land, forest land, residential area, wetland, surface water	(Chandio et al., 2014)
Urban development	Slope, transport, LULC, land-price, geology	(Kumar, 2013)
Organic farming	Drainage, highway, soil, geology, LULC, slope	(Mishra et al., 2015)
Urban growth	Population, distance from marketplace, educational, residential, industrial area, networks: railway, powerline, river; LULC, slope, soil texture and slope	(Aburas et al., 2017)
Solar farms exploitation	average annual temperature, transportation, distance from power transmission lines residential area, slope, LULC, average yearly gloomy days, dusty days, relative humidity, Solar radiation, elevation	(Noorollahi et al., 2016)
Installing new petrol filling stations	Land use protection, accessibility, hydrological condition, natural environment, topography, utility services	(Khahro et al., 2014)
Agricultural land use	Geology, Slope, LULC, elevation, soil moisture, aspect, drainage and road network	(Pramanik, 2016)

Wind farm development	Wind speed, distance from the electricity grid, settlements, roads, safe distance from airports, slope, impact on birds etc.	(Baseer et al., 2017)
Solid waste management	Land use and land cover, wetland, river, road, elevation, slope, airport	(Hazarika and Saikia, 2020)
Potential pollution sources	Top soil pollution, surface sediment permeability, groundwater vulnerability, surface water protection, slope gradient	(Bagdanovičiūtė and Valiūnos, 2012)
Hospital sites	LULC, Transportation, railway, existing hospitals, educational institutions,	(Halder et al., 2020)
Biogas digester plant for municipal waste	Distance from settlements, roads, rivers, water bodies, agricultural land, slope, LULC	(Akther et al., 2018)
Groundwater potential zone	Slope, geology, geomorphology, LULC, water level fluctuation, drainage density, soil, lineament density, precipitation	(Tiwari et al., 2019)
River bank filtration	Geological features, water quality, water pollution, water shortage, cost, facilities	(Lee and Lee, 2010)
Drought risk assessment	Maximum evapotranspiration, Annual and monthly precipitation, monthly evapotranspiration, highest temperature, relative humidity, land use land cover, ground water, slope, soil texture, population, cultivators, agricultural labourers, monthly temperature	(Palchaudhuri and Biswas, 2016)
Electric vehicle fast charging station	Population, supermarket, road, salary, conveyance, gas station, common areas, greeneries, slopes, land price	(Guler and Yomralioglu, 2020)
Rainwater harvesting suitability	Soil, slope, curve number, alluvial map, drainage density, distance to stream, rainfall, runoff depth	(Balkhair and Rahman, 2019)

5.3 Chapter outline

This chapter has two segments. In the first segment weightages of 12 parameters have been generated through AHP and in the second segment weighted overlay analysis has been applied to generate an irrigation suitability map (Figure 5.1).

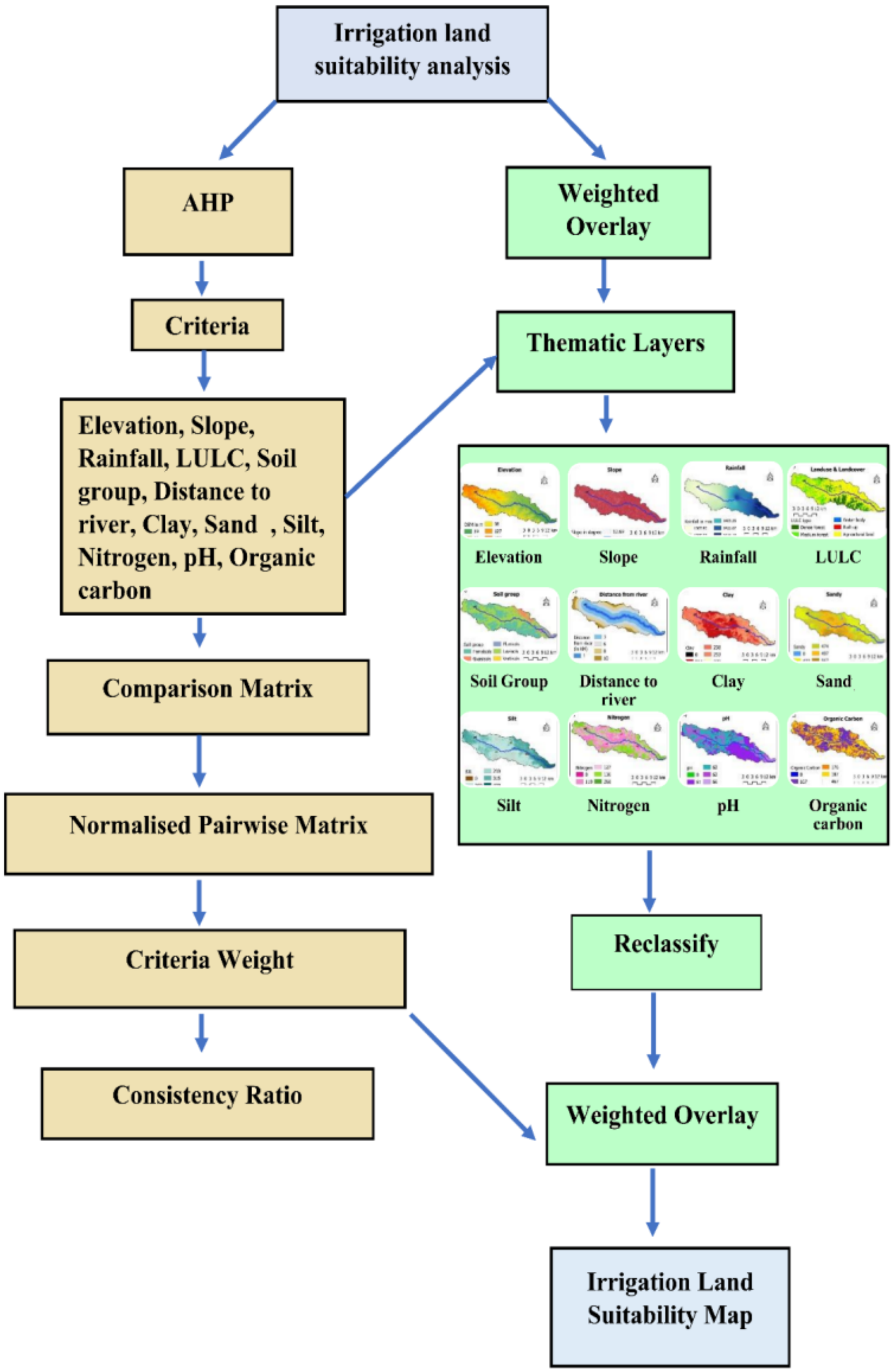

Figure 5.1 Schema showing the process of preparing irrigation land suitability map

5.4 Methodology

5.4.1 Analytical Hierarchy Process (AHP)

It is an MCDA based on mathematics and psychology (Saaty, 2001). It helps to select the best factor among the other decision-making factors based on qualitative and quantitative features of the factors (Weerakoon, 2014). In 1970, Thomas L Saaty proposed the AHP. Saaty described AHP in four phases: demonstrating, evaluation, prioritisation, and amalgamation. Firstly, based on the characteristics of parameters a hierarchical structure has been created where at the top level the main objective has been placed and other appropriate objectives are placed in the remaining levels. Secondly, AHP includes a comparison of pairs of criteria, sub-criteria, and alternatives. After creating a pairwise comparison matrix, AHP uses a nine-point fundamental scale to specify individual inclinations of each factor (Table 5.2) (Saaty, 1990).

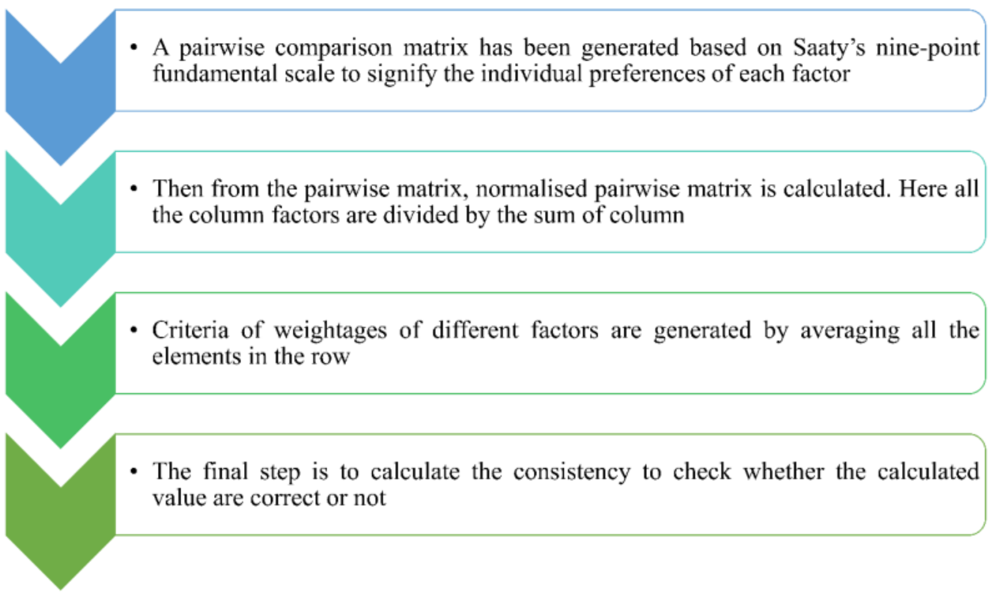

Figure 5.2 Phases of AHP

Table 5.2 AHP rating nin-point scale based on Saaty

Intensity of significance	Description	Elucidation
1	Equally significant	The objective is supported by two factors equally
2,4,6,8	Midway values	When cooperation is required
33	Slightly more significant	One factor is favoured based on judgement and experience over another factor
55	Noticeably significant	One factor is intensely favoured based on judgement and experience than another factor

77	Extremely significant	One factor is very intensely favoured based on judgement and experience than another factor
99	Absolutely significant	One factor is validated based on evidence over another factor

The AHP also assesses the steadiness of the pair-wise matrix by providing mathematical measurements. As given in Eqs. 5.1–5.2, Consistency Index (CI) calculates uniformity between the factors of the pairwise matrix (Saaty, 1990).

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{5.1}$$

where n signifies total criteria numbers, λ_{max} considers as the main eigenvalue of the pair-wise matrix.

Saaty also proposed a consistency ratio (CR) to accurately ensure the consistency of the pair-wise matrix.

$$CR = \frac{CI}{RI} \tag{5.2}$$

where RI (random index) varies based on the total number of criteria.

Table 5.3 RI table generated by Saaty (1990)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

If the value of CR is below 0.10, then it indicates an agreeable consistency but if the CR value is above 0.10 then it specifies an unacceptable consistency of the pairwise matrix.

5.4.2 Overlay analysis

The AHP method calculates the weightage of each parameter. Then, a suitability map was produced using weighted-over analysis through GIS software. The formula for weighted overlay analysis is as follows in Eq. 5.3 (Bozdağ et al., 2016).

Irrigation Suitability =

$$\begin{bmatrix} (E_w \times E_i) + (S_w \times S_i) + (R_w \times R_i) + (SG_w \times SG_i) + C_w \times C_i) + (S_w \times S_i) + (SI_w \times SI_i) \\ +(N_w \times N_i) + (OC_w \times OC_i) + (P_w \times P_i) + (LULC_w \times LULC_i) + (DR_w \times DR_i) \end{bmatrix} \tag{5.3}$$

where E is the elevation, S means slope, R determines rainfall, SG denotes soil group, C signifies clay, S indicates sand, SI shows silt, N represents nitrogen, OC specifies organic carbon, P means pH, and DR represents the distance from the river, 'w' represents the assigned weightage of the parameter, 'i' signify the percentage of influence.

5.5 Parameters for the land suitability analysis for irrigation

Based on literature reviews, 12 parameters are selected to identify suitable land for the irrigation of Shali River basin. Thus, elected factors are classified into five broad segments. They are topography (elevation, slope), climate (rainfall), soil (soil group, texture & properties), LULC and proximity (distance from the river). Detailed information about all criteria is discussed as follows (Tables 5.4 and 5.5).

Table 5.4 Data used for AHP

Criteria	Need for irrigation land suitability analysis	Data Source
Topography		
Elevation Slope	Determines the suitable location for irrigation	DEM (Digital Elevation Model)
Climate		
Rainfall	Most important factor because the amount of irrigational water is depending on rainfall	IMD (India Meteorological Department)
Soil		
Soil group	Controls the water holding capacity	Bhuvan Indian Geo-platform of ISRO
Soil texture Clay Sandy Silt	Determines porosity of soil particles that influence infiltration rate	Bhuvan Indian Geo-platform of ISRO
Soil properties Nitrogen Organic Carbon pH	Regulates the fertility of the soil	Bhuvan Indian Geo-platform of ISRO
LULC	Helps to identify the croplands	Landsat 8 Satellite Image
Proximity		
Distance from river	Signifies the distance of the agricultural lands from the river	Landsat 8 Satellite Image

5.5.1 Elevation and slope

Topographically, the Shali River basin is dissected part of the Chhota Nagpur plateau, so the terrain is undulating. The average elevation of Shali River basin is about 85 m. Comparatively; the western portion is higher than the eastern portion. The Shali River flows from west to east according to relief. In this study, based on the highest and lowest elevation, elevation is categorised into five groups: very high (128 to 156 m), high (99 to 127 m), moderate (69 to 98 m), low (40 to 68 m) and very low (0 to 39 m). The western and north-western portions of Shali River basin have high to very high elevated zones. Whereas, the east and north-eastern portions of Shali River basin have low to very low elevated areas. The average slope of Shali River basin is around 12°. The maximum portion of Shali River basin is covered with a low slope area (Figures 5.3 and 5.4).

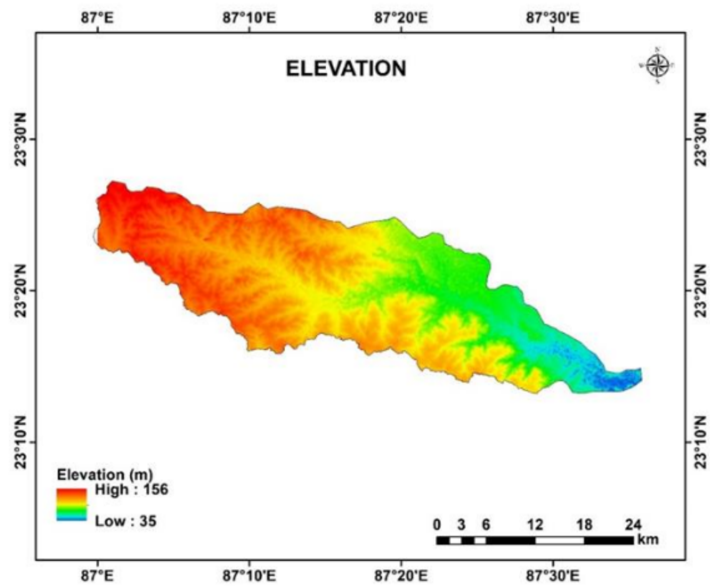

Figure 5.3 Elevation of Shali River basin

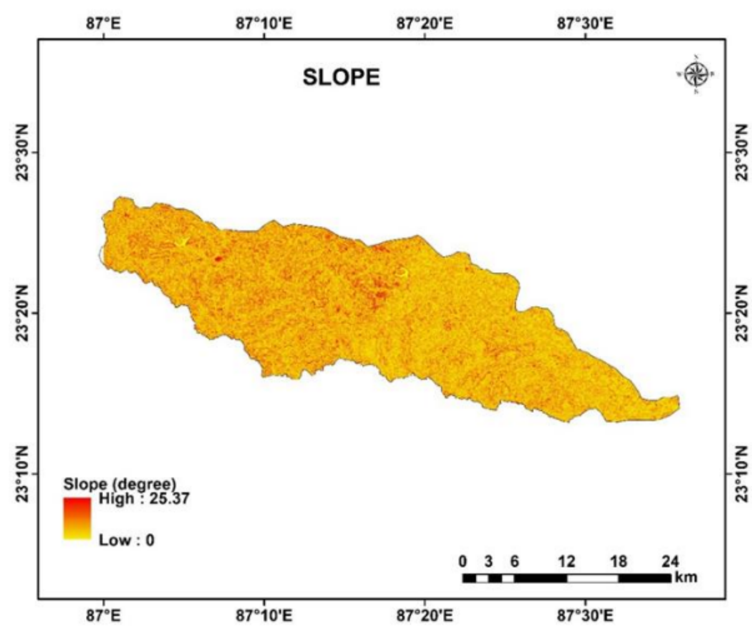

Figure 5.4 Slope of Shali River basin

5.5.2 Rainfall

Rainfall is considered an important parameter of irrigation land suitability analysis. The rainfall amount determines the water level of the Shali reservoir. The average annual rainfall of Shali River basin is 1400 mm and the monsoon receives the maximum rainfall. The highest and lowest annual rainfall observed was around 1438 and 1367 mm. Based on annual rainfall, the Shali River basin area is categorised into five classes: Very high (above 1438 mm), high (1421 – 1438 mm), moderate (1403 – 1421 mm), low (1385 – 1403 mm) and very low (1367 – 1385 mm). The north-western and north segments of the Shali-basin receive low to very-low annual rainfall and the east and south-eastern portion get moderate to very high rainfall (Figure 5.5).

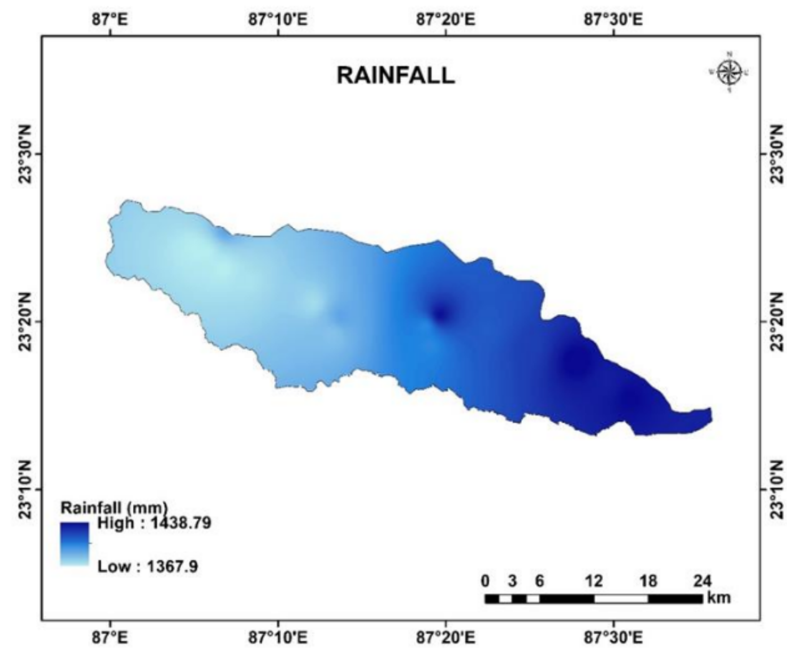

Figure 5.5 Rainfall of Shali River basin (1991- 2020)

5.5.3 Soil group

According to USDA soil classification, the Shali River basin area comprises five soil groups such as Ferralsols, Gypsisols, Fluvisols, Luvisols and Vertisols. Ferralsols covers around 40% area of the Shali River basin. Red and yellow tropical soils are known as Ferralsols. It is formed with iron and aluminium. The Ferralsols have good physical but bad chemical properties. It has a low water holding capacity. Thus, irrigation is required (Jordanova, 2017). Gypsisols form with gypsum. It is mainly found in arid climatic zones. It has low water holding capacity but irrigated crops can be grown here. It covers around 5% land of the Shali River basin. Fulvisols cover only 4% area of Shali River basin, it is a dry land soil, and with proper irrigation, rice cultivation can be done in this type of soil (Jordanova, 2017). Luvisols is a dark brown soil, mainly found in dry regions, which is superb for agriculture. Luvisols cover around 50% land of the Shali River basin (Adams et al., 2019). Vertisols types of soil are mainly found in arid to semi-arid regions. It can be used for crop production with proper irrigation, about 1% area enclosed by Vertisols of Shali River basin (Figure 5.6) (Eswaran and Reich, 2005).

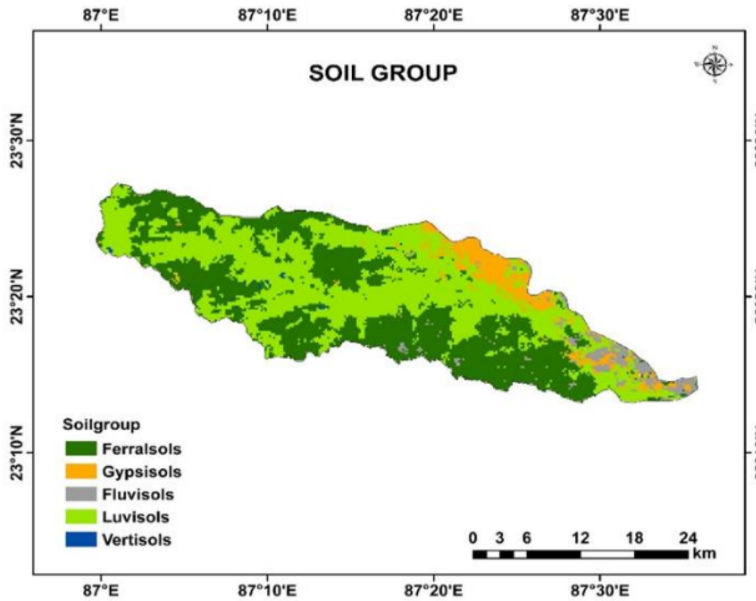

Figure 5.6 Soil group of Shali River basin

5.5.4 Soil texture

It defines the dimension of soil particles that signifies the water-retaining capacity of the soil. There are three main types of soil particles such as sand, silt, and clay. Sandy soil has a large particle (0.10–2 mm) size, so water retention capacity is very low. The particle size of silt (0.005–0.05 mm) is smaller than sand. Clay has a tiny particle size (<0.002 mm). It has a good water retention capacity (Upadhyay and Raghubanshi, 2020). The Shali River basin has around 25.03%, 23.79% and 24.34% of the area with the highest amount of clay, sand, and silt (Figures 5.7-5.9).

5.5.5 Soil properties

In this study, nitrogen, organic carbon, and pH are considered parameters for irrigation suitability analysis. Nitrogen increases plant growth. pH measures the amount of acidity and alkalinity in the soil. According to pH value, soil can be classified into three groups such as acidic (less than 6.5), neutral (6.5 to 7.5) and alkaline (over 7.5). Organic carbon consists of the topmost layer of the soil; it determines the quantity of organic matter in the soil. In Shali

River basin, about 24% of the soil is occupied with very high concentrated nitrogen, around 4.12% soil has a high content pH level and 16.64% of the soil has a high amount of organic carbon (Figures 5.10-5.12) (Biswas and Mukherjee, 1994).

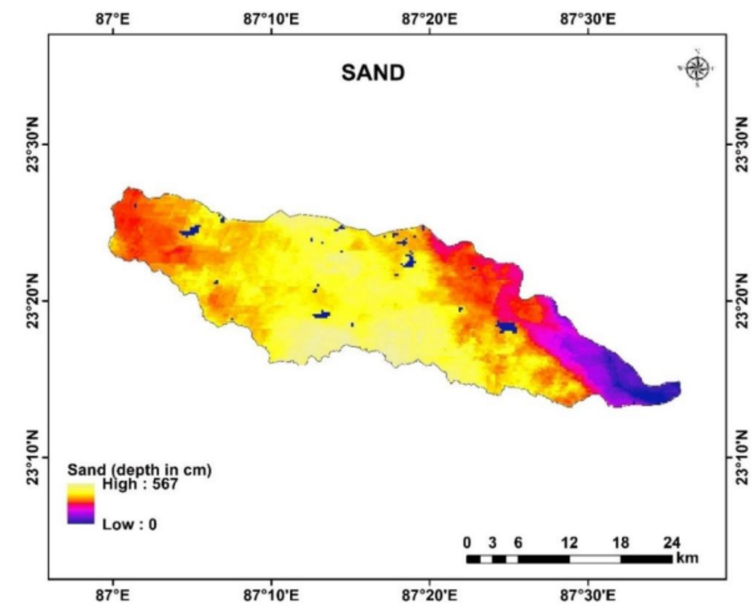

Figure 5.7 Sand distribution area in Shali River basin

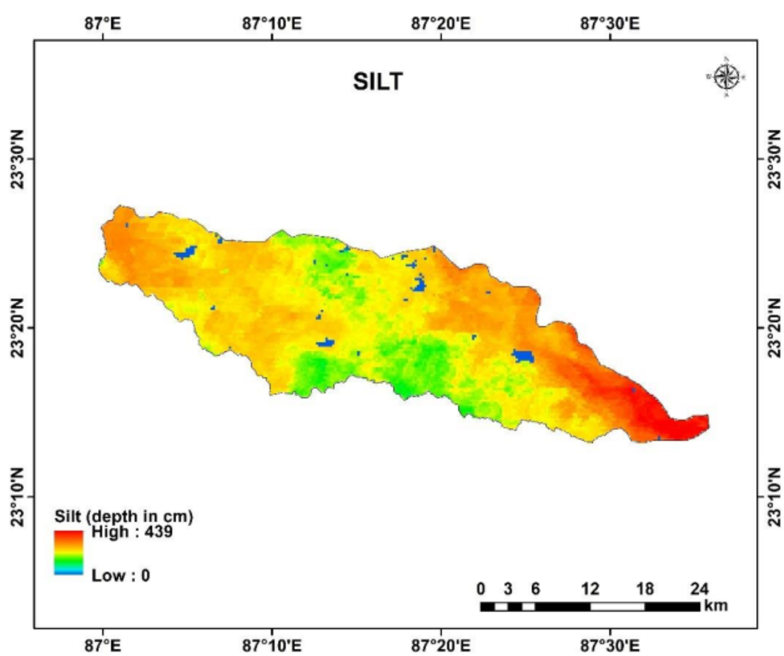

Figure 5.8 Silt distribution area in Shali River basin

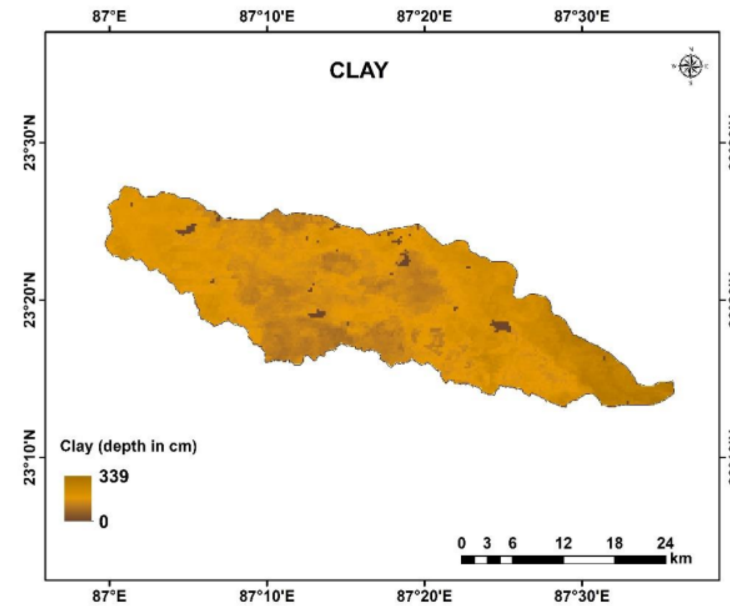

Figure 5.9 Clay distribution area in Shali River basin

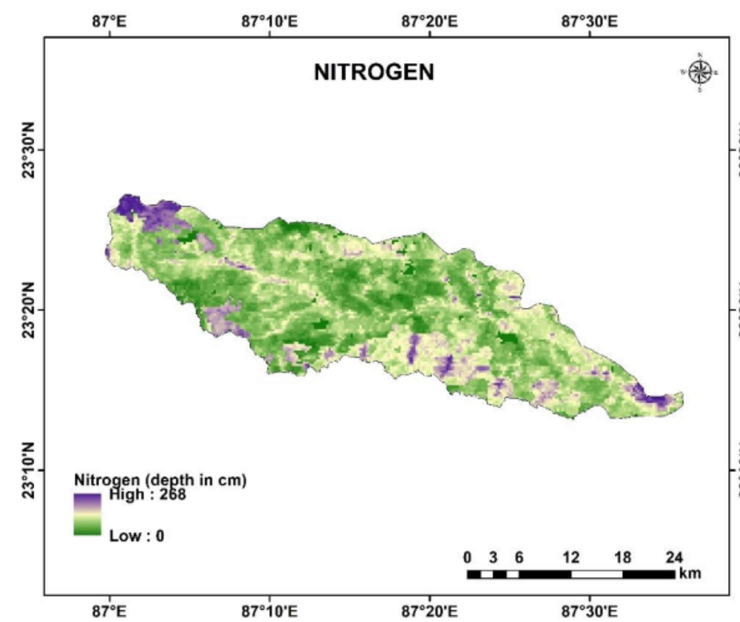

Figure 5.10 Nitrogen distribution area in Shali River basin

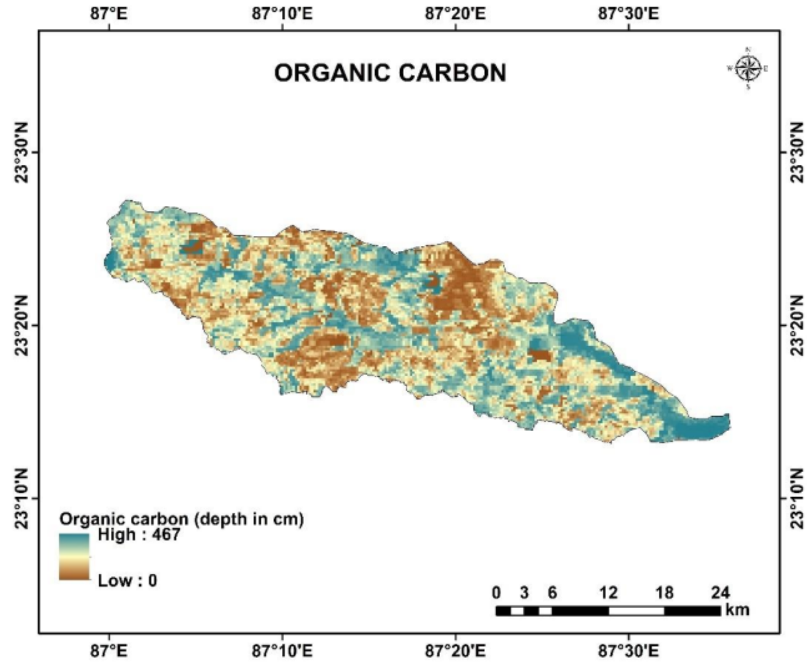

Figure 5.11 Organic carbon distribution area in Shali River basin

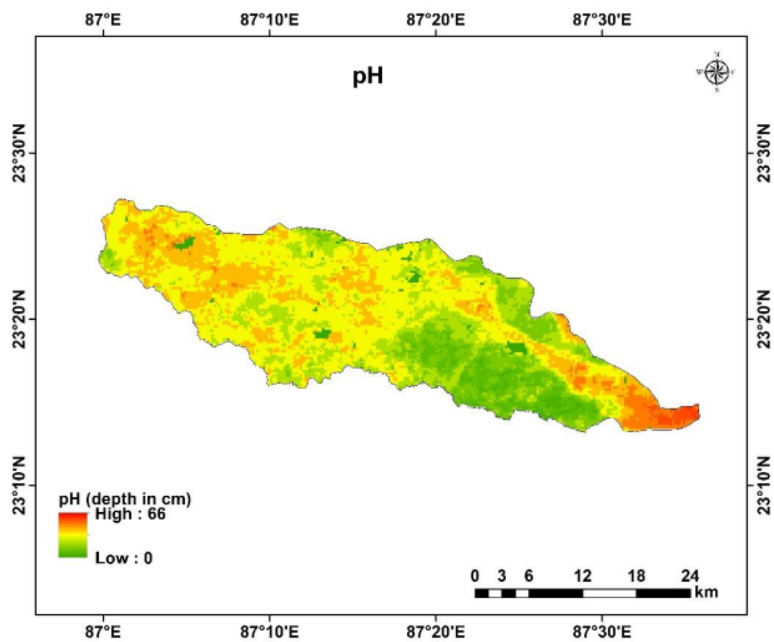

Figure 5.12 pH distribution area in the Shali River basin

5.5.6 LULC

LULC is a significant factor in irrigation land suitability analysis. The Shali River basin area is dominated by five types of LULC such as dense forest, medium forest, urban areas, barren lands and, agricultural land. In the Shali River basin, dense forest covers around 14%, medium forests 17%, urbanised area 4%, water bodies 2%, agricultural land 61% and barren land 2% of the land (Figure 5.13).

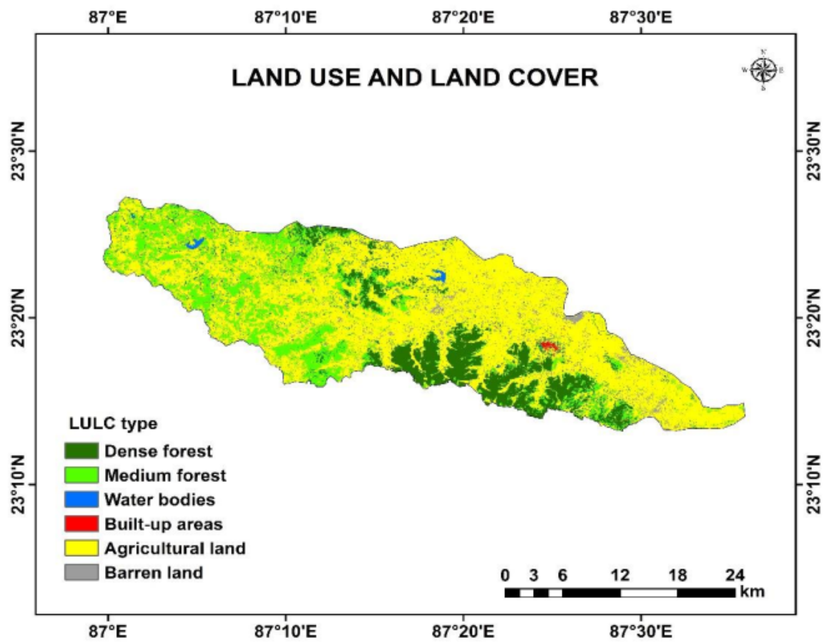

Figure 5.13 LULC of Shali River basin (1991 - 2020)

5.5.7 Distance from the river

This is the most important factor in irrigation land suitability analysis. In the study, a distance map has been created from the Shali River using Euclidean distance (Figure 5.14).

5.6 Weightages for suitability mapping

In the second phase of irrigation land suitability analysis, a comparison matrix has been prepared using 12 selected parameters (Table 5.5). Then normalised pair-wise matrix and criteria weightages have been produced using a comparison matrix (Tables 5.6-5.7).

Saaty's pairwise matrix has been applied to generate criterion weightage. The pair-wise matrix shows that the distance to the river has the maximum influence and relief has the minimum influence on irrigation suitability analysis (Table 5.8). While CR value of the pair-wise matrix is around 0.024 for suitability analysis which has verified the acceptance of pair-wise matrix.

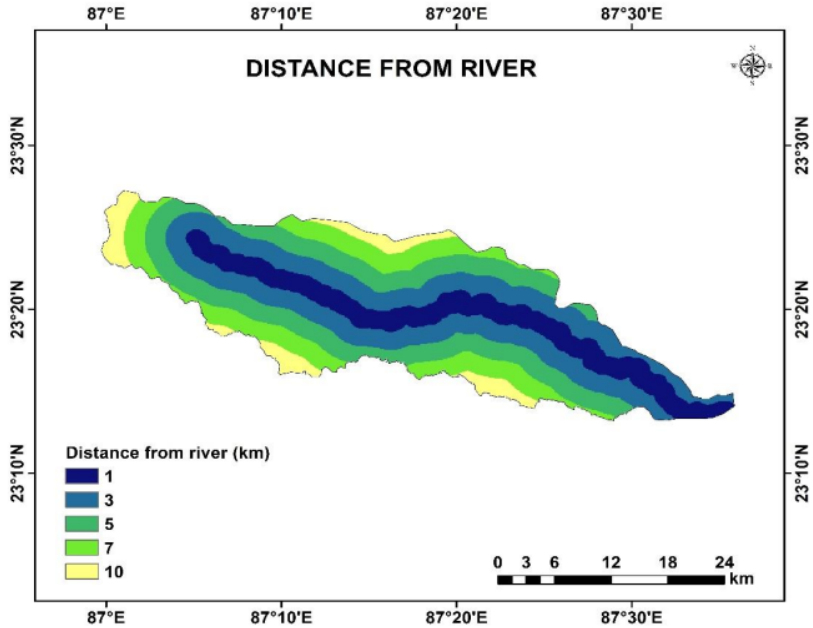

Figure 5.14 Distance from the Shali River

Table 5.5 Spatial distribution of selected criteria for irrigation land suitability analysis

Criteria	Sub-criteria	Area (km^2)	Area (%)
Distance to river (km)	1	133.57	18.39
	3	225.75	31.08
	6	186.99	25.74
	8	124.23	17.10
	10	55.86	7.69
Rainfall (mm)	0-1368	0.34	0.05
	1369-1386	288.29	39.68
	1387-1404	125.55	17.28
	1405-1422	190.38	26.20
	1423-1439	121.99	16.79
Clay (depth in cm)	0-223	9.31	1.37
	224-238	127.68	18.73
	239-253	188.75	27.69
	254-339	173.67	25.48
	above 339	182.23	26.73
Sandy (depth in cm)	0-433	9.31	1.28
	434-474	59.91	8.24
	475-497	161.10	22.17
	498-567	322.66	44.40
	above 567	173.67	23.90

Silt (depth in cm)	0-269	9.31	1.28
	270-290	171.23	23.56
	291-315	182.87	25.17
	316-439	185.37	25.51
	above 439	177.86	24.48
Nitrogen (depth in cm)	0-119	9.55	1.31
	120-127	170.73	23.50
	128-136	196.89	27.10
	137-268	174.11	23.97
	above 268	175.16	24.11
Organic carbon (depth in cm)	0-167	9.55	1.32
	168-176	184.07	25.39
	177-187	183.32	25.29
	188-467	227.00	31.31
	above 467	121.00	16.69
pH (depth in cm)	0	9.55	1.31
	61	127.00	17.48
	62	421.00	57.96
	63	138.81	19.11
	66	30.00	4.13
Soil group (Soil type)	Ferralsols	308.87	42.59
	Gypsisols	46.76	6.45
	Fluvisols	25.75	3.55
	Luvisols	341.54	47.09
	Vertisols	2.37	0.33
LULC type	Dense forest	101.78	14%
	Medium forest	123.59	17%
	Barren landd	14.54	2%
	Water body	14.54	2%
	Built-up	29.08	4%
	Agricultural land	443.47	61%
Slope (in degree)	0-12	350.49	48%
	13-25	375.35	51.70
	above 25	0.13	0.02
Elevation (in m)	0-39	0.20	0.03
	40-68	220.51	30.37
	69-98	272.87	37.58
	99-127	196.77	27.10
	128-156	35.73	4.92

Table 5.6 Pairwise comparison matrix for AHP

Criteria	Distance from river	Rain	Clay	Sandy	Silt	Nitrogen	Organic carbon	pH	Soil group	LULC	Slope	Elevation
Distance to river	1	5	2	2	2	4	4	4	6	8	9	9
Rain	0.2	1	2	2	2	4	4	4	5	7	9	9
Clay	0.5	0.5	1	2	2	3	3	3	5	3	4	4
Sandy	0.5	0.5	0.5	1	2	3	3	3	5	3	4	4
Silt	0.5	0.5	0.5	0.5	1	3	3	3	5	3	4	4
Nitrogen	0.25	0.25	0.33	0.33	0.33	1	2	2	5	3	4	4
Organic carbon	0.25	0.25	0.33	0.33	0.33	0.5	1	2	5	3	4	4
pH	0.25	0.25	0.33	0.33	0.33	0.5	0.5	1	5	3	4	4
Soil group	0.16	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1	5	9	9
LULC	0.12	0.14	0.33	0.33	0.33	0.33	0.33	0.33	0.2	1	9	9
Slope	0.1	0.1	0.25	0.25	0.25	0.25	0.25	0.25	0.1	0.1	1	9
Elevation	0.1	0.1	0.25	0.25	0.25	0.25	0.25	0.25	0.1	0.1	0.1	1

Table 5.7 Normalised pairwise matrix of AHP

Criteria	Distance to river	Rain	Clay	Sandy	Silt	Nitrogen	Organic carbon	pH	Soil group	LULC	Slope	Elevat ion	Criteria weighta ge
Distance to river	0.220	0.807	0.120	0.212	0.188	0.248	0.224	0.202	0.291	0.336	0.226	0.130	0.220
Rain	0.044	0.161	0.120	0.212	0.188	0.248	0.224	0.202	0.243	0.294	0.226	0.130	0.161
Clay	0.110	0.081	0.120	0.212	0.188	0.186	0.168	0.152	0.243	0.126	0.101	0.058	0.120
Sandy	0.110	0.081	0.120	0.106	0.188	0.186	0.168	0.152	0.243	0.126	0.101	0.058	0.116
Silt	0.110	0.081	0.120	0.053	0.094	0.186	0.168	0.152	0.243	0.126	0.101	0.058	0.094
Nitrogen	0.055	0.040	0.120	0.035	0.031	0.062	0.112	0.101	0.243	0.126	0.101	0.058	0.092
Organic carbon	0.055	0.040	0.120	0.035	0.031	0.031	0.056	0.101	0.243	0.126	0.101	0.058	0.056
pH	0.055	0.040	0.120	0.035	0.031	0.031	0.028	0.051	0.243	0.126	0.101	0.058	0.051
Soil group	0.035	0.032	0.120	0.021	0.019	0.012	0.011	0.010	0.049	0.210	0.226	0.130	0.049
LULC	0.026	0.023	0.120	0.035	0.031	0.020	0.019	0.017	0.010	0.042	0.226	0.130	0.042
Slope	0.022	0.016	0.120	0.026	0.023	0.016	0.014	0.013	0.005	0.004	0.025	0.130	0.025

Table 5.8 Criteria influence for overlay analysis

Criteria	Influence (in %)
Distance to river	22
Rainfall	16
Clay	12
Sand	11
Silt	9
Nitrogen	9
Organic carbon	5
pH	5
Soil group	4
LULC	4
Slope	2
Elevation	1

5.7Suitability mapping

The irrigation suitability map of Shali River basin has been prepared to incorporate overlay analysis using GIS software. The resulting suitability values are separated into four groups: very high suitable land (75 – 100%), high suitable land (50 – 74%), moderately suitable land (25 – 49%), and low suitable land (0 – 24%). The result shows that very high and highly irrigation-suitable lands have been observed around 28% and 36% area of the Shali River basin, whereas, around 3% and 32% of the land have been found under moderate and low suitable areas. So, the Shali River basin has about 64% irrigation suitability land. Very high and high irrigation-suitable land is observed along the Shali River and the north, north-western and north-eastern portions because these portions are covered with fertile luvisols which are widely used for cropping and rich in nitrogen and organic carbon (Figures 5.15). Overall irrigation land suitability result shows that Shali River basin has around 64% irrigation-suitable land. These suitable lands are observed along the Shali river and north, north-eastern, and north-western portions because these portions are covered with fertile luvisols which are widely used for cropping and rich in nitrogen and organic carbon (Table 5.8).

Table 5.8 Irrigation land suitability analysis results

Suitability type	Area in km^2
Very High	201.15
High	255.26
Moderate	24.04
Low	226.97

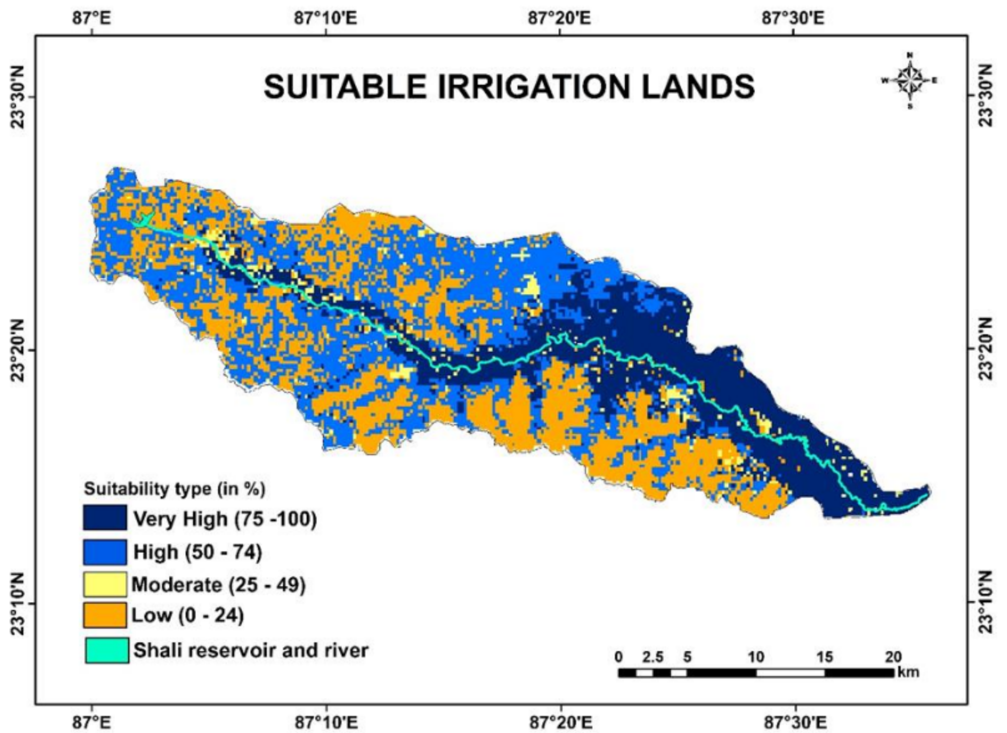

Figure 5.15 Irrigation suitable land of the Shali basin

5.8 Block-wise irrigation land suitability analysis

The block-wise irrigation suitability analysis shows that Gangajalghati block has around 9% very high suitable irrigation land of the total amount of very high suitable irrigation land, which is concentrated along the Shali River. In Barjora block, around 19% area has been observed under a very high irrigation suitable category. Whereas in Sonamukhi block around 52% area has been identified under the very high irrigation suitable category and Patrasayer block has around 19% very high suitable irrigation land. In the highly suitable category, Gangajalghati block has around 39% high suitable irrigation land, Barjora block has around 44% and Sonamukhi block has around 15% high suitable irrigation land. Whereas, Patrasayer block has only 0.6% highly suitable irrigation land. In the moderate irrigation suitability category, Gangajalghati and Barjora blocks have around 35% and 30% irrigation-suitable land. Sonamukhi block has around 26% moderate irrigation suitable land but Patrasayer block has around 7% moderately suitable land. In the low irrigation land suitability category, Gangajalghati and Barjora blocks have around 37% and 34% low irrigation suitable land. Whereas, Sonamukhi and Patrasayer blocks have around 24% and 2% low irrigation suitable land (Figure 5.16) (A1. Ch. 5.2).

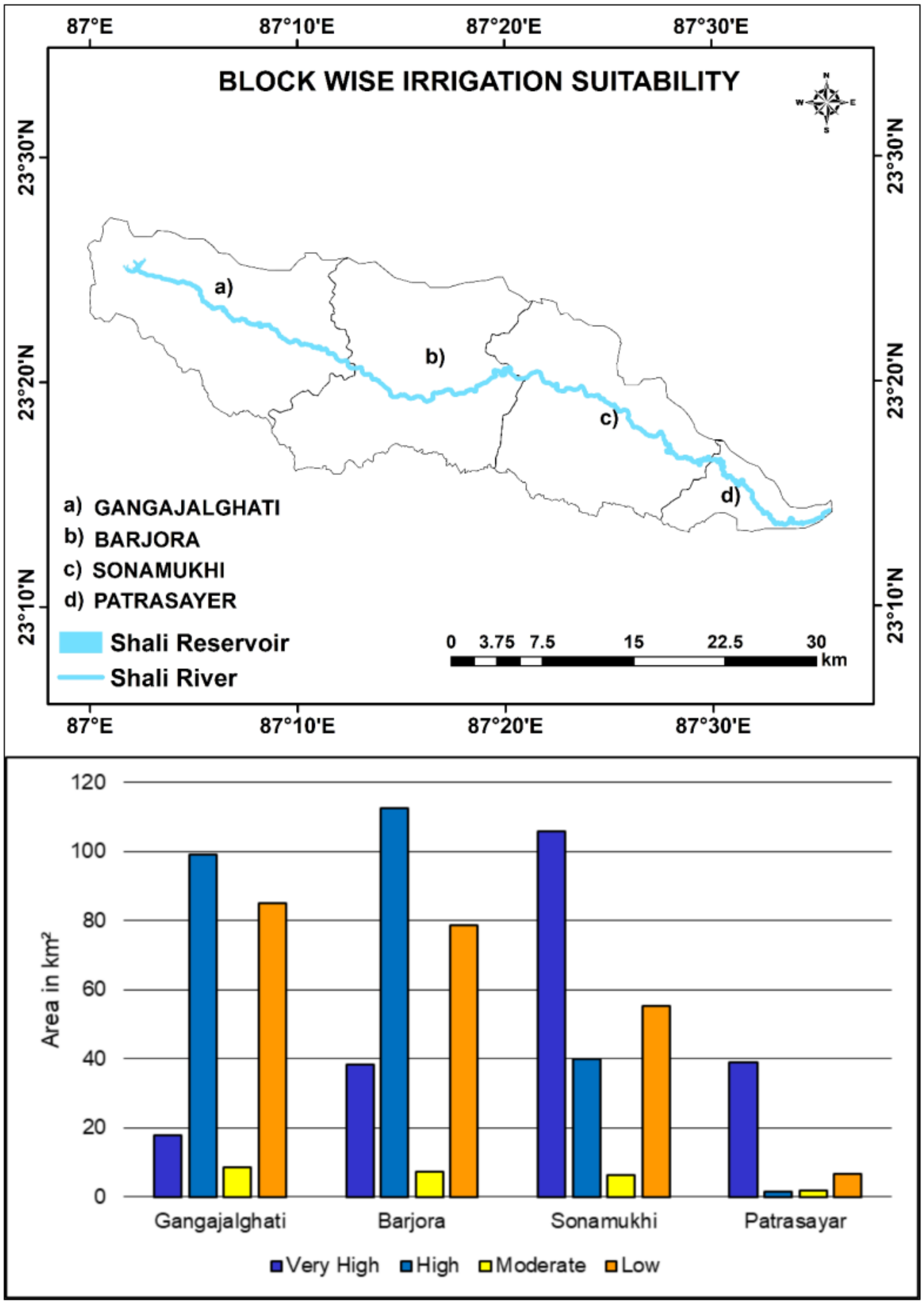

Figure 5.16 Block-wise irrigation suitability of Shali River basin

Table 5.9 Villages found very highly suitable for irrigation

Area (in ha)	Village names
220 – 615	Keshiara, Kapishtha, Sankara, Radharamanpur, Palshare, Rautara, Purba Patrahati, Ban Paruliya, Nischinapur, Rampur, Karachmani, Kendgare, Balarampur, Benda, Mamudpur
117 - 219	Thumkonra, Bhairabpur, Ramnagar, Amthia, Gopinathpur, Bankurardanga Tentulia Danga, Bhatla Para, Abhirampur, Muktapur, Tilasuli, Bhalukapahari, Benachapara, Bhairabdanga, Dhulai, Harishchandrapur, Shitaljor, Dubrajhati, Kamardanga, Katnia, Birsingpur, Paschim Patrahati, Ruppal, Rupat Ganj, Bahulia, Shyamsundarpur, Basumara, Rampur, Churamanipur, Amghata, Salda, Saheb Ganj, Goltor, Khuldanga, Amshol, Nanchanhati, Jaga Mohanpur, Sona Dwipa, Rajda, Chakdhoyakure, Anandapur, Lalpur, Muktapur, Khosalpur, Dhamsa, Telsanra, Dayalpur
1 - 116	Mandarbani, Numuigarya, Gururbad, Kotalpukur, Balikhun, Arjuni, Baradihi, Shuabasa, Harekrishnapur, Ita Dangra, Shirsha, Dharampur, Dhwajamanipur, Phulberrya, Damodarpur, Dangarpara, Bahadurpur, Madhabpur, Kanchchala, Selera, Dhabani, Mandi, Namaghansara, Kururiya, Balarampur, Malkuriya, Ekarya, Majuddagara, Nischintapur, Radharamanpur, Salbedya, Gobindapur, Kallapur, Suara, Sonagara, Nabasan, Charadihi, Gobindapur, Khopaganj, Pataspur, Jemua, Chandaibot, Gopalpur, Palsana, Bhiringi, Malkonra, Barajuri, Arba, Bihar Jurya, Gobardhanpur, Pirrabani, Birndabanpur, Radha Krishnapur, Saldanga, Purushottampur, Krishnapur, Mathuaberia, Bhairobpore, Rauetara, Borkura, Maturadaga, Radhakantopore, Srikrishnopore, Kantobese, Nityanandopore, Gangabad, Pathan Palashi, Manush Mari, Bank Simla, Belgaria, Belut, Ulai, Pear Bera, Paschim Nandapur, Basu Nandanpur, Kubir Bandh, Shibdanga, Jaypur, Karjbani, Aligang, Baikunthapur, Jambani, Patjor. Parbbatia, Shalchaturia, Hamirhati, Khausa, Basumara, Jashra, Patsol, Ratnapur, Mathurabati, Bara Narayanpur, Bhulai, Kesheshal, Tiuera, Kalyaanpur, Bedamushal, Dakshinashol, Indokata, Shapuradii, Sonaamukhi, Kshertamohanpur, Siltiya, Maheshpur, Madanmohanpur, Chaitanpur, Bhaluk Khan, Bneshe, Junshara, Naruala, Kuchiagopalpur, Dhan Simla, Kendua, Machdoba, Ranibandh, Dhagaria, Hamirpur, Khamardihi, Hadal, Ram Nagar, Sonatikri, Parulia, Keshabpur, Brindaban Pur, Chak Patrasayer, Panch Para, Arbetal, Saulia

5.9 Village-wise irrigation land suitability

In village-wise irrigation land suitability analysis, very high and high irrigation-suitable lands have been analysed based on the area (ha). The Shali River basin villages have a small area, therefore, village-wise suitability has been performed in hectares. Here, very high irrigation suitability areas are classified into three classes: 220-615 ha, 117-219 ha and 1-116 ha. In the

Shali River basin around 21 villages have 220–615 ha of very highly suitable irrigation land and 64 villages have 117-219 ha of very highly suitable irrigation land. Whereas, about 95 villages have 1-116 ha of very high suitable irrigation land. (Figures 5.18 and 5.19) (A1. Ch. 5.3).

Table 5.10 Villages found highly suitable for irrigation

Area (ha)	Village names
373 - 913	Saharjora, Metia Narayanpur, Hanri Bhanga, Dangarpara, Bahadurpur, Thumkonra, Dhabani, Kapishtha, Kallapur, Tentulia Danga, Jashra,
188 - 373	Shitla, Koch Kunda, Khanrari, Uara, Baradihi, Nadihi, Bamundiha, Shuabasa, Harekrishnapur, Gopkande, Purunia, Sangrampur, Lakshminarayanpur, Banshol, Dharampur, Selera, Bhairabpur, Balarampur, Ekarya, Nischintapur, Gobindapur, Suara, Gopalpur, Malkonra, Barajuri, Ramkanali, Bihar Jurya, Pirrabani, Birndabanpur, Bhatla Para, Benachapara, Manush Mari, Bhula, Kuchiagopalpur, Saulia
1 - 188	Muktatar, Beleshola, Chak Keshya, Manjmura, Monoharbati, Kanchanpur, Pabayan, Dakaisini, Deucha, Dejuri, Chhotalalpur, Hahtashuriya, Mondarboni, Dewangarya, Sharali, Madnahati, Numuigariya, Kelai, Guruband, Kotolpur, Balikhun, Arjune, Bararampur, Sagarya, Nutangram, Khajuri, Payermohan, Jamshala, Chhotalacchipur, Chholabaid, Ita Dangra, Shirsha, Gangadharpur, Kalpaini, Dhwajamanipur, Phulberrya, Nutangram, Madhabpur, Kanchchala, Ramchandrapur, Mandi, Kururiya, Malkuriya, Majuddagara, Gadardi, Radharamanpur, Salbedya, Ramnagar, Sonagara, Sankara, Nabasan, Charadihi, Gobindapur, Khopaganj, Pataspur, Jemua, Chandaibot, Palsana, Bhiringi, Dandulya, Kenduabari, Arba, Ashanchuya, Arjunpore, Horekrishnopur, Swargabati, Gobordhonpur, Radhakrishapur, Amthia, Gopinathpur, Bankurardanga, Saldanga, Purushottampur, Abhirampur, Muktapur, Tilasuli, Bhalukapahari, Krishnapur, Mathuaberia, Bhairabdanga, Raoutara, Barakura, Rajamadhavpur, Radhakantopore, Shrikrishnapore, Kantobese, Nityanandopore, Gangaband, Duulai, Pothanpolasi, Banksimla, Belagariya, Pashchimdubrajpore, Krishnonagar, Belut, Harishchandropore, Radharamonpore, Ulaai, Peerbera, Prayagpore, Paschim Nandapur, Basunandopore, Shitolaljar, Kubirband, Dubrajahati, Sibdaga, Kumardanga, Birshingopur, Pashchimpotrahati, Palasaree, Aligangj, Jamboni, Patjor, Parbotiya, Baahulia, Salchaturiya, Haamirhati, Basumara, Khausa, Bashumora, Patshal, Ratnopore, Mothuraboti, Boronarayanpore, Narayanpur, Kesheshol, Khayrakura, Churamanipur, Tiura, Bhedomushal, Rautara, Saheb Ganj, Goltor, Nanchanhati ,Purba Patrahati, Naruala, Nischinapur, Ramchandrapur, Kunda Pushkarini, Kashipur, Baharpur, Dhan Simla, Karachmani, Ranibandh, Chakdhoyakure, Kendgare, Khamardihi, Dayalpur, Mamudpur, Arbetal

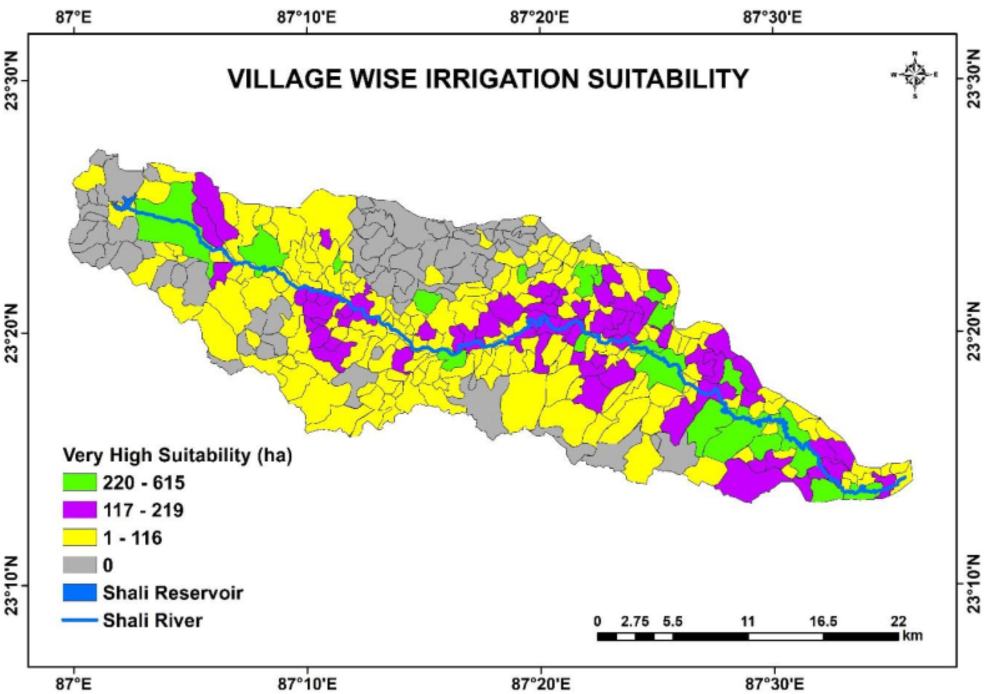

Figure 5.17 Village-wise very high suitability land

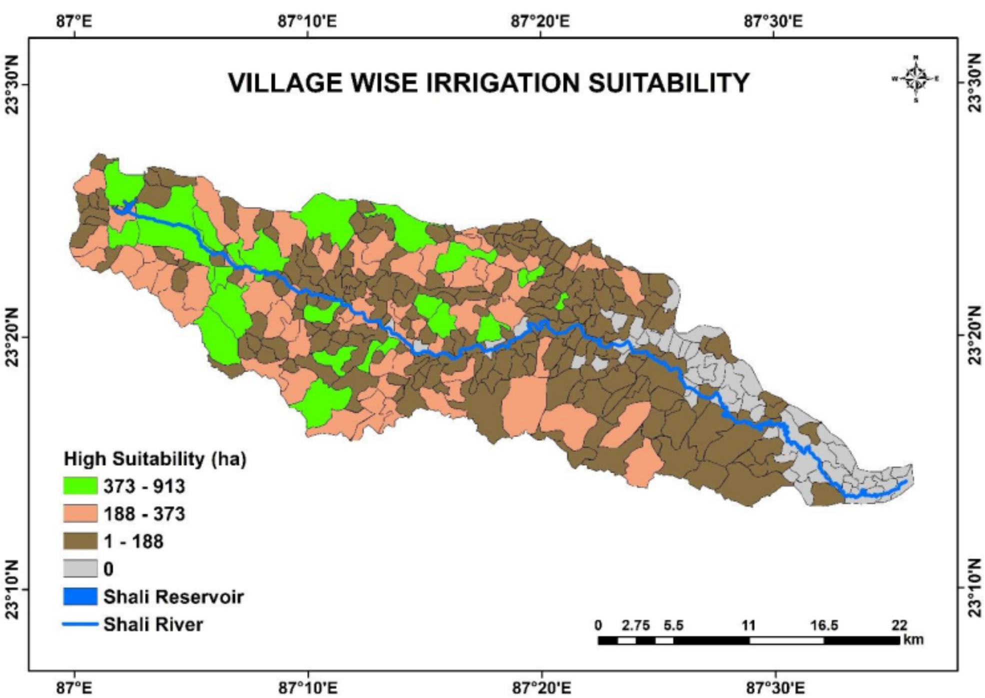

Figure 5.18 Village-wise high suitable land

While around 70 villages have no very high suitable irrigation land. The high irrigation suitable land category is also classified into three classes: 373-913 ha, 188-373 ha, and 1-188 ha respectively. In the Shali River basin around 23 villages have 373-913 ha high suitable irrigation land and 67 villages have 188-373 ha high suitable irrigation land. Whereas, around 109 villages have around 1-188 ha high suitable irrigation land and 51 villages have no high irrigation suitable land.

5.10 Conclusion

Shali River basin receives a little low amount of monsoonal rainfall than other parts of West Bengal. Therefore, the Shali reservoir is made at the origin of the Shali River stores monsoonal water and provides irrigational water through the Shali River. Shali reservoir helps to cultivate both summer and winter crops. The foremost objective behind the study highlighted in this chapter is to prepare an irrigation land suitable map of the Shali reservoir to identify the potential land for irrigation. The AHP has been applied to prepare irrigation land suitability analysis. AHP and MCDA processes require several measures, so based on literatures, 12 criteria are selected such as slope, relief, soil group, soil texture (clay, sand, silt), soil properties (nitrogen, pH, organic carbon), LULC, distance from river and rainfall. Then, the normalised pairwise matrix has been created to generate the criteria weightage of each factor. The criteria weightage analysis results that the distance from the river has the maximum influence over other parameters. Then based on the weightages of each criterion, the final irrigation land suitable map has been produced using overlay analysis. Results show that the Shali River basin has around 64% irrigation-suitable land. These suitable lands are observed along the Shali River and north, north-eastern, and north-western portions because these portions are covered with fertile luvisols which are widely used for cropping and rich in nitrogen and organic carbon. Suitability analysis shows that the villages of Sonamukhi block have the highest number of very high irrigation suitable land but the villages of Gangajalghati and Barjora blocks have the highest number of high irrigation suitable land. These two blocks are situated near the Shali reservoir (upper portion of the Shali River basin); therefore, they are getting more irrigational water than the other two blocks namely Sonamukhi and Patrasayer. The irrigational suitability reveals that the villages near the river have highly irrigation-suitable lands. So, it can be said that the distance to the river is playing a major role because it determines the irrigation water availability.

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Distribution of irrigated areas

6.1 Introduction

In the previous chapter, irrigation land suitability analysis reveals that the villages located near the Shali River have the maximum amount of irrigation suitability land. Therefore, in this chapter village-wise and block-wise irrigated area transformations have been analysed using Census population data sets (1991, 2001 and 2011). Here irrigated area signifies those areas which are irrigated by the Shali reservoir and Shali River.

6.2 Chapter outline

The chapter has been categorised into two segments. In the first segment, block-wise irrigated areas have been discussed, whereas in the second segment, village-wise irrigated area distribution has been observed. A correlation analysis has also been made between village-wise suitable land and irrigated areas to validate the irrigation land suitability results.

6.3 Method

Z- Score

It is a statistical method that defines an association between values among mean values. It is computed as SD from the mean. It can be negative or positive. The positive value indicates the score is higher than the mean and the negative value indicates below the mean (Mahmood 1998). Here Z-Scores have been calculated (Eq. 6.1) to discover the village-wise distribution of irrigated areas in 1991, 2001 and 2011.

$$Z \text{ score} = \frac{x - \bar{x}}{\delta} \tag{6.1}$$

where, x = individual value, $\bar{x}$ = mean, δ = SD.

6.4 Block-wise irrigated area

After the creation of the Shali reservoir growth in agricultural land has been observed. According to Bankura district census datasets, in 1991 the mean and SD of irrigated areas of Gangajalghati block were around 58.90 and 60.51 km^2 and in 2001 they increased to around 63.31 and 68.52 km^2. Whereas, in 2011 the mean and SD of the irrigated area increased to 66.52 and 75.05 km^2. It signifies that after the creation of the Shali reservoir irrigation project, the number of irrigated areas has increased in the Gangajalghati block.

In 1991, the mean and SD of irrigated areas of Barjora block were around 19.63 and 26.95 km^2. Then in 2001, a positive change was observed. The mean and SD of the irrigation area were increased in the Barjora block to 24.59 and 31.67 km^2. Whereas, in 2011 it increased to 28.77 and 34.07 km^2.

In the Sonamukhi block, around 46.4 and 45.53 km^2 irrigated mean and SD were observed in 1991 but in 2001 positive changes were noticed in mean and SD. While in 2011, a slight decrease was observed in irrigated mean and SD in the Sonamukhi block. In 2011 the irrigated mean and SD of the Sonamukhi block were 68.3 and 73.20 km^2.

In the Patrasayer block, around 83.10 and 67.27 km^2 of irrigated mean and SD were observed in 1991. A positive change was identified in 2001, the mean and SD increased to 90.06 and 69.49 km^2 but in 2011 they decreased to 86.22 and 66.24 km^2 (Figures 6.1 and 6.2) (A1. Ch. 6.1).

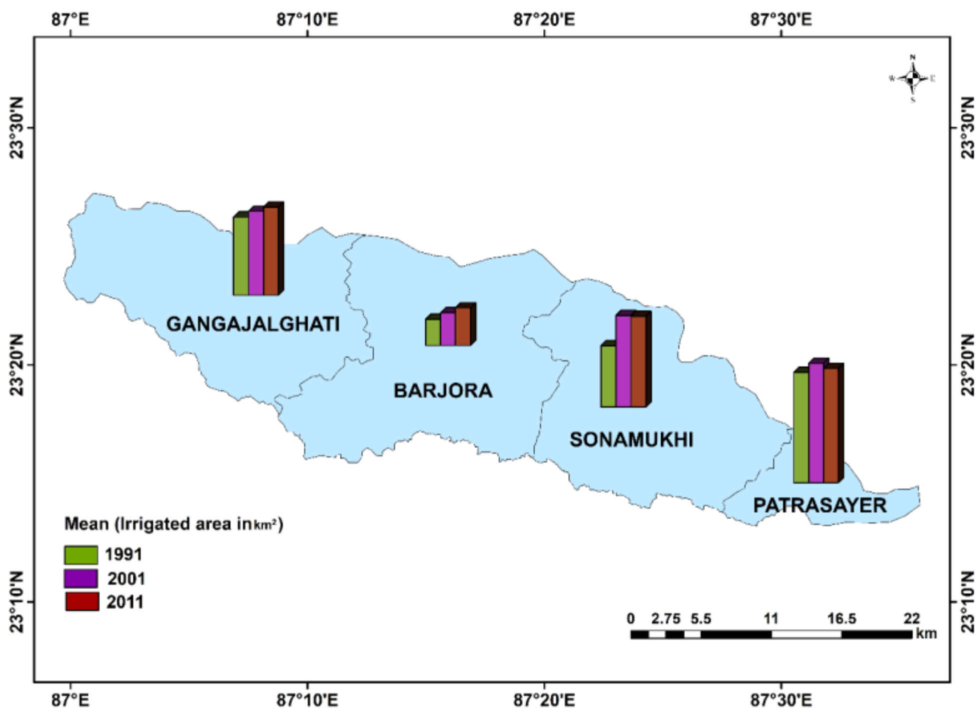

Figure 6.1 Block-wise mean irrigated areas of the Shali River basin

The block-wise irrigated land analysis signifies that after the creation of the Shali reservoir irrigation project irrigational development has occurred in Shali River basin but the upper portion is getting more benefit than the lower portion. Maximum irrigation development has been observed in Gangajalghati and Barjora blocks. These two blocks are in the upper portion of Shali River basin and get more irrigation water than the lower part blocks (Sonamukhi and Patrasayer).

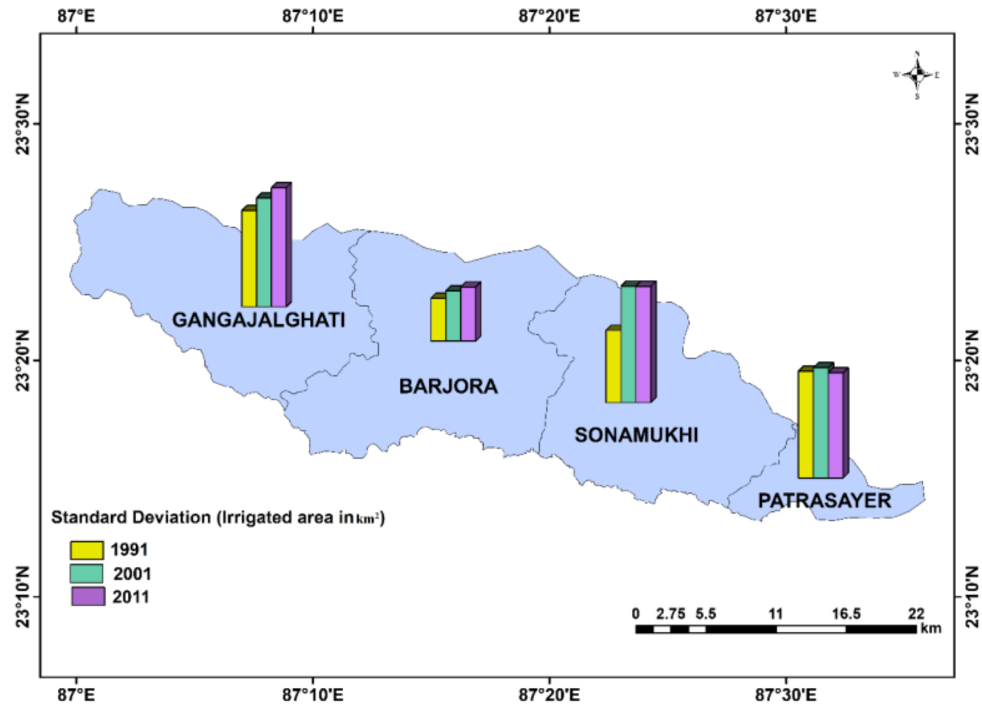

Figure 6.2 Block-wise SDs of irrigated areas of the Shali River basin

6.5 Village-wise distribution of irrigated area

The Shali River basin consists of around 339 villages. Therefore, the Z-score magnitudes have been calculated to analyse the village-wise distribution of irrigated areas of the Shali River basin. The Z-Score magnitudes have been categorised into, 3 identical classes: High, Moderate and Low. The high positive Z-Scores magnitudes (above 1) are considered as High, medium, and low positive magnitudes (0-1) as Moderate and negative magnitudes (below 0) are considered as Low. According to Bankura census data, in 1991 the mean of the irrigated area was 53.70 km^2 and the SD was 64.46, whereas after the Shali reservoir creation in 2001 mean of the irrigated area was 60.28 and the SD was 78.07 km^2. In 2011, the mean and SD of the irrigated areas were 66.70 and 74.42 in the Shali River basin.

Here, the positive magnitude of Z scores has been considered a favourable sign for cultivators than the negative Z score values, because the negative Z score value determines that the villages have a lower irrigated area than the average value. A z score having a smaller positive magnitude indicates a more secure state than a Z score having a smaller negative value. Once the Z scores are positive and high positive, it states that the concerned village is in a better position than the other villages. Near to negative and negative Z scores represents an inferior state in the concerned villages. In 1991, 12 villages have been found in better condition which a z-score magnitude is more than 1 and 60 villages have a Z-score value of 0-1. After the creation of the Shali reservoir irrigation project irrigated area has been improved in the Shali River basin area. High and moderate irrigated villages increased from 1991 to

2001. In 2001, around 23 villages of the Shali River basin have Z-score values of more than 1 and around 96 villages have Z-score values between 0-1. Whereas, in 2011 the number of high and moderate-irrigated villages have been increased to 51 and 113. Therefore, it is clear that after the Shali reservoir irrigation project there are a lot of improvements in irrigation have been observed in the Shali River basin area (A1. Ch. 6.2).

Table 6.1 Number of villages based on Z-score values

	Number of Villages		
Year	High (above 1)	Moderate (0-1)	Low (below 0)
1991	12	60	267
2001	23	96	220
2011	51	113	175

6.6 Correlation between village-wise irrigation suitability and irrigated areas

In the correlation method, village-wise irrigated areas are considered '*x*' axis and village-wise suitable lands are considered as the '*y'* axis. The correlation between village-wise irrigation suitability and irrigated areas shows a positive correlation and the R^2 value is 0.90. Therefore, the AHP produced an acceptable outcome that has been verified which means, high irrigation suitable areas have high irrigated areas and vice versa (Figure 6.6).

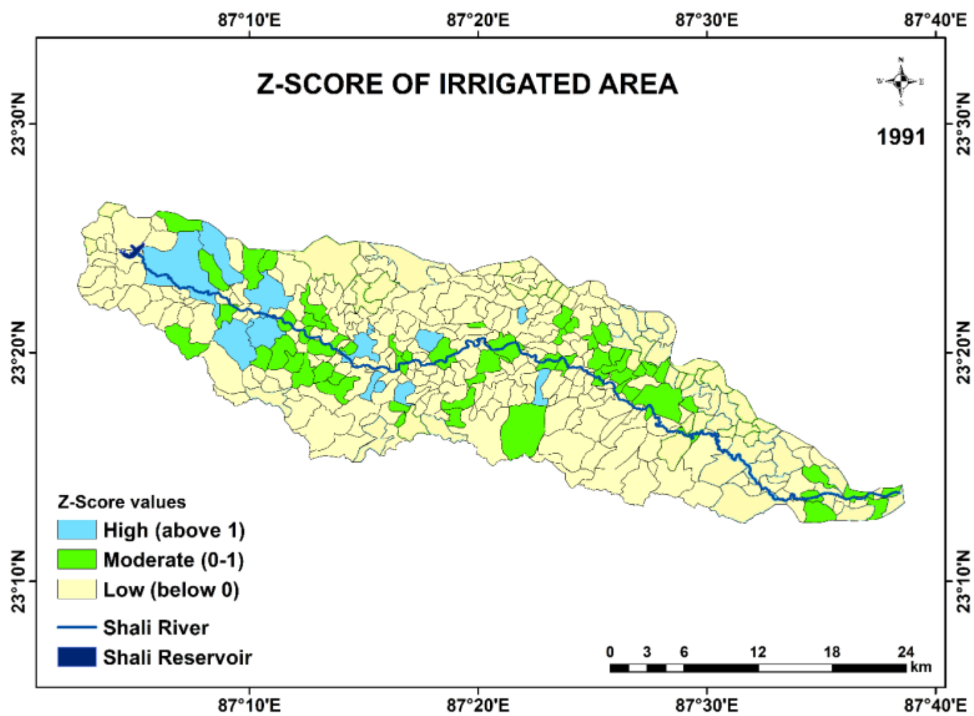

Figure 6.3 Z-score of irrigated area of Shali River basin in 1991

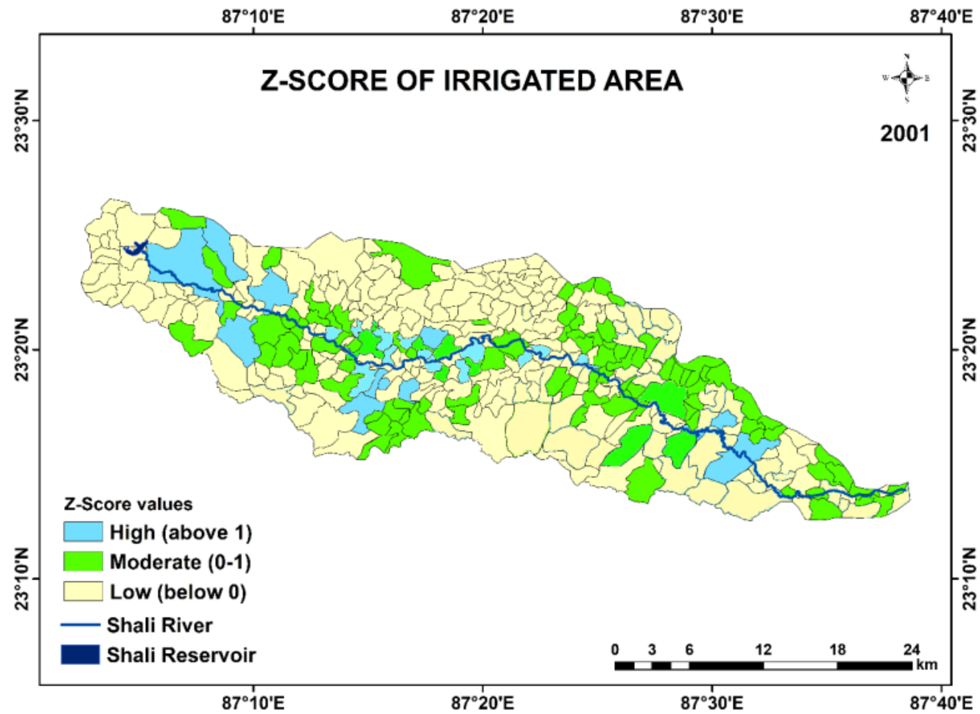

Figure 6.4 Z-score of irrigated area of Shali River basin in 2001

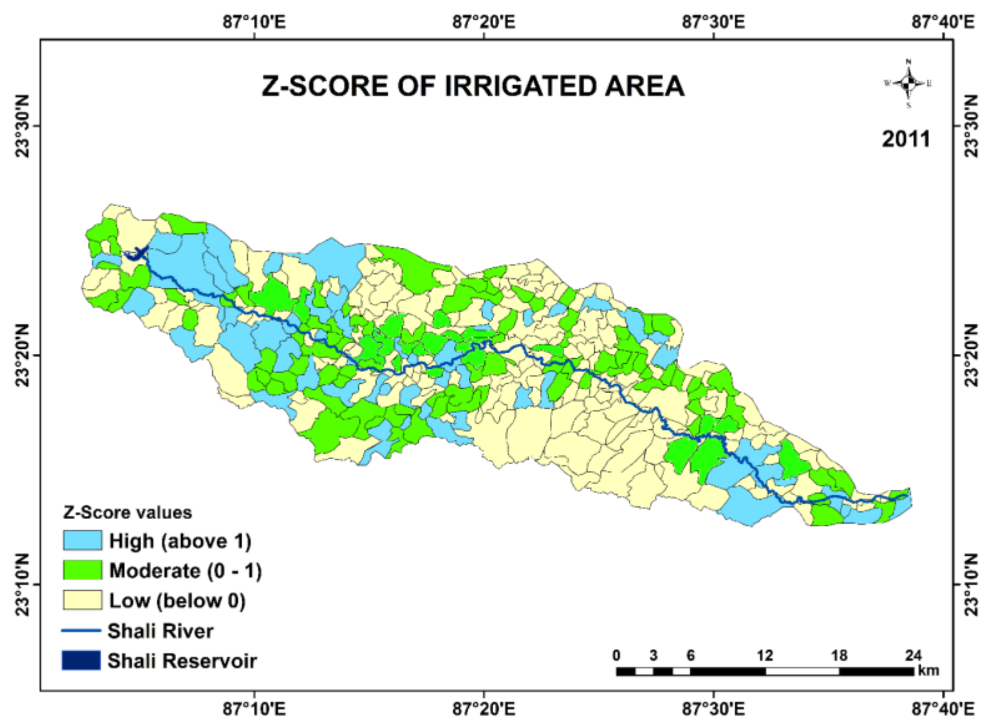

Figure 6.5 Z-score of irrigated area of Shali River basin in 2011

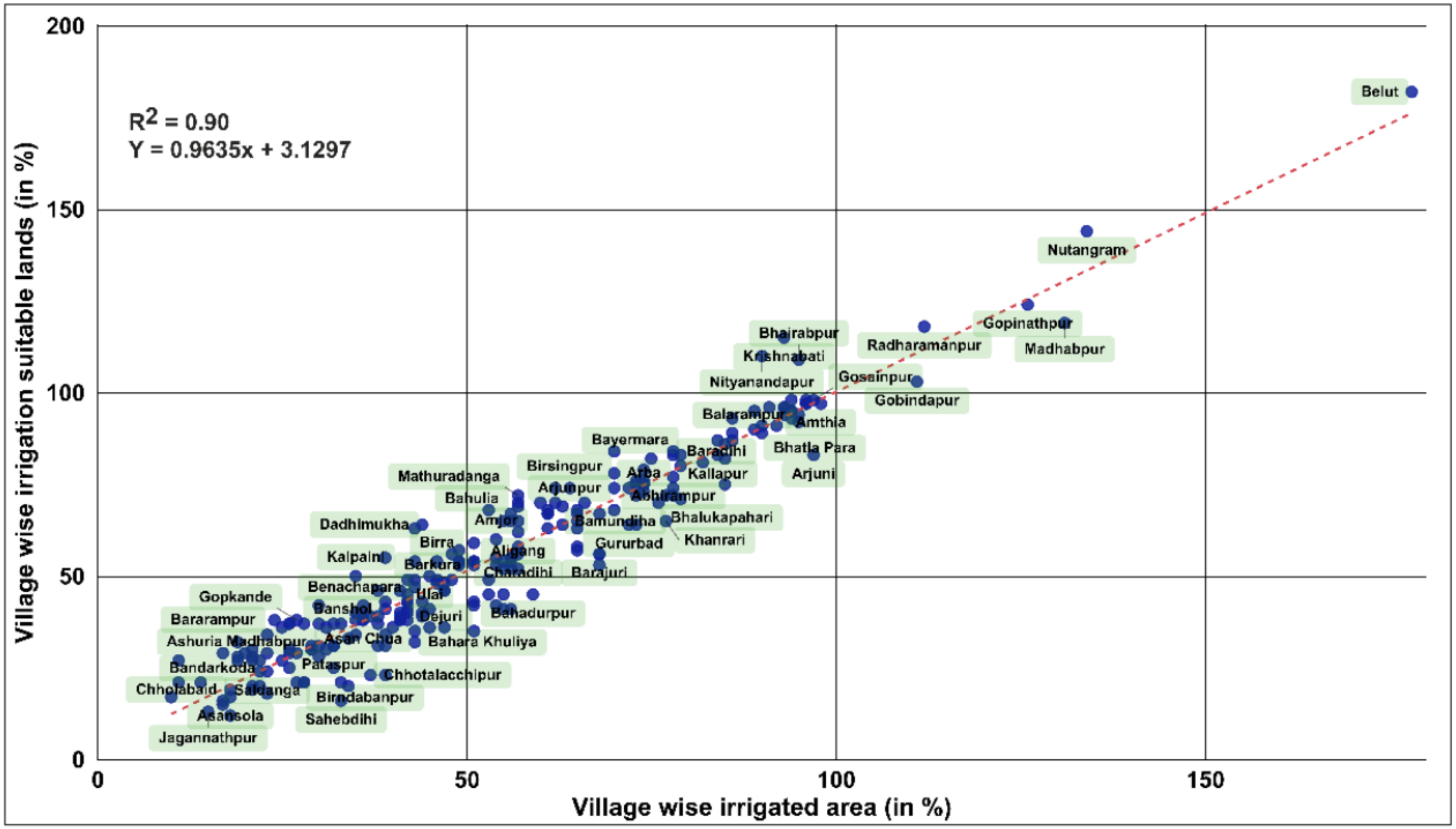

Figure 6.6 Correlation between village-wise irrigated area and irrigation-suitable lands

6.7 Conclusion

This chapter analyses the allocation of irrigated areas in Shali River basin after the creation of the Shali reservoir irrigation project. The study reveals that the number of irrigated areas has increased from 1991 to 2011. Block-wise study approves that the Gangajalghati and Barjora blocks are getting more benefits than the other two blocks in the Shali River basin. whereas, village-wise analysis reveals that the number of low-irrigated villages has been reduced from 1991 to 2011. In 1991, around 267 villages have low irrigated areas but in 2001 it reduced to 220 villages. Whereas, in 2011 a huge change has been observed, around 175 villages were found under the category of low irrigated area. Maximum changes have been observed near the Shali Riverside villages.

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Chapter 7

Change in seasonal crop production area

7.1 Introduction

In chapter 6, the impact of the Shali reservoir on irrigated areas has been analysed. The results address that after the creation of the reservoir, the number of irrigated areas have been increased in the Shali River basin. In this chapter major crops of the Shali River basin have been discussed. Shali reservoir and Shali River basin are in the Bankura district. Since basin-wise crop-related information is not available thus, Bankura district's crop production scenario has been discussed in this chapter for better understanding.

According to I&WD, the Shali River basin area produces both the Kharif (summer) and Rabi (winter) crops after the creation of the Shali reservoir. West Bengal Directorate of Economics and Statistics Reports (2014) stated that rice, wheat, potato, and mustard are the key crops but rice is the predominant crop over other crops of the Shali River basin area. The Shali River basin is situated in the Bankura district where paddy production is comparatively high than in the other districts of West Bengal. In West Bengal, rice is the predominant crop among oil seeds, cereals, and other food crops. According to the DES (2020-21) data, West Bengal has the maximum amount of rice production area after Uttar Pradesh but this state produces the highest amount of rice than other rice-producing states. In West Bengal, season-wise, three varieties of rice cultivation have been observed. They are aman, aus and boro.

7.2 Chapter outline

This chapter is categorised into two segments. In the first segment, the major produced crops: rice/ paddy, potato, wheat, and mustard of the Shali River basin have been discussed. Meanwhile, in the second segment seasonal crop mapping has been done by utilising RS methods. Rice is the main crop of this region so; rice mapping has been done to produce a clear view of the rice production area. The following method is incorporated to observe the change in seasonal crop production area (Figure 7.1).

7.3 Literature reviews

Seasonal rice area mapping using remote sensing techniques was never done before for the Shali River basin area. So, a brief literature review has been done on this topic.

The detailed literature reviews of crop mapping reveal that rice mapping is very popular than other crops because it considers a major food staple around the globe. Universally, about 50% of people consume rice. Rice mapping reveals that during 1980 – 1990, RS data sources were incorporated for mapping of rice fields and in present days' work-related rice mapping has increased worldwide. To explore the studies on rice mapping using remote sensing, the Scopus database has been used in this study. About 40 documents (37 research articles, 2 review articles, and 1 short survey) have been found on rice mapping from 1999 to 2021 using remote sensing. After 2020, the number of articles on rice mapping using remote sensing data has increased rapidly.

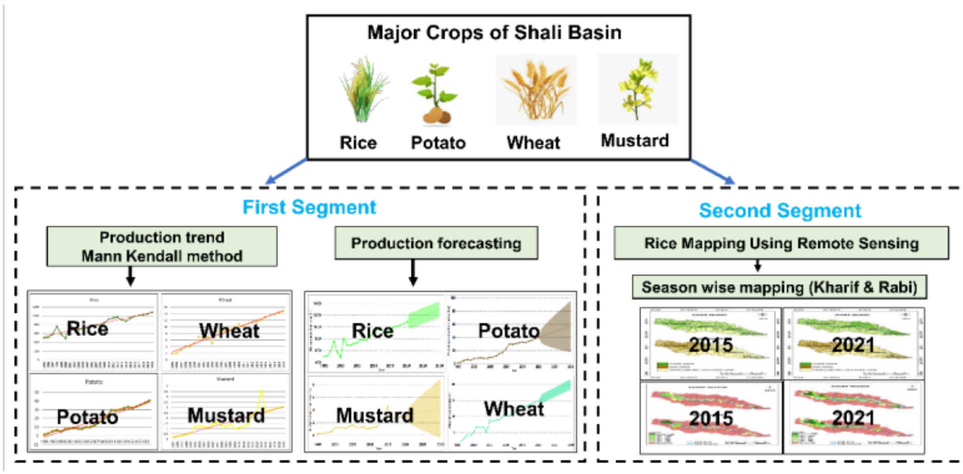

Figure 7.1 Chapter outline

Rice mapping is becoming very popular in the present day. Remote sensing techniques are used in rice mapping (Dong and Xiao, 2016). From 1980 to 1990, the major source of rice mapping was Landsat MSS and TM datasets. (Rao and Rao, 2007). Meanwhile, SPOT XS images were used for rice mapping (Turner and Congalton, 2010). Since 2000, improvement in rice mapping has been noticed. MODIS datasets were incorporated to distinguish rice fields (Peng et al., 2011). The use of vegetation indices in rice mapping increased. EVI and NDVI were used broadly in rice mapping. Besides NDVI and EVI, some water-based indices were also used to create rice mappings such as LSWI and NDWI. (Singha et al., 2016; Son et al., 2013; Kontgis et al., 2015; Dong and Xiao, 2016). Since 2015, Sentinel 1 SAR datasets were becoming very popular in rice mapping. It produces 10 m spatial resolution images that can determine rice areas precisely (Cai et al., 2019).

McCloy et al., (1987) utilised Landsat MSS datasets for rice mapping in Murumbridgee of South Wales which was the major rice-producing region. They used 1984 and 1985 images for rice mapping. Maximum likelihood classifier (MLC) applied in image classification. Aerial photographs were used to validate the results. The result showed that Landsat images produced 2.6% greater rice area than aerial photographs. They concluded that mapping with aerial photographs was costlier than Landsat images. So, they recommended Landsat data sets for rice mapping.

Dong et al., (2016) applied phenology and pixel-based paddy mapping (PPPM) algorithm in rice mapping. They mapped the rice-growing regions of north-eastern Asia, comprising North Korea, Japan, South Korea, and China (north-east). All images of Landsat OLI 8 in 2014 were used for rice mapping. The outcome produced good accuracy (92%) and gave a brief layout of rice distribution.

Cao et al. (2020) used Landsat OLI 8 times series data from 1988 to 2017 in rice mapping of the Ganphu plain of China (south). They applied the EVI index for rice field detection. The result produced an overall accuracy between 82% to 93%. The time series data revealed that from 1988 to 2017, the rice-producing areas were reduced.

Peng et al. (2011) incorporated MODIS datasets in rice mapping, from 2000 to 2007 in Hunan province China. EVI and LSWI indices were used to identify different stages of rice production. The outcomes were justified with high-resolution (2.5 m) data sets and statistical rice area data of China and the results showed a positive correlation.

Gumma et al. (2014) used NDVI (MODIS) datasets to compute the seasonal rice regions of Bangladesh. MODIS-derived time series rice datasets were correlated with statistical rice production data of Bangladesh. The overall accuracy varied from 78% to 90%. They also mentioned that this approach was appropriate for the seasonal rice mapping of Bangladesh.

Luintel et al. (2021) investigated spatial and temporal variations in rice-producing areas of Nepal from 2003 to 2018. MODIS data and pheno rice algorithm were used for mapping. Results stated that the rice cultivated started earlier in western Nepal in comparison to the eastern portion. Time series data revealed a decadal negative change in rice-producing areas.

Clauss et al. (2018) used Sentinel 1 dataset to identify rice areas of the Mekong delta, Vietnam. They analysed the seasonal rice production of 2015 in the Mekong delta and validated the data with secondary datasets published by a district-level statistical office. The results showed a very positive correlation.

Cai et al. (2019) combined Sentinel 1 and 2 datasets to create good accurate rice field maps of the Dongting wetland of China. The object-based random forest (RF) method and time series data were used to identify rice-producing areas. The overall kappa accuracy was above 95%. They also mentioned that this method can identify rice fields during the rainy season. (Wei et al. 2021) used deep learning techniques to identify phenological similarities of rice distribution in a large area. For this purpose, they choose the Arakan River basin (58504 km^2). The sentinel 1 images of 2017 and 2018 (previous years) were collected to train the datasets and 2019 data was used to check the robustness of the network. The study results illustrated that the selected method was beneficial to identify phenological similarities of rice.

7.4 Data sources

For the first segment, the West Bengal Directorate of Economics and Statistics (2020) reports data and primary survey data sets are used to analyse the crop production trends for the Shali River basin. In India, crop production areas are measured in hectares (Directorate of Economics and Statistics, India, 2020), therefore in this chapter, no unit conversion has been performed to analyse the crop production area trend. All the analyses are performed in hectares.

In the second segment, seasonal rice production area mapping: Kharif and Rabi seasons have been done using remote sensing techniques. Rice is the predominant crop of the Shali River basin; thus, the focus has been given towards rice production in the Shali River basin area. The season-wise paddy production area was analysed through remote sensing techniques.

7.4.1 Sentinel - 1 SAR data for seasonal rice production zone mapping

It is an imaging radar, that can provide non-stop images in any atmospheric conditions. It has high consistency, improved visit time, geographical coverage, and rapid data broadcasting that support numerous effective applications: land and marine monitoring, disaster management etc.

Metadata and filtering of the Sentinel 1 SAR data

It is necessary to filter the Sentinel 1 SAR data set to create a homogenous subset. The filtering metadata fields are transmitted receiver polarisation, instrument mode, orbit properties and resolution.

Image properties

1. Every Image has three resolutions (10, 25 0r 40 meters)
2. Four Band combinations
3. Three instrument modes
4. Each image contains 1 or 2 possible polarization bands which depend on the instrument's polarization settings.

Band combinations

1. VV: single co-polarization, vertical transmit/ vertical receive
2. HH: single co-polarization, horizontal transmit/ horizontal receive
3. VV + VH : dual-band cross polarization, vertical transmit/ horizontal receive
4. HH + HV: dual-band cross polarization, horizontal transmit/ vertical receive

Sentinel 1 pre-processing

In this study, Google Earth Engine (GEE) cloud platform has been used to assess the Sentinel 1 SAR data sets. The GEE uses five pre-processing steps to derive the backscatter coefficient in each pixel. Such as applying orbit file, GED border noise removal, thermal noise removal, radiometric calibration, terrain correction etc. (google earth developers https://developers.google.com/earth-engine/guides/sentinel1) (GEE has been discussed in detail in the previous chapter).

7.5 Methods

In the first segment production area trend of major crops has been analysed using MK trend analysis and ARIMA forecasting method also used to forecast the production areas.

7.5.1 Mann Kendall (MK) trend analysis

Discussed in detail in Chapter 3.

7.5.2 ARIMA model

ARIMA Model, commonly used for time series forecasting. In 1970, Jenkins and Box formulated Autoregressive Integrated Moving Average (ARIMA) Model. It is an advantageous model which requires appropriate time-series datasets. It can forecast short-term datasets as well. This model comprises three segments: "AR" denotes autoregressive, "I" denotes variance and "MA" is equivalent to the moving average (Yang et al., 2021).

Table 7.1 ARIMA model structure

Parameters name	Meaning
q	Number of MA terms
p	AR coefficient
d	Time differential

The main phases of the ARIMA model are given thereafter.

Phase 1

In the first phase, it uses the ADF test to determine the stability of the time series data. After that, it determines the d parameter. If time-series datasets are unstable then it performs a different operation to make the data stable.

Phase 2

In the second phase, it calculates ACF and PACF which signify auto and partial correlation coefficient and also estimates the order of parameters (Table 7.1) and using the AIC rule determines the model parameters.

Phase 3

The last phase predicts the data after checking the model.

In the second phase of crop mapping, Sentinel 1 datasets are used from 2015 to 2021, because sentinel datasets are available from 2014 onwards.

7.5.3 Supervised classification

A supervised image classification technique has been adopted to map season-wise rice production area maps for 2015 and 2021. For classification, the RF classifier technique has been adopted to produce accurate classified maps. A detailed description of the RF classifier has been discussed in the previous chapter. For accuracy assessment, the kappa coefficient method has been applied which is also discussed in the previous chapter.

7.5.4 Linear regression analysis

Discussed in detail in Chapter 3.

7.6 Major crops in Shali River basin area

The planning commission and the national remote sensing agency divided India into 15 agroclimatic regions to reduce regional inequalities in agriculture. The Shali River basin is part of two agroclimatic regions: the eastern plateau hills and the lower Ganga plains. A maximum portion of Shali River basin falls under the eastern plateau hills and a few portions of Shali River basin is under the lower Ganga plain. The Chotonagpur plateau region is under the eastern plateau and hills regions. Here, the annual temperature ranges between 25-35°C during summer and 18-25°C during winter. The mean yearly rainfall varies between 10000-15000 mm. in this region soils are mainly red and yellow. Agricultural activities are mainly based on rainwater. The main crops of Shali River basin are rice, potato, wheat, mustard etc.

According to district statistical handbook data, the crop production area has improved from 1995-2020. In 1995, the amount of crop production area was around 504 hectares but in 2020, the amount of production area increased to around 1144 ha (Figure 7.2). The MK trend (Z score) of the crop production area is 5.86 which signifies a high positive trend. The forecasting analysis also shows a positive trend. In 2025 and 2030 the amount of crop production area will be around 1257 and 1379 ha (Figure 7.3) (A1. Ch. 7.1).

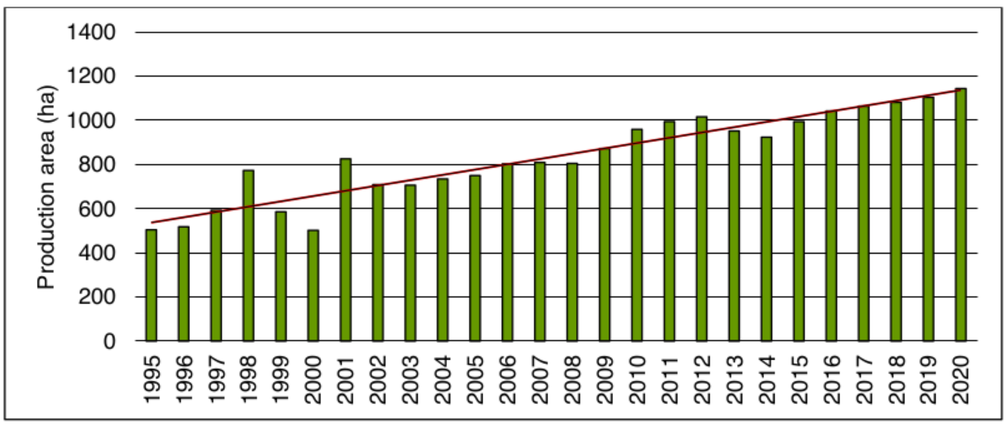

Figure 7.2 Crop production area trend of the Shali River basin

7.6.1 Rice/ Paddy

Rice (*Oryza sativa*) is a food staple for 50% and above of the population around the globe. There are a lot of controversies about the origin of rice. It was believed that rice is a tropical plant, though it was cultivated mostly in the Himalayan foothills. Contrarily, researchers consider that the rice plants originated in south India and then it spread to north India and China. Around 2000 B.C., rice arrived in Korea and the Philippines and around 1000 B.C. rice arrives in Japan and Indonesia. Though some researchers believed that, during 327 B.C.

Change in seasonal crop production area

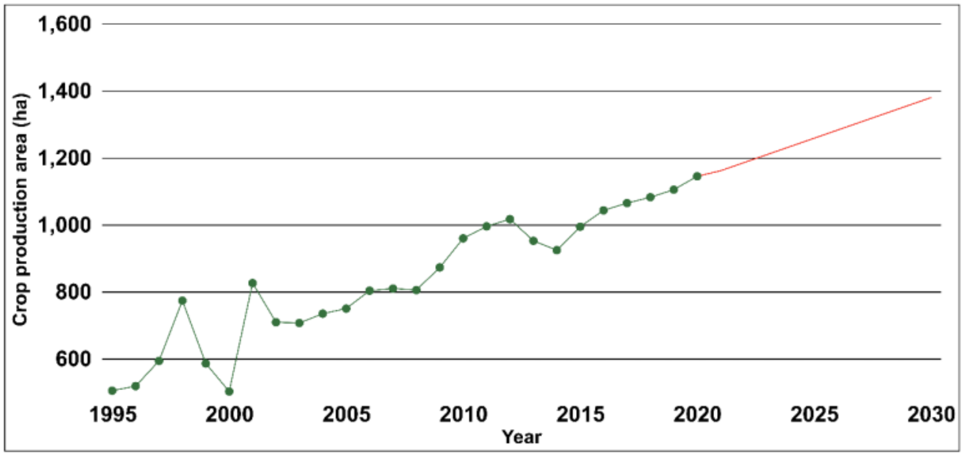

Figure 7.3 crop production area forecasting of the Shali River basin

Alexander invaded India and took rice from India to Greece. Then Arab travellers took it to Egypt, Morocco, and Spain. In this way, rice travelled across the Globe. However, the journey of rice across the globe was sluggish, nonetheless, it became a major agricultural and economic product in every country where it has been travelled. It became an essential food grain around the world wide (Rice in India: A Status Paper, 2014).

At present times, about 118 countries are producing rice across the Globe. In 2020-21, around 750 million tonnes of rice were consumed worldwide (USDA, 2021). China and India together contributed about 50% of rice production to the World. According to Food and Agriculture Organization Corporate Statistical Database (FAO STAT), in 2021 China produces the highest amount of rice around the globe. India produces the largest amount of rice after China. India has the largest area under rice cultivation and shares about 27% of production in the World.

Rice is the leading food crop that covers around 1/4th of the total harvested area of India. It has around 10000 varieties throughout the world of which India have 4000 varieties. In India, it is mostly produced between 8-30° N lat. and about 2500 m above sea level. Rice needs high temperature and humidity; the average requirement of rice is 24°C for growth. The temperature should be 20-22°C in sowing time, 23-25°C during growth and 25-30°C in harvesting time. In India, rice requires 150 cm annual average rainfall. But, rice grows well where the annual average rainfall is around 200 cm. In the low rainfall regions, rice cultivation has been done using irrigation. In Punjab, Haryana and western UP about 50% of rice production is done through irrigation (ICAR, 2020). Rice grows well in lowland areas. In mountainous areas, rice has been cultivated using terrace farming. Rice can be grown in silts, loamy and clay types of soils. In India, four types of rice cultivation methods have been practised, such as broadcasting method, drilling method, Transplantation method and Japanese method. In the broadcasting method, for sowing seeds spread by hand in to land. In dry and less fertile regions this type of method has been used. This method also requires a minimum number of labours in the field. In peninsular India, the drilling method has been noticed. Here, only two people are required for ploughing and sowing. The transplantation method has been observed in high rainfall, fertile and abundant labour areas. In this process, nurseries have been utilized for sowing and preparing the seeds and saplings, then after a few weeks, saplings are planted in the field. The entire process has been done with the hand. This process yields the maximum amount of rice. Lastly, the Japanese method is used for high-yield seeds. In this process, a high amount of fertilizer is required (Khullar, 1999).

In India, based on physical parameters rice growing areas are classified into five categories such as eastern, north-eastern, western, northern and southern regions (Table 7.2). This north-eastern portion includes Assam, Meghalaya, Manipur, Tripura, and Arunachal Pradesh. etc. In the Brahmaputra basin rice grows well and gets an adequate amount of rainfall for rice production. The eastern region produces the highest amount of rice in India, because of sufficient rainfall. Here, rice grows in Mahananda and Ganga river basins. This region covers West Bengal, Chhattisgarh, Bihar, Jharkhand, Madhya Pradesh, Orissa and Eastern UP. While, the northern region covers Punjab, western UP, Haryana, Uttarakhand, J&K and Himachal Pradesh. Here, rice is grown only in one season i.e., May-July to September-December because this region experiences low winter temperatures (Table 7.3). Rajasthan, Gujarat, and Maharashtra comprise the western region. Only in the monsoon season, rice is being grown here. This southern region covers Andhra Pradesh, Tamilnadu, Karnataka and Kerala. Here rice is mostly grown in the deltaic plain of Krishna, Godavari and Cauvery Rivers (Figure 7.4) (Rice in India: A Status Paper, 2014).

Table 7.2 Rice growing regions in India

Region name	States covered
North Eastern	Assam, Arunachal Pradesh, Manipur, Tripura, Meghalaya
Eastern	West Bengal, Jharkhand, Chhattisgarh, Bihar, Orissa, Eastern-UP and Madhya Pradesh
Northern	Haryana, Western-UP, Uttarakhand, Himachal Pradesh, Jammu & Kashmir, and Punjab
Western	Rajasthan, Maharashtra and Gujarat
Southern	Andhra Pradesh, Tamilnadu, Karnataka and Kerala

Table 7.3 Rice cropping seasons in India

Crop-seasons	Regional name	Sowing time	Harvesting time
Autumn (Kharif)	Aus	May – Jun.	Sep. – Oct.
Winter (Rabi)	Aman	Jun. – Jul.	Nov. – Dec.
Summer (Spring)	Boro	Nov. – Dec.	Mar. – Apr.

In West Bengal according to the agricultural statistics report 2018-19, Paschim Medinipur produced the maximum amount of rice. It produced around 19, 21, 251 metric tonnes of rice. Purba Bardhaman and Purba Medinipur districts were in second and third position. They produced around 17,44,632 and 12,97,004 metric tonnes of rice in 2018-19 (Figure 7.5) (A1. Ch. 7.2).

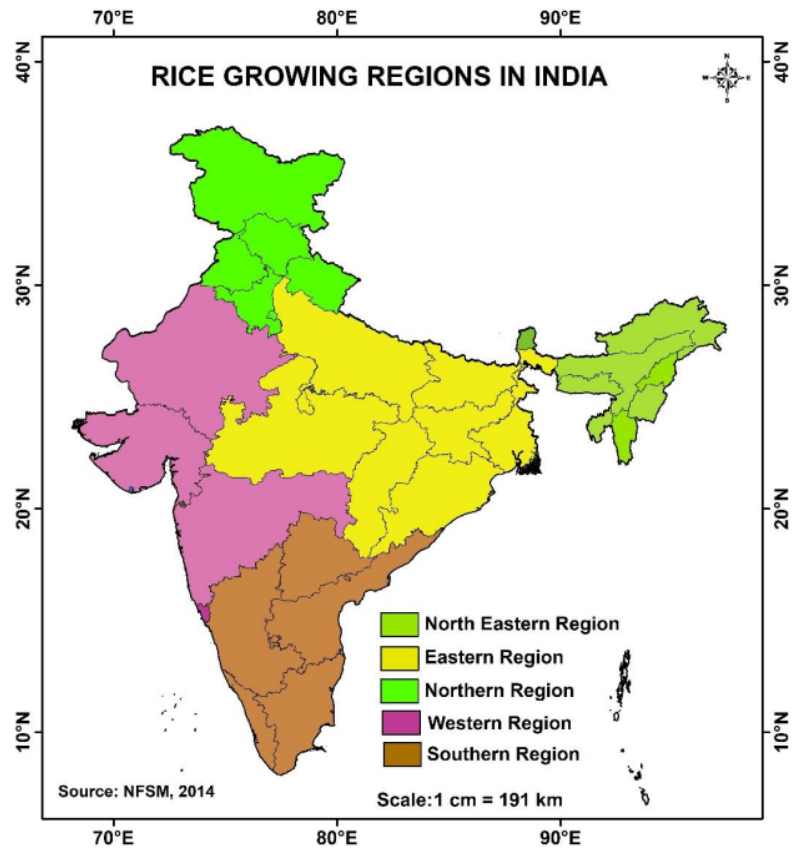

Figure 7.4 Rice-producing areas of India (NFSM, 2014)

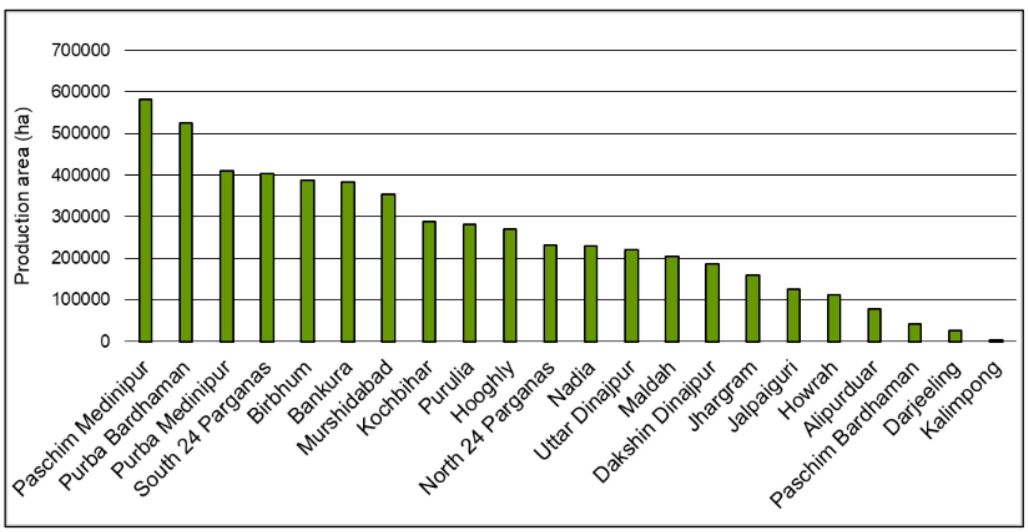

Figure 7.5 District-wise rice production area in West Bengal (2018-19)

Change in seasonal crop production area

The Shali River basin is situated in the Bankura district. Rice is the predominant crop of this region. According to the agricultural report (2019), Bankura was in sixth position according to the rice production area in 2018-19.

Based on WBDES reports (2020) around 92% of the Shali River basin area is used for rice cultivation. In the Shali River basin, from 1995 to 2020 Mann Kendall trend assessment has been executed to recognise the trend direction of the rice production area. In 1995 the Shali River basin was around 423 ha rice production area. In 1998 the amount of rice production area increased to 772 ha. Then the rice production area was reduced from 1999 to 2000, but in 2001 the rice production area increased to 809 hectares. After 2002, again the rice production area was reduced. After 2009, the rice production area increased. The MK trend (Z score) of 5.82 shows a positive trend in the rice production area from 1995-2020 in the Shali River basin region (Figure 7.6).

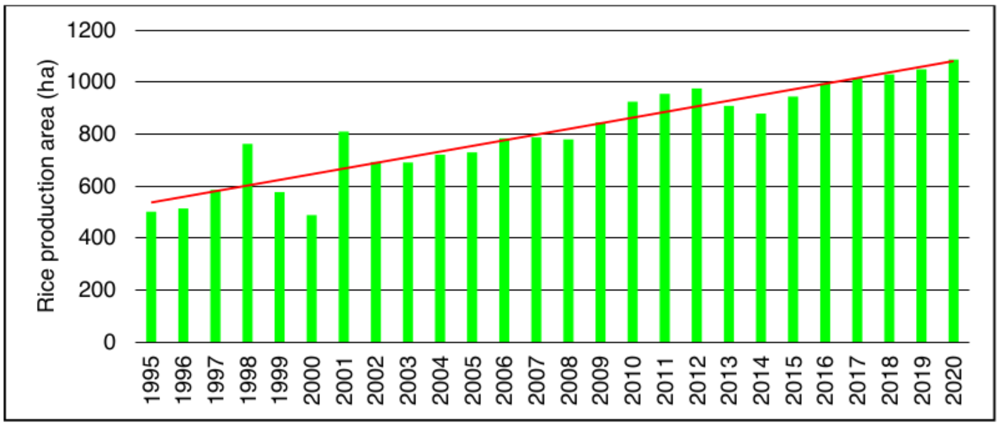

Figure 7.6 Rice production area trend from 1995 to 2020 in the Shali River basin

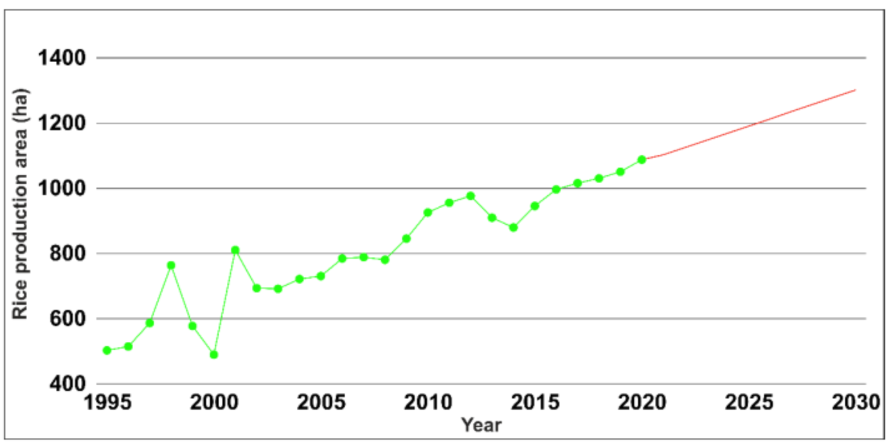

Figure 7.7 Rice production area forecasting for the Shali River basin area

Figure 7.7 shows the rice forecasting graph, where the light green colour represents the rice production area trend and red signifies the forecasting trend. The rice production areas in the Shali River basin are showing a positive trend. In 2020, it has a 1086 ha rice production area, whereas the forecasting graph is showing that in 2025 and 2030 the Shali River basin will be 1189 and 1300 hectares respectively.

The Shali River basin produces three varieties of rice: aus, aman and boro (Table 1). According to the district statistical handbook (2020), the aman rice has a maximum production area than boro and aus rice. Aman rice is very popular than the other two types of rice, though in 1995 around 74 ha was under aman production area, 233 hectares under the boro production area and 194 hectares under aus production area. Whereas in 2020, the amount of aman production area has increased to 430 hectares, boro increased to around 343 hectares, aus increased to 313 hectares. The Mann-Kendall trend analysis also shows a positive trend in aman, aus and boro production areas. The MK Z value of aman, aus and boro production areas are 5.97, 5.31 and 3.11, respectively. Therefore, the trend analysis depicts that the increasing trend of aman rice is maximum in the Shali River basin area from 1995 to 2020. The amount of boro production also increased but the increasing trend is low than aman and aus (Figures 7.8-7.10) (A1. Ch. 7.4).

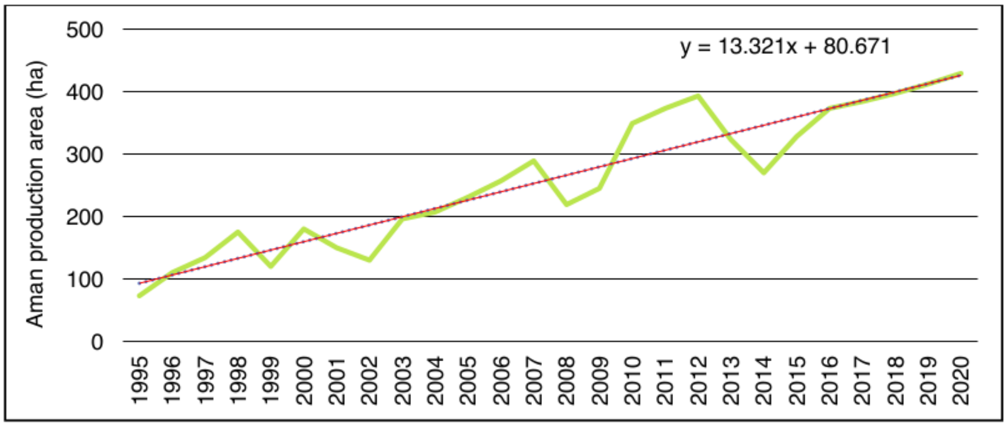

Figure 7.8 Aman production area trend

Figure 7.9 Aus production area trend

Figure 7.10 Boro production area trend

7.6.2 Potato

Potato (*Solanum tuberosum)* introduced in South America, is nowadays produced globally. In India, potato stands 4th in the staple food category after rice, wheat and maize. Potato is cultivated in around a hundred countries globally. India ranked second across the globe in potato production (FAO, 2019 – 20). In India, potato is produced in 23 states; UP, west Bihar, West Bengal, Gujarat and Punjab are the main potato-yielding states. Mid-June to mid-July and October to November are considered the best potato cultivation season. According to agricultural statistics of India (2020), around 85% of potatoes are grown in north India (Indo-Gangetic plains). The districts of UP, Punjab West Bengal, Gujarat and Bihar produced above 80% of the entire production. Potatoes are grown in well-drained soil; they can grow in damp soil also. All types of soils are suitable for potato production but alkaline and saline soils are not preferable. It also needs plenty amount of humus in soil for growth, besides good aeration, and drainage. A soil pH level of 5.1-6.4 is appropriate for potatoes and around, 14-21 °C temperature is perfect (Bhardwaj et al., 2022).

In India, potato growing regions are classified into eight regions: Sikkim and north Bengal hills, north-eastern hills, north India hills, south Indian hills, Plateau, north-western plains, north-eastern plains and central plains (Table 7.4).

Table 7.4 Potato growing regions in India

Region name	States covered
Sikkim and North Bengal hills	Sikkim and northern hills (Darjeeling district) of West Bengal
North Eastern hills	Arunachal Pradesh, Meghalaya, Tripura, Mizoram, Manipur, and Nagaland
North Indian hills	Himachal Pradesh, Uttarakhand, and parts of Jammu & Kashmir

South Indian hills	Western portion of Tamilnadu
Plateau	Eastern portion of Gujarat, Maharashtra, Madhya Pradesh, Karnataka, and southern part of Orissa
North Eastern plains	Eastern-UP, West Bengal, Orissa (Upper part), Bihar and Assam
North Western pains	Punjab, Haryana, northern part of Rajasthan
Central plains	Parts of Madhya Pradesh, Western Uttar Pradesh

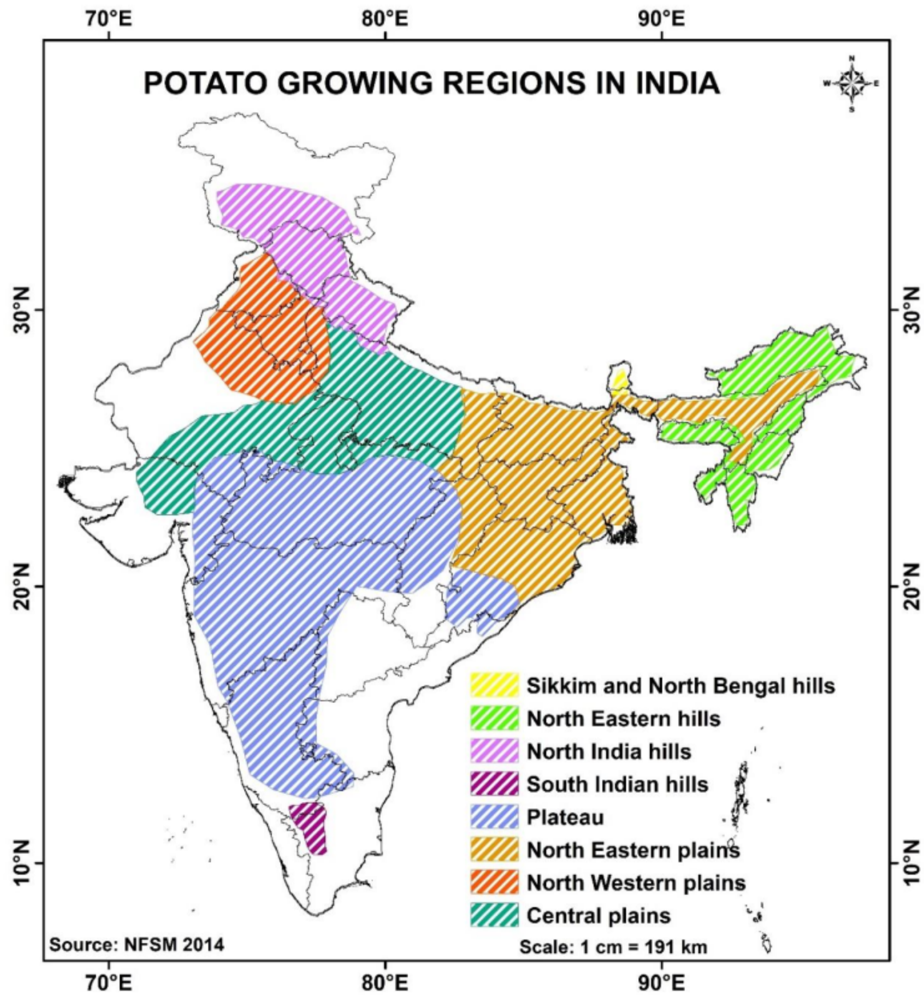

Figure 7.11 Potato growing regions in India

In India, after UP, West Bengal ranked 2nd in potato production. In West Bengal, Hooghly district has the maximum amount of potato production area, whereas Bankura district ranked fourth (Figure 7.12) (A1. Ch. 7.5).

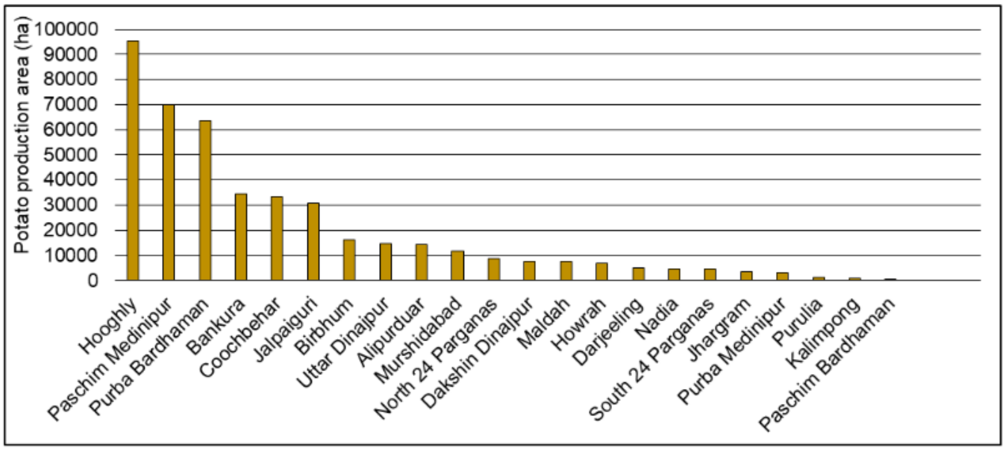

Figure 7.12 District-wise potato production area in West Bengal (2019-20)

The Shali River basin of Bankura district is placed in West Bengal which falls under the north-eastern plains zone of potato cultivation. The second major crop of the Shali River basin is the potato, around 5% of agricultural land has been used for potato cultivation. In 1995, only a 1.1 ha area was under potato cultivation. Then the potato production area was increased to 23 and 40 hectares in 2010 and 2020 respectively. Mann Kendall trend shows a high positive trend (Z value equalling 6.79) in potato cultivation (Figure 7.13.) In potato cultivation, the forecasting map shows a positive change. In 2020, around 40 ha of the area was under potato cultivation, whereas in 2025 and 2030 potato cultivation will be 48 and 56 ha. In Figure 7.14, brown and red colours are showing potato production area trends and forecasting (A1. Ch. 7.6).

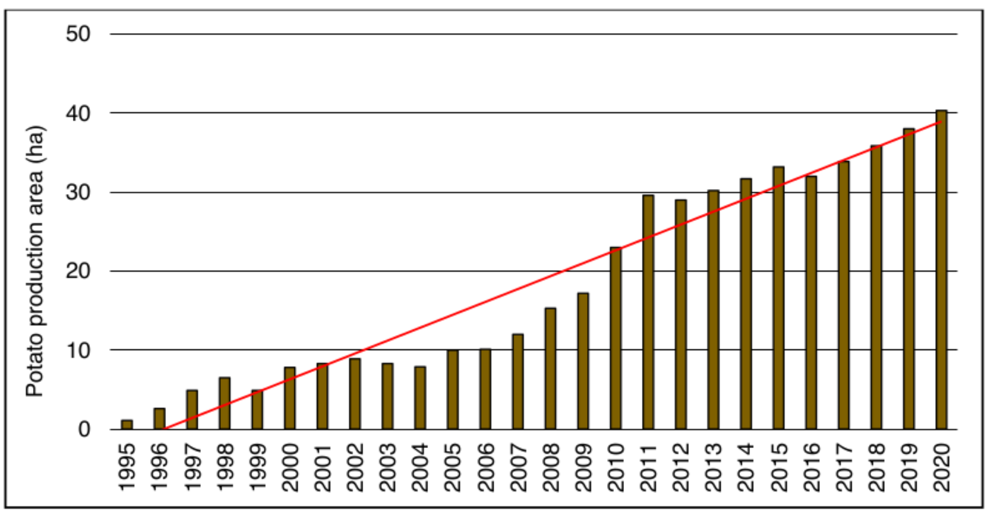

Figure 7.13 Potato production area trend from 1995 to 2020 in the Shali River basin

Change in seasonal crop production area

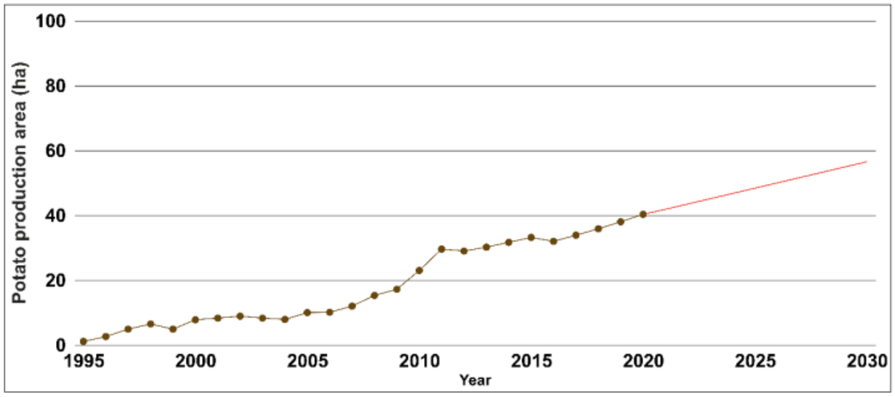

Figure 7.14 Potato production area forecasting

7.6.3 Wheat

Wheat (*Triticum aestivum*) is the second most produced cereal crop in India after rice. According to FAO wheat production data 2019-20, India ranked three among wheat-producing countries. It produced around 10,35,96,230 tonnes of wheat in 2019-20. The wheat crop has extensive adaptability that can be produced in any region: tropical, sub-tropical, temperate and cold regions. Wheat has extreme tolerance capacity; it can survive in severe cold regions and resume growth with the setting in of warm weather in spring. In India, the perfect soil for wheat cultivation is clay with a loamy texture. Besides, medium water holding capacity and good profile. Wheat needs around 20-25°C temperatures (Gupta et al., 2018).

In India, wheat-producing regions are categorised into six regions: northern hills, peninsular, north-eastern plains, central, north-western plains, and southern hills, respectively. In India, maximum wheat production is concentrated in Uttar Pradesh, Punjab, and Haryana. According to agricultural statistics (2019-20) data, West Bengal is listed among the top ten wheat-producing states in India. In West Bengal, Birbhum district has the highest amount of wheat production area, whereas Bankura district is in the 9th position (Figure 7.16) (A1. Ch. 7.7).

The Shali River basin area falls under north eastern plain category based on wheat-producing regions in India category. It has only 2% area under wheat production. In 1995, around 2 ha area was used for wheat cultivation. Then the amount of wheat cultivation area increased over time. Mann Kendall trend produces a positive trend (Z value 6.70) in wheat cultivation from 1995 to 2020. The wheat forecasting graph also shows a positive trend in wheat production (Figure 7.14). In 2020, around 14 ha land was used for wheat cultivation but in 2025 and 2030 around 17 and 20 ha land will be used for wheat cultivation (Figure 7.17) (A1. Ch. 7.8).

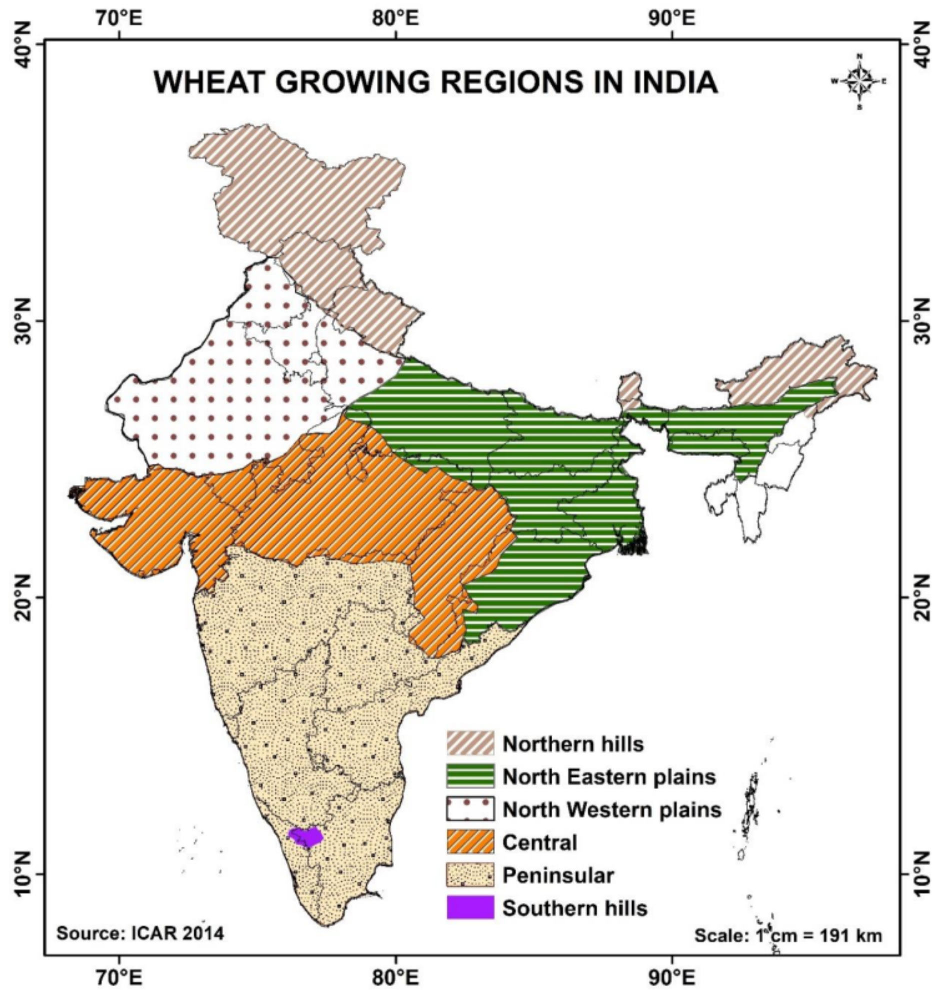

Figure 7.15 Wheat growing regions in India

Table 7.5 Wheat growing regions in India

Regions	States covered
Northern-hills	Western Himalayan zones (J&K) excepting Kathua and Jammu district.); H.P. (except Paonata and Una Valley); Uttaranchal (without Tarai region); Sikkim and West Bengal (hilly areas) and North Eastern States.
North-Eastern plains	Jharkhand, West Bengal, Odisha, Bihar, Assam, Eastern UP and plains of North Eastern States
North-Western plains	Uttarakhand (Tarai area), Punjab, Western UP, Haryana, Rajasthan (excluding Udaypur and Kota) Delhi, Rajasthan

	(except Kota and Udaipur divisions), Kathua and Jammu district (Part of J&K) and Paonata and Una valley of H.P
Central	Jhansi (UP), Chhattisgarh, Udaipur & Kota (Rajasthan), Gujarat, and Madhya Pradesh
Peninsular	Goa, Karnataka, plains of Tamil Nadu, Maharashtra and Andhra Pradesh
Southern hills	Tamil Nadu (hilly parts) and Kerala (Palini and Nilgiri)

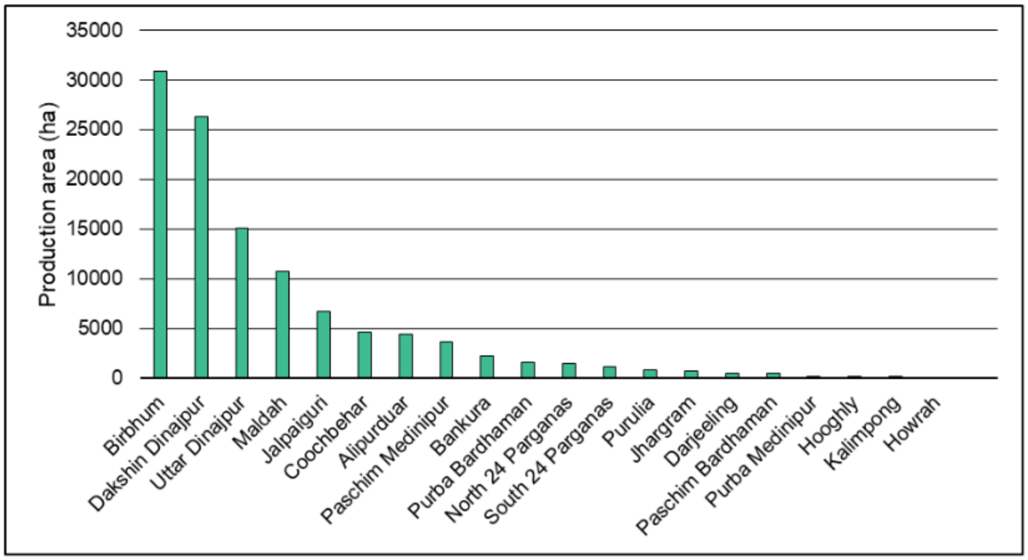

Figure 7.16 District-wise wheat production in West Bengal

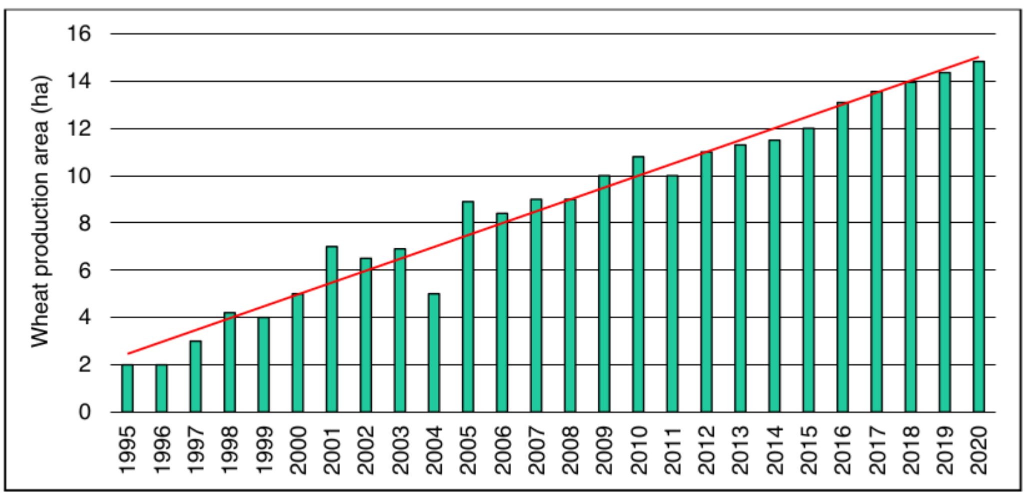

Figure 7.17 Wheat production area trend from 1995 to 2020

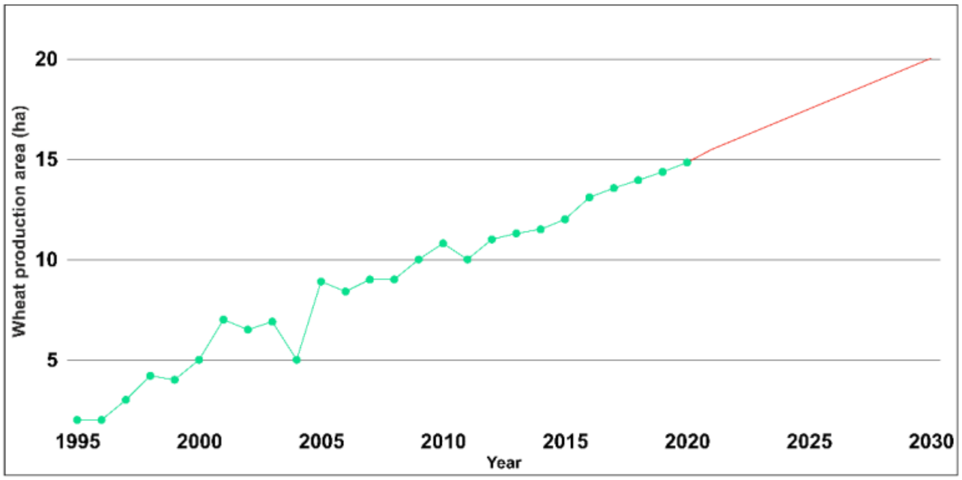

Figure 7.18 Wheat production area forecasting

7.6.4 Mustard

Mustard (*Brassica juncea*) is the main rabi oilseed crop of India. According to FAO, India is the leading producer of mustard globally. Mustard can grow both in tropical and subtropical countries. According to Agricultural Statistics (2021), Rajasthan produces the maximum amount of mustard. Mustard can cultivate fine in dry and cool weather. Thus, mustard is considered a Rabi crop. Mustard needs around 10-25°C temperature. It also requires an annual rainfall of around 625-1000 mm. Mustard can grow in any type of soil but alluvial and it cannot survive in water logging conditions.

In India, mustard-growing areas are classified into seven regions: Northern, North Eastern, North Western, Eastern, Central, Western and Southern. The north region has low winter temperatures; therefore, mustard has been grown from October-November to February-March. In the north-eastern region, mustard is cultivated in the plains. The north-western region is the largest contributor to India's mustard production. Whereas, in the southern region mustard cultivation is very sparse.

Table 7.6 Mustard growing regions in India

Region	States covered
Northern	Uttar Pradesh
North Eastern	Assam
North Western	Punjab and Haryana
Eastern	Bihar and West Bengal
Central	Madhya Pradesh
Western	Rajasthan and Gujarat
Southern	Tamilnadu

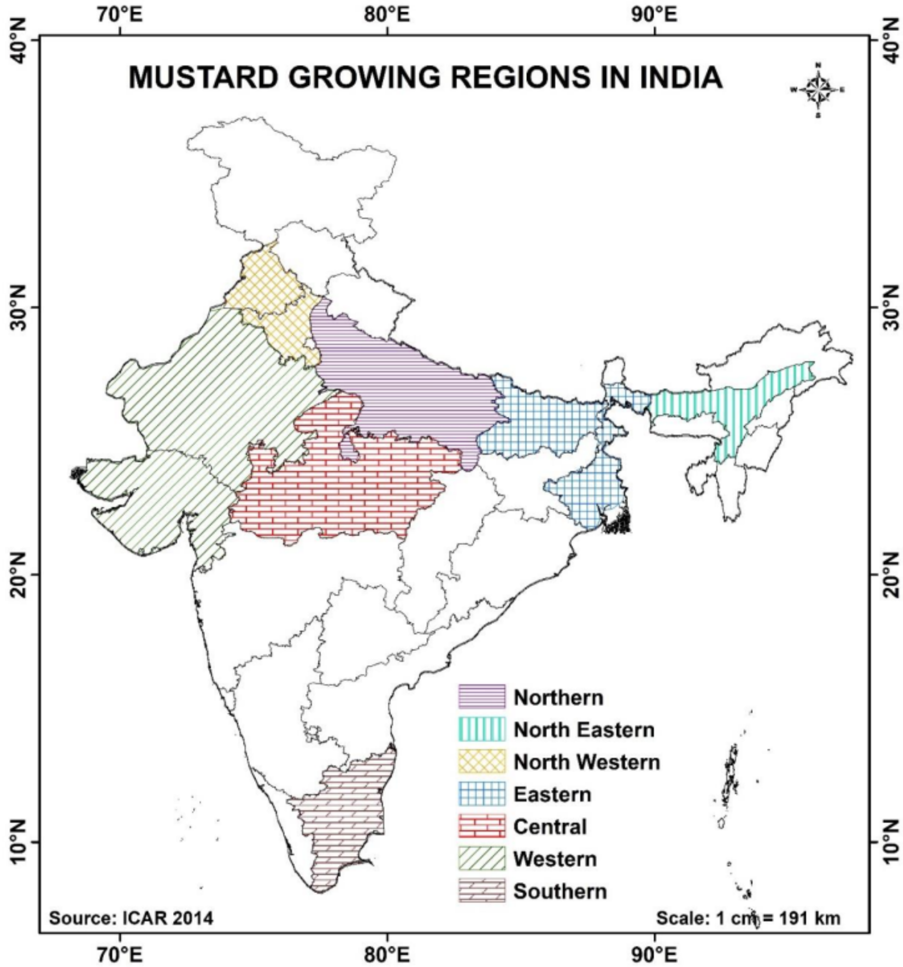

Figure 7.19 Mustard growing regions in India

According to the agricultural statistics report 2019-20, Rajasthan produced the maximum amount of mustard in India. West Bengal ranked 5th in the master production in India. Though, Bankura district is not a good producer of mustard among the other districts of West Bengal. Bankura district ranked nine in mustard production (Figure 7.20) (A1. Ch. 7.9).

The Shali River basin includes under eastern mustard-producing region, In the Shali River basin area, mustard has only 1% production area. In the Shali River basin, mustard cultivation is very less than other crops that have been observed. In 1995, only 0.2 ha area was used for mustard cultivation but in 2020 the amount of mustard cultivation has increased to 3 ha. The Mann-Kendall trend of mustard production (Z value 5.25) also shows a positive trend and the forecast graph also discovers a positive trend (Figure 7.21). In 2025 and 2030 the mustard cultivation will be 3.67 and 4.25 ha respectively (Figure 7.22) (A1. Ch. 7.10).

Change in seasonal crop production area

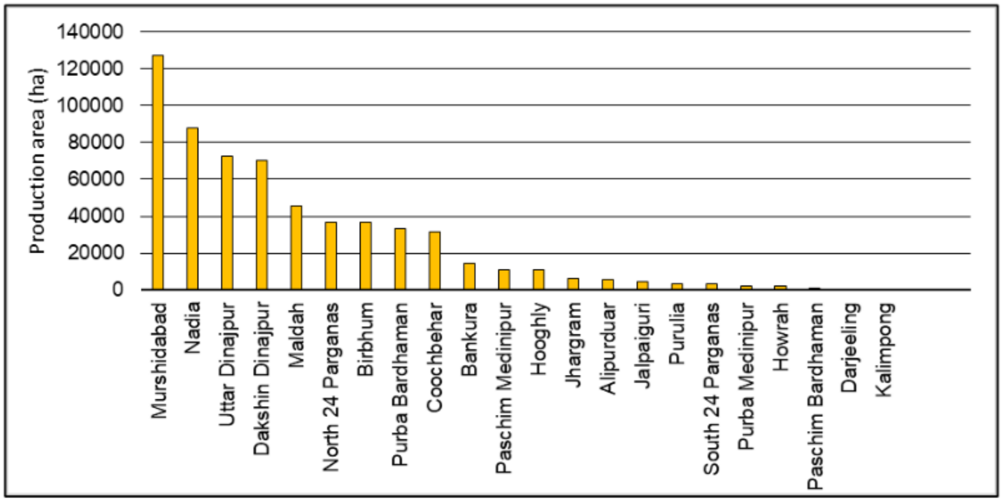

Figure 7.20 District-wise mustard production area

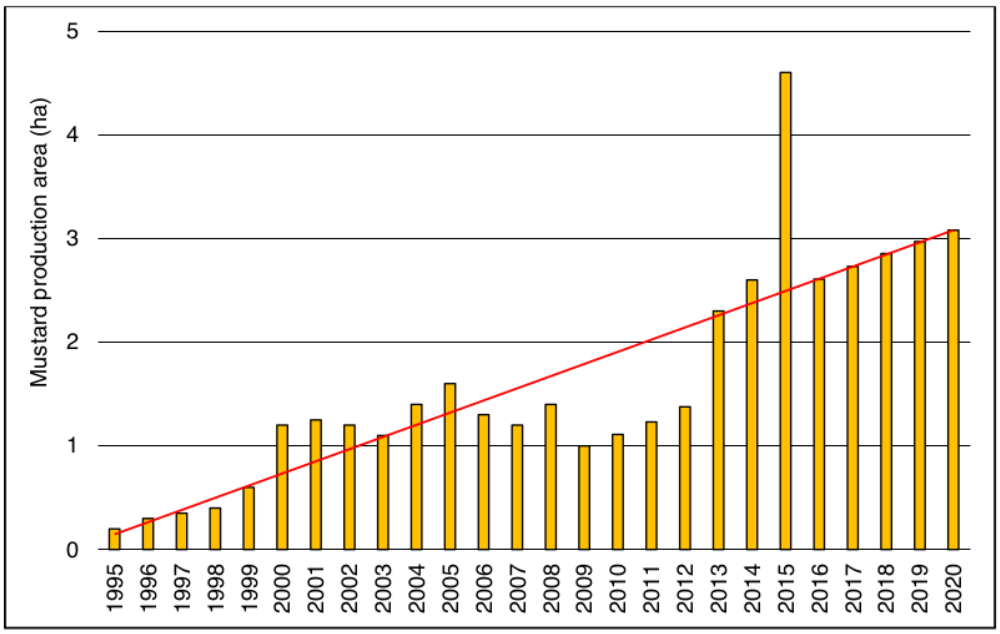

Figure 7.21 Mustard production area trend of Shali River basin

In the Shali River basin, rice is the dominant crop and the amount of rice cultivation area has increased from 1995 to 2020 but the MK test reveals that the positive trend in wheat and potato cultivation is better than rice. Both the crops are rabi crops (winter), which means after the creation of the Shali reservoir winter crop cultivation has increased in the Shali River basin area (Figure 7.23) (A1. Ch. 7.11).

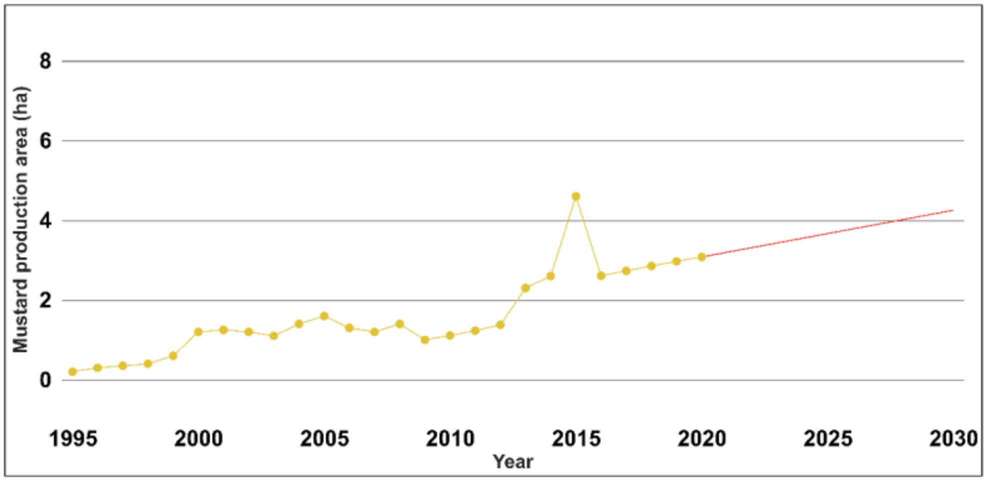

Figure 7.22 Mustard production area forecasting trend of Shali River basin

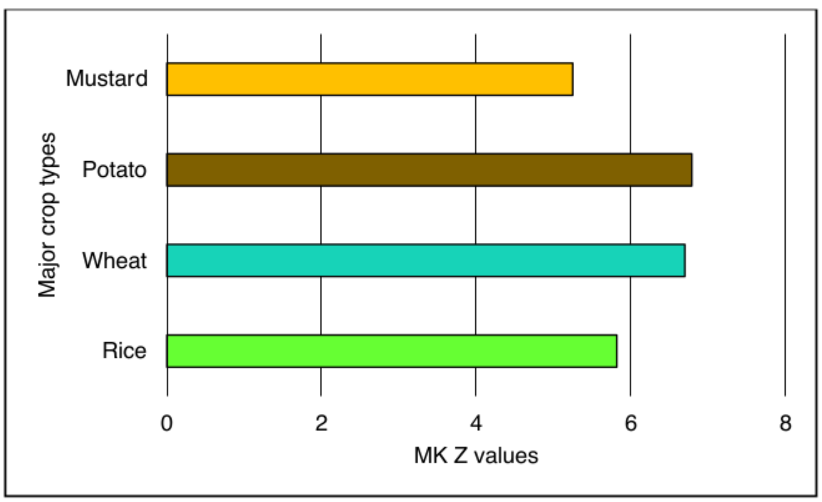

Figure 7.23 Trend rate comparison of major crops of the Shali River basin

7.7 Seasonal rice mapping

Shali River basin produces both kharif and rabi crops. After the creation of the Shali reservoir, crop production areas have increased in the Shali River basin both in Rabi and Kharif seasons. Rice is the main crop of the Shali River basin area, so seasonal (Kharif and Rabi) rice production area mapping has been performed using RS techniques. For mapping the high-spatial resolution, Sentinel-1 SAR datasets are used. It has a 10 m spatial resolution only but these datasets are available from 2014 onwards. Therefore, in this study, 2015 to 2021 datasets have been incorporated for mapping. For kharif rice area mapping, October to November datasets are used, whereas for rabi rice area mapping March to April datasets are used. The rice areas are identified using a supervised image classification process. RF classifier method has been used for great accuracy. Kappa values also lie between 0.80 to 0.95 which indicates a perfect classification. A temporal change in rice production area has been displayed using seasonal crop mapping. In 2021, the amount of rabi rice production area has increased to 47%. The seasonal rice mapping study from 2015 to 2021, depicts that the crop production area is not the same every year. The percentage of crop production area has increased (Figures 7.24-7.25) (A1. Ch. 7.12).

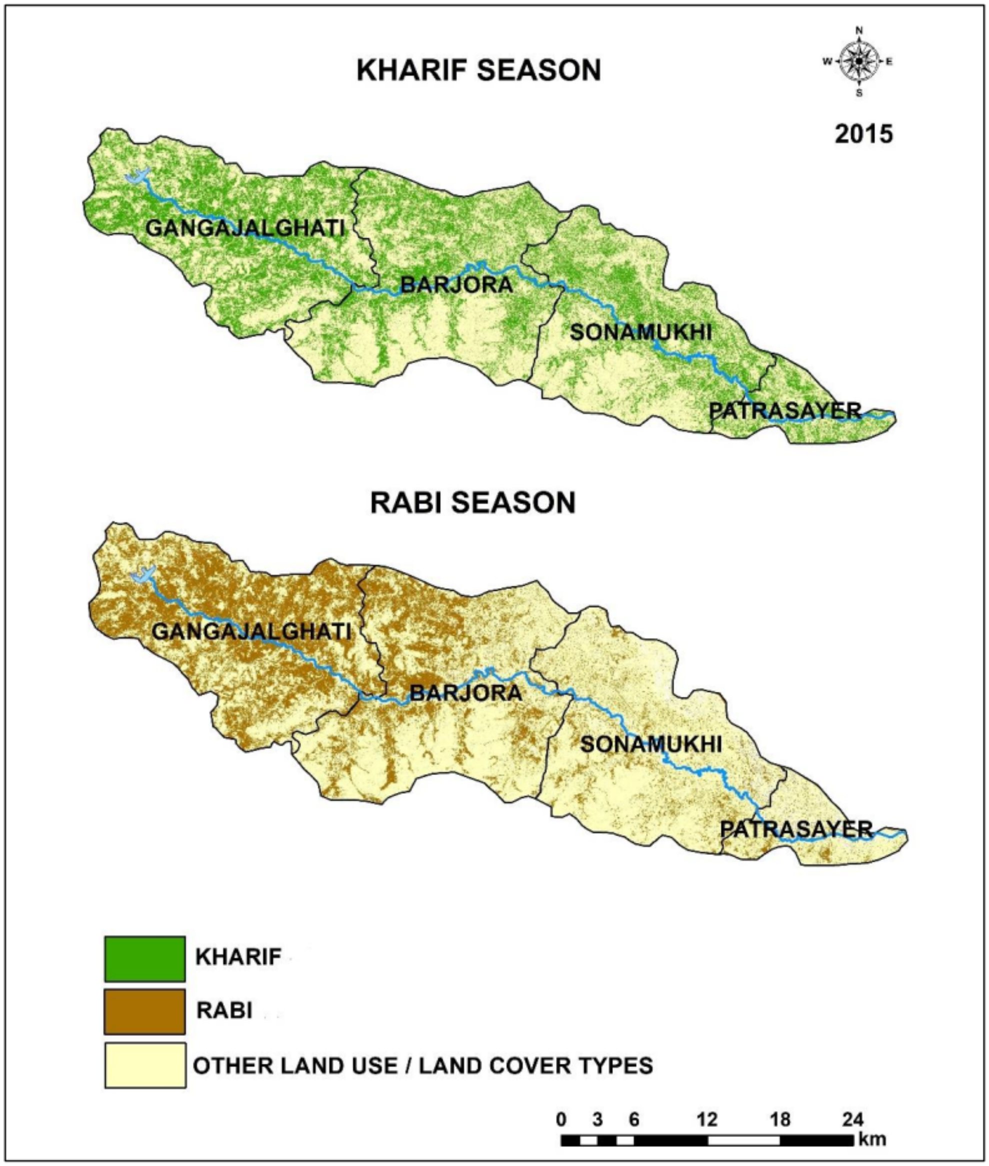

Figure 7.24 Seasonal rice mapping in 2015 of the Shali River basin

Change in seasonal crop production area

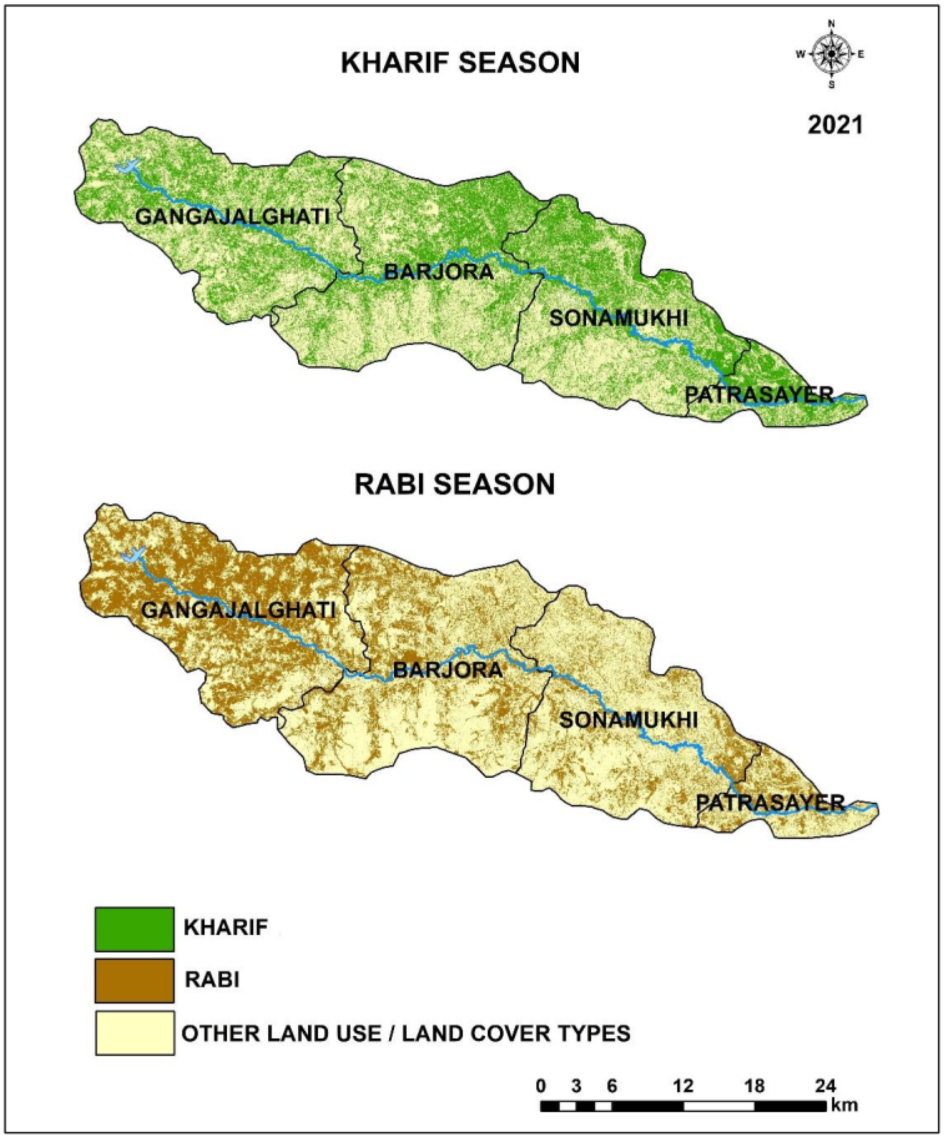

Figure 7.25 Seasonal rice mapping in 2021 of the Shali River basin

The block-wise comparison shows that, in 2015, Patrasayer has the maximum amount of kharif rice production area in other blocks, it has around 66% kharif rice production area, whereas Gangajalghati block has the minimum amount of Kharif rice area. Meanwhile, in the rabi season, the highest amount of rice production area has been observed in the Gangajlaghtai block. Sonamukhi and Barjora block has the lowest amount of rabi rice production area. In 2021, the Patrasayer block remains in having the highest kharif production area. Whereas, in the Rabi season, the amount of production area has increased in the Gangajalghati block (Figure 7.26).

Change in seasonal crop production area

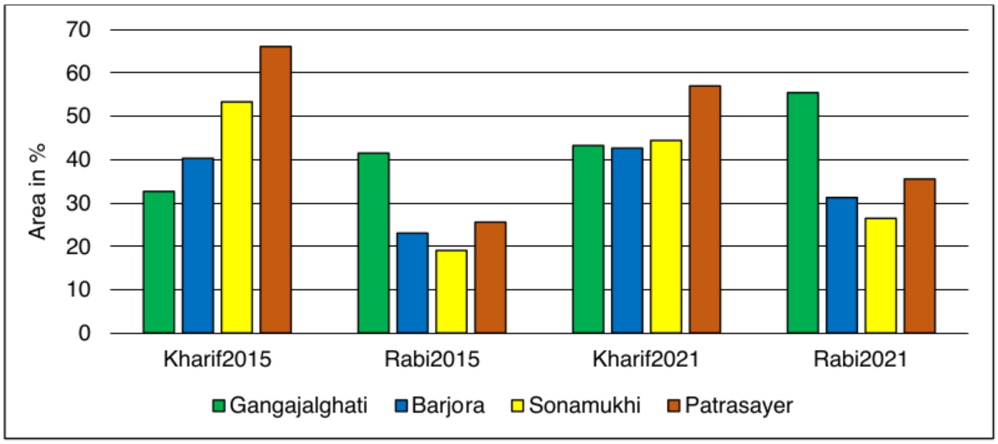

Figure 7.26 Block-wise comparison in seasonal crop mapping

7.8 Village-wise rice mapping

In this segment village wise seasonal rice production areas have been calculated. For this purpose, rice production areas are classified into six classes: above 400 ha, 351-400 ha, 301-350 ha, 251-300 ha, 201-250 ha and below 200 ha. Due to the unavailability of high-resolution data sources 2015 and 2021 seasonal rice production area mapping has been done.

In 2015, only one village have above than 400 ha of rice production area in the kharif season. In 351-400 and 301-350 ha categories, six villages were observed. Around 17 and 40 villages were found in 251-300 and 201-250 ha categories. Whereas in the below 200 ha category, 275 villages were observed. In the rabi season, two villages were found in the above 400 ha category, one village in the 351-400 ha category, two villages in the 301-350 ha category, 12 villages in the 251-300 ha category and 28 villages in 201-250 ha category were observed. In the below 200 ha category, 294 villages were identified (Figure 7.27).

In 2021, around three villages in the above 400 ha category, 15 villages in the 351-400 ha category, 22 villages in the 301-350 ha category, 32 villages in the 251-300 ha category and 41 villages in the 201-250 ha category were observed in Kharif season. Whereas, in the below 200 ha category 226 villages were observed. In the rabi season, around five villages in the above 400 ha category, 13 villages in the 351-400 ha category, 17 villages in the 301-350 ha category, 26 villages in the 251-300 ha category and 28 villages in 201-250 ha were observed in Shali River basin. In the below 200 ha category 250 villages were found (Figure 7.28).

The seasonal rice production area mapping has produced a clear image of seasonal change in the rice production area between 2015 and 2021. In Shali River basin average rice production area is around 200 ha in both seasons. From 2015 to 2021, production areas increased in both seasons, especially in the rabi season. Rice mapping also depicts that the Shali reservoir and riverside villages utilize a huge amount of agricultural land for rice cultivation.

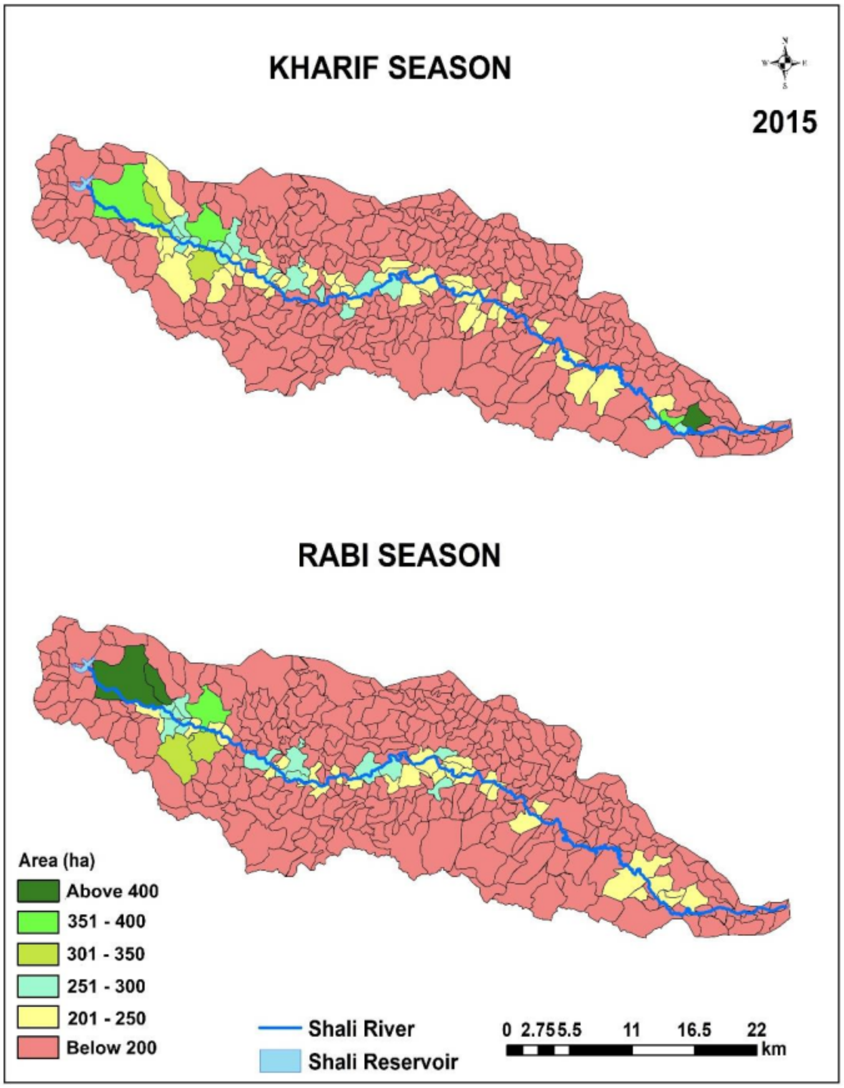

Figure 7.27 Village-wise seasonal rice mapping in 2015

Table 7.7 Seasonal rice cropped area in 2015

	Number of villages	
Area (ha)	Kharif season	Rabi season
Above 400	1	2
351 - 400	3	1
301 - 350	3	2
251 - 300	17	12
201 - 250	40	28
Below 200	275	294

Table 7.8 Seasonal rice cropped area in 2021

	Number of villages	
Area (ha)	Kharif season	Rabi season
Above 400	3	5
351 - 400	15	13
301 - 350	22	17
251 - 300	32	26
201 - 250	41	28
Below 200	226	250

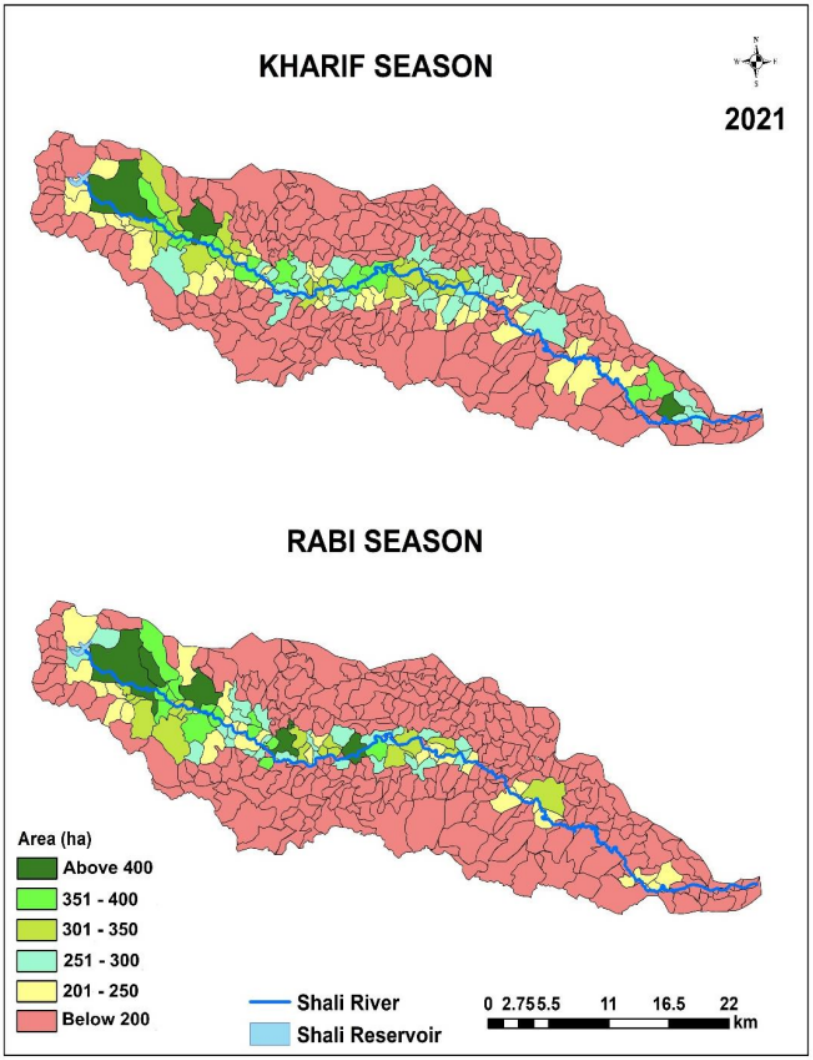

Figure 7.28 Village-wise seasonal rice mapping in 2021

7.9 Conclusion

This chapter discusses the major crops of Shali River basin which are potato, wheat, rice and mustard. The first segment reveals that after the creation of the Shali reservoir, crop production area has increased, and around 640 hectares of crop production area have increased from 1995 to 2020. Rice is the leading crop of Shali River basin. Three (aus, aman, boro) types of seasonal rice have been cultivated. Around 585 ha of rice production area has been increased from 1995 to 2020. The MK trend values signify that potato has the maximum increasing trend and rice has the minimum increasing trend. It signifies that after the creation of the Shali reservoir, both Kharif and Rabi crop production areas have increased in the Shali River basin area. In the second segment rice production area mapping has been done using high-resolution sentinel 1 satellite datasets. The rice mapping reveals that in the Kharif season, less amount of land has been increased between 2015 and 2021, whereas a noticeable change has been observed in the Rabi season.

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Agricultural development: irrigation, cropping and agricultural labour intensity

8.1 Introduction

In the previous chapter, the impact of the Shali irrigation project on crop production areas has been discussed. The results specify that after the creation of the Shali reservoir, crop production areas have been enhanced in the Shali River basin. In this chapter, the impact of the Shali reservoir on irrigation intensity (IRINTST), cropping intensity (CRPINTST) and agricultural labour intensity (AGLBINTST) has been analysed.

IRINTST, CRPINTST and AGLBINTST are the main considerable indicators for analysing the agricultural development of any area. Irrigation is the prime component of the agricultural development of an economy. After many years of independence, the Indian economy is still agrarian and the proportion of GDP in the agricultural sector is around 19%. In India, around 50% of people are very much dependent on agricultural activities to sustain their lives. In India, irrigation helps to increase food security, reduce dependency on monsoons, improve agricultural productivity and generate rural job prospects. India's irrigation system is categorised into four classes: canal irrigation, tank irrigation, river-lift irrigation and tube-well irrigation. IRINTST is the percentage of the net-irrigated area of the net-sown area. It determines the sufficiency of available irrigation facilities in any area and improves crop yield. Whereas, CRPINTST signifies the nature of crop production. It also elucidates crop rotation, crop pattern etc. The CRPINTST is the percentage of the gross-cropped area of the net sown area. Higher CRPINTST signifies extensive usage of the agricultural fields. The CRPINTST increases rural employment. Both the IRINTST and CRPINTST have a positive impact on AGLBINTST. AGLBINTST is the ratio of the number of agricultural workers and net sown area.

8.2 Chapter outline

This chapter has been classified into three segments. In the first segment, a block-wise comparison of irrigation, cropping and agricultural labour intensity has been done. In the second segment, village-wise comparisons of irrigation, cropping and agricultural labour intensity have been discovered. In the third segment correlation analysis has been performed. The linear regression (LR) analysis has been done between irrigation and cropping intensity and MLR has been performed between irrigation, cropping and agricultural labour intensity (Figure 8.1).

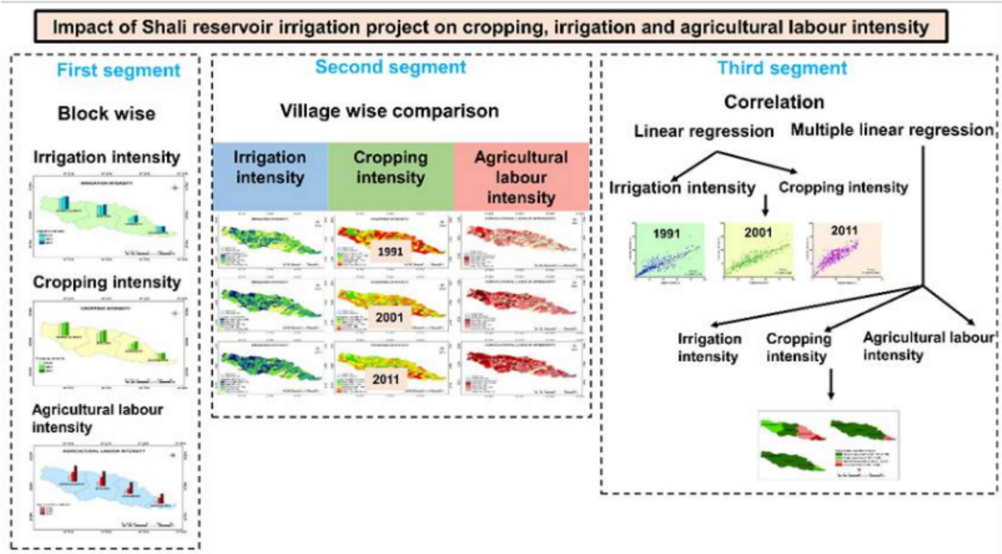

Figure 8.1 Chapter outline

8.3 Literature reviews

Irrigation, cropping and agricultural labour intensity are the prime key factors of agricultural development for any region. therefore, it is necessary to discuss previous works of literature on these key factors. Rehman and Lata (2012) observed an association between IRINTST and CRPINTST in 70 districts of Uttar Pradesh, India from 2000 to 2004. They applied the Z-score technique to measure the irrigation development of each district and employed the LR method to determine the relationship that resulted in a positive relation. The study also showed that the western portion got more irrigational benefits than the other portions. Haque (2015) analysed the association between IRINTST and CRPINTST of the blocks of Murshidabad district. KarlPearson's product-moment correlation method was used for correlation. The prime objectives of the study are to analyse the relationship among IRINTST and CRPINTST in 1994 -95 and 2010-11, a comparative analysis between the blocks etc. and the whole study was based on a secondary database which was obtained from the Principal Agricultural office of Murshidabad district. The results revealed that in 1994-95 the correlation coefficient value was 0.30 and in 2010-11 the correlation coefficient value was 0.06 which indicates that relations between IRINTST and CRPINTST became weak over time. Ganguly and Patra (2016) studied the relationship between IRINTST and CRPINTST in the drought-prone blocks of the Birbhum district by using Karl Pearson's product-moment correlation method. they classified the results, based on IRINTST and CRPINTST into three divisions: high, moderate, and low. The study revealed a 0.47 correlation coefficient value which defined a moderate positive relationship-between IRINTST and CRPINTST. The overall study revealed that the eastern blocks of Birbhum enjoyed a high status of irrigation than the western blocks. Ali (2018) assessed the cropping pattern and relationship between IRINTST and CRPINTST of Murdabad district, West

Bengal. the result revealed a positive relationship. Mondal and Sarkar (2021) examined the association between IRINTST and CRPINTST of blocks of North twenty-four Parganas in West Bengal from 1996 to 2015. They used the ordinary least square method to establish an association between IRINTST and CRPINTST. The study revealed that the percentage of CRPINTST increased from 1996 to 2015 and the correlation analysis was a positive correlation.

All the above-mentioned works of literature are showing that IRINTST and CRPINTST have a positive relationship and LR is the popular method for identifying the relationship. Therefore, in this chapter LR approach has been applied to identify the association between IRINTST and CRPINTST.

8.4 Methods

8.4.1 Irrigation, cropping and agricultural labour intensity

IRINTST is a percentage between the net-irrigated and net-sown area (Eq. 8.1). Whereas, CRPINTST defines the percentage between gross-cropped and net-sown area (Eq. 8.2) and AGLBINTST signifies ratio between the number of agricultural labour and net sown area (Eq. 8.3).

$$\text{Irrigation intensity} = \frac{\text{Net irrigated area}}{\text{Net sown area}} \times 100 \tag{8.1}$$

$$\text{Cropping intensity} = \frac{\text{Gross cropped area}}{\text{Net sown area}} \times 100 \tag{8.2}$$

$$\text{Agricultural labour intensity} = \frac{\text{Total number of agricultural labour}}{\text{Net sown area}} \times 100 \tag{8.2}$$

8.4.2 Linear regression analysis

Discussed in detail in chapter 3.

8.4.3 Multiple linear regression analysis

A simple linear regression line signifies a general association between two variables and provides a basis for estimating the dependent variable (*Y*) by using the independent variable value (*X*) as the predictor. Therefore, an LR analysis is unable to produce accurate results because, in the real world, a dependent variable relies on several independent variables. So, to have a better estimate of a phenomenon it is essential to consider more than one explanatory variable to combine into a new regression equation named multiple linear regression analysis (Eq. 8.4).

$$\hat{Y} = a + b_1 X_1 + b_2 X_2 + \ldots + b_k X_k \pm \varepsilon \tag{8.4}$$

$$= a + \sum_{i=1}^{k} b_i X_i \pm \varepsilon$$

where, X_i represent the values for the k number of independent variables. $\hat{Y}$ value estimates dependent variable, a is Y-intercept when the $X_{i\,s}$ are all zero as in the linear regression equation and ε is the error term, b_is are the estimated partial regression coefficient related to the independent variables $X_{i\,s}$ because each gives the rate of change in the dependent variable (Pal, 1998).

R-squared (coefficient of determination)

It measures a general association between two variables which can be positive or negative. In this chapter R squared value has been used to identify the correctness of the linear model (Eq. 8.5).

$$R^2 = \frac{\sum_{i-1}^{n} (y_i - y)^2}{\sum_{i=1}^{n} (y_i - y)^2} \tag{8.5}$$

All required information for irrigation and agricultural labour intensity has been obtained from Bankura District Census (1991, 2001 & 2011) data sets. For cropping intensity, Landsat5-TM, and Landsat 8-OLI seasonal data sets (Kharif and Rabi) were used for 1991, 2001 and 2011. The supervised image classification technique has been applied to extract the cropping areas.

8.5 Block-wise irrigation intensity

The Shali River basin consists of four blocks: Gangajalghati, Barjora, Sonamukhi and Patrasayer (A1. Ch. 8.1).

According to Bankura district census datasets, in 1991 the irrigation intensity of the Gangajalghati block was around 55% and in 2001 it increased to around 62%. Whereas, in 2011 it increased to 65%. It signifies that after the creation of the Shali reservoir irrigation project irrigation development has been intensified in the Gangajalghati block.

In 1991, the irrigation intensity of the Barjora block was around 47%. Then a slight change has been observed in 2001. The percentage of irrigation intensity increased to 49% in 2001. Whereas, in 2011 around 54% irrigation intensity has been observed. In the Barjora block from 1991 to 2001 only 2% positive change has been discovered but from 2001 to 2011 around 6% change in irrigation intensity has been noticed.

In Sonamukhi block, around 22% irrigation intensity was observed in 1991 but in 2001, about 10% positive change in irrigation intensity was noticed. In 2011, the percentage of irrigation intensity increased to 35%.

During 1991, the Patrasayer block had around 24% irrigation intensity. In 2001, only a 2% positive change was noticed. In 2011, the block had around 28% irrigation intensity.

The block-wise irrigation intensity analysis reveals that after the creation of the Shali reservoir irrigation project the irrigation development has been intensified in all four blocks of the Shali River basin but the rate of increase in irrigation intensity is not the same. In Gangajalghati, irrigation intensity increased by around 10% from 1991 to 2011. While around a 7% increase has been observed in the Barjora block. Around 13% of irrigation intensity has increased in the Sonamukhi block from 1991 to 2011. Hence, only a 4% increase in irrigation intensity has been observed in the Patrasayer block. In 1991, Gangajalghati was the maximum irrigation intensity and Sonamukhi was the minimum irrigation intensity. In 2001, the Gangajalghati block was maximum and Patrasayer block was minimum irrigation intensity and 2011 depicts the same result as 2001 (Figure 8.2).

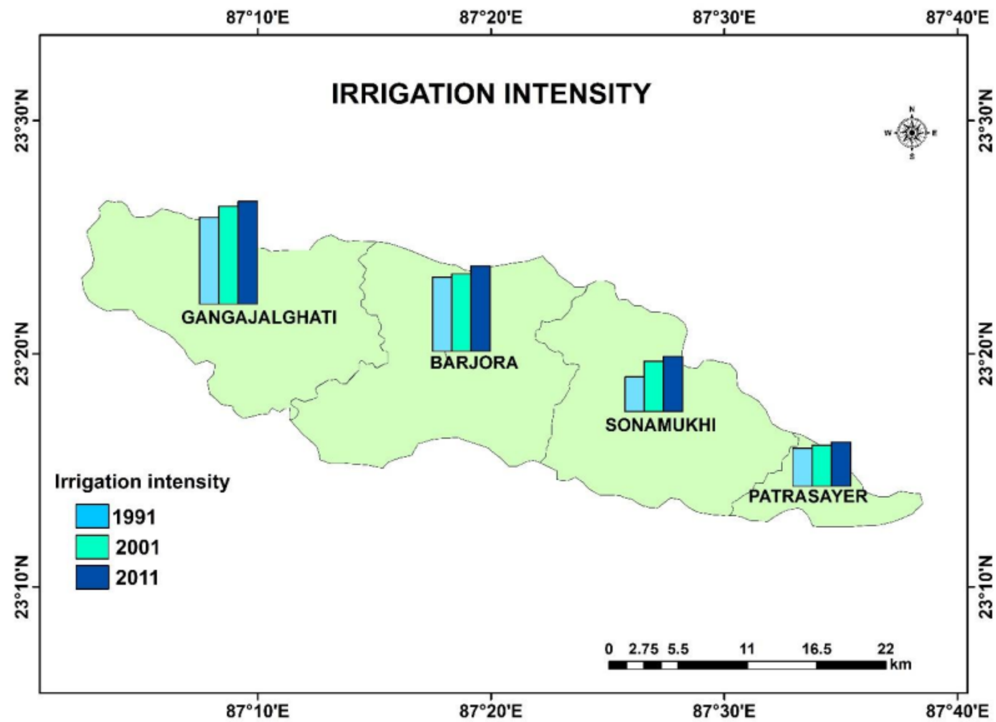

Figure 8.2 Block-wise comparison in IRINTST

8.6 Block-wise cropping intensity

In 1991 the cropping intensity of the Gangajalghati block was around 67% and in 2001 it increased to around 72%. Whereas, in 2011 it increased to 76%. It signifies that after the creation of the Shali reservoir irrigation project gross cropped area has been amplified in the Gangajalghati block.

In 1991, the cropping intensity of the Barjora block was around 50%. Then a rise in cropping intensity has been observed in 2001. The percentage of cropping intensity increased to 57% in 2001. Whereas, in 2011 around 65% cropping intensity has been observed. In the Barjora block from 1991 to 2001 around 7% positive change has been detected but from 2001 to 2011 around 8% change in cropping intensity has been observed.

In the Sonamukhi block, around 25% cropping intensity was observed in 1991 but in 2001, about a 10% increase in cropping intensity was noticed. In 2011, the percentage of irrigation intensity improved to 45%.

In 1991, the Patrasayer block had around 26% cropping intensity. In 2001, only a 4% positive change was noticed. In 2011, the block had around 35% cropping intensity.

The block-wise cropping intensity analysis elucidates that after the creation of the Shali reservoir irrigation project, the gross cropped area has increased in all four blocks of the Shali River basin but the rate of intensification in cropping intensity is not the same. In Gangajalghati, cropping intensity increased by around 9% from 1991 to 2011. While around a 15% increase has been observed in the Barjora block. From 1991 to 2011, around 20% and 9% CRPINTST has been increased in Sonamukhi and Patrasayer blocks. In 1991, Gangajalghati was the maximum CRPINTST and Sonamukhi was the minimum CRPINTST. In 2001, the Gangajalghati block was maximum and the Patrasayer block was minimum CRPINTST and 2011 depicts the same result as 2001 (Figure 8.3) (A1. Ch. 8.2).

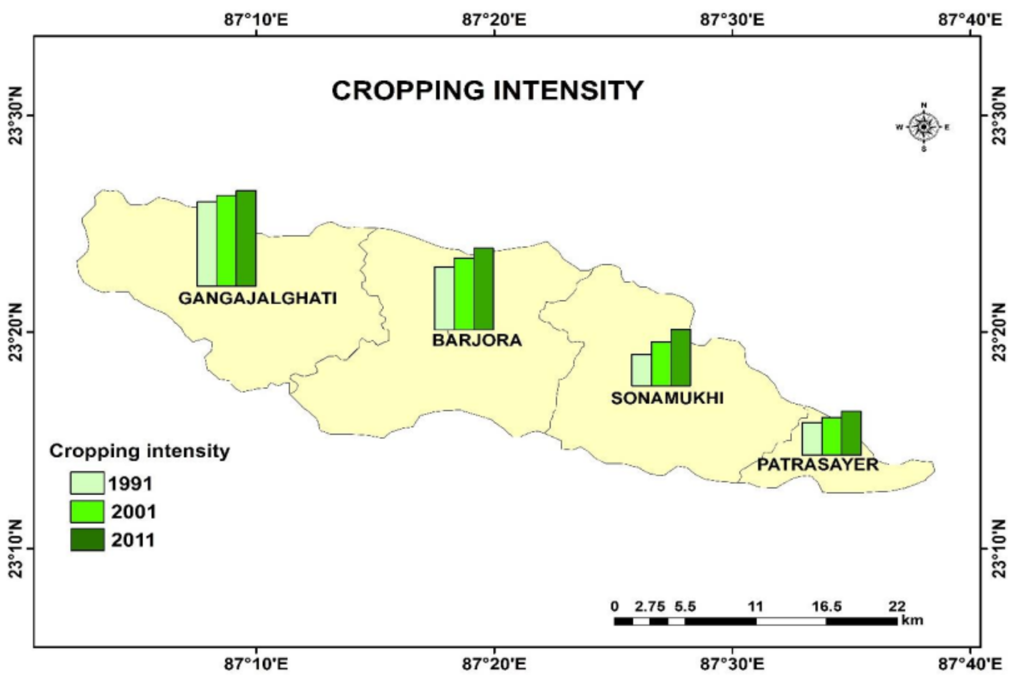

Figure 8.3 Block-wise comparison in CRPINTST

8.7 Block-wise agricultural labour intensity

In 1991, Gangajalghati block had around 32% agricultural labour intensity and in 2001 it increased to around 52%. Whereas, in 2011 it increased to 86%. It indicates that after the creation of the Shali reservoir irrigation project, the number of agricultural labours has increased in the Gangajalghati block.

In 1991, the agricultural labour intensity of the Barjora block was around 22%. Then growth in agricultural labour intensity has been detected in 2001. The percentage of agricultural labour intensity increased to 48% in 2001. Whereas, in 2011 around 80% of agricultural labour intensity has been noticed. In the Barjora block from 1991 to 2001 around 26% positive change has been detected but from 2001 to 2011 around 32% change in agricultural labour intensity has been observed.

In the Sonamukhi block, around 16% agricultural labour intensity was observed in 1991 but in 2001, about a 13% increase in agricultural labour intensity was noticed. In 2011, the percentage of irrigation intensity improved to 64%.

In 1991, the Patrasayer block had around 13% agricultural labour intensity. In 2001, around 17% positive change was noticed. In 2011, the block had around 53% agricultural labour intensity (Figure 8.4).

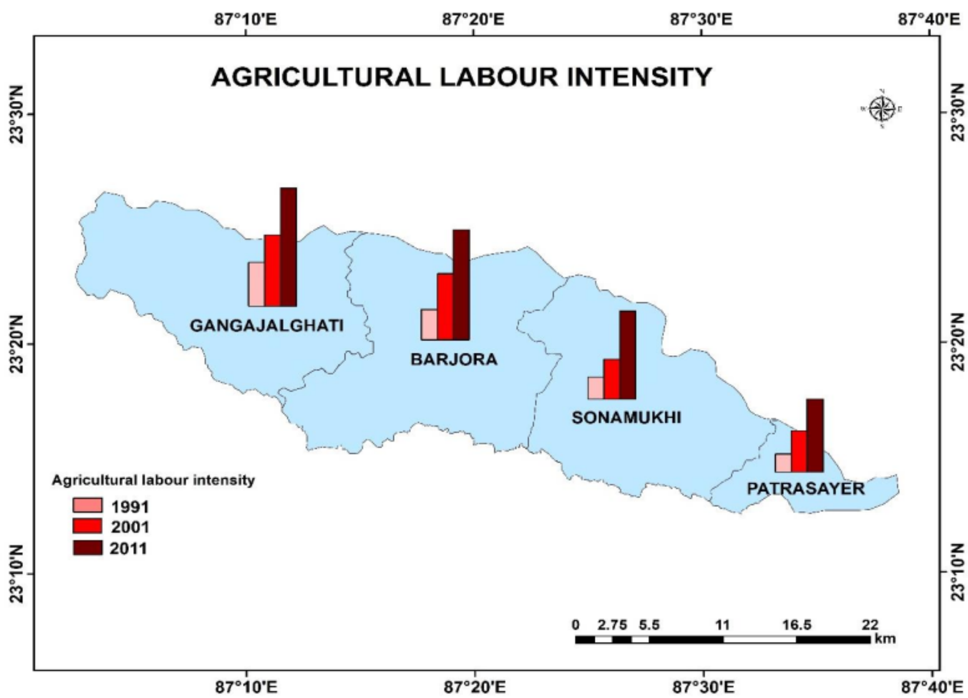

Figure 8.4 Block-wise comparison in AGLBINTST

The block-wise agricultural labour intensity analysis depicts that after the creation of the Shali reservoir irrigation project the number of agricultural labours has improved in all four blocks of the Shali River basin but the rate of increase in agricultural labour intensity is not the same. In Gangajalghati, agricultural labour intensity increased by around 54% from 1991 to 2011. While around a 58% increase has been observed in the Barjora block. Meanwhile, from 1991 to 2011, around 48% in the Sonamukhi block and around 40%

increase in agricultural labour intensity have been observed in the Patrasayer block. In 1991, Gangajalghati was the maximum and Patrasayer was the minimum agricultural labour intensity. In 2001, the Gangajalghati block was maximum and Sonamukhi block was minimum agricultural labour intensity and in 2011 the Gangajalghati block was maximum and Patrasayer block was minimum agricultural labour intensity (A1. Ch. 8.2).

8.8 Village-wise Irrigation intensity

The Shali River basin consists of around 339 villages. Therefore, the village-wise irrigation intensity values are classified into five categories: very high, high, moderate, low and very low (A1. Ch. 8.4).

In 1991, the maximum and minimum irrigation intensities were around 92% and 0.60% and the mean was around 31% in the Shali River basin. In 1991, only seven villages were observed under the very high category. In the high and moderate categories, 33 and 67 villages were noticed. While around 232 villages were observed in the low and very low categories (Figure 8.5).

In 2001, 94% and 0.86% were the maximum and minimum irrigation intensities of the Shali River basin. The village-wise mean irrigation intensity value was around 42%. This time around 25 villages were included under the very high irrigation intensity category and 45 villages were under the high category. In the moderate category, 96 villages were found. Lastly, in low and very low categories, 118 and 55 villages were identified (Figure 8.6).

In 2011, the Shali River basin was around 98% and 3% maximum and minimum irrigation intensity. The mean irrigation intensity value was around 50%. During 2011, 35 and 65 villages were under the very high and high category. About 125 villages were under the moderate category. Finally, about 88 and 26 villages were found under the low and very low categories (Figure 8.7).

The result reveals that after the creation of the Shali reservoir irrigation project village wise irrigation development has been observed throughout the Shali River basin. The village-wise mean of irrigation intensity has increased (around 19%) from 1991 to 2011. Mainly the villages near to reservoir and Shali River has good irrigation intensity than the other villages. Villages of Gangajalghati and Barjora blocks have the maximum number of very high and high-intensity villages than Sonamukhi and Patrasayer blocks.

Table 8.1 Year wise very high and high irrigation intensity village names

Year	Irrigation intensity type	Village names
1991	Very High	Kotalpukur, Arjuni, Mautara, Balarampur, Gobindapur, Dandulya, Gosainpur.
	High	Chhotalalpur, Numuigarya, Kelai, Radhaballavpur, Keshiara, Belianarayanpur, Dharampur, Malkuriya, Kotmadanmohanpur, Majuddagara, Kallapur, Jharia, Jemua, Balijora, Palsana, Bhiringi, Malkonra, Arjonapur, Biharjuria, Harekrishapur, Piraboni, Dhabani Gobindapur, Radha Krishnapur, Kantabani,

		Tentuliyadaga, Belut, Simlanagar, Batlapara, Aviirampur, Bhalukapahari, Nityanandapur, Parulia.
2001	Very High	Chhotalalpur, Kotalpukur, Arjuni, Krishnabati, Keshiara, Belianarayanpur, Dharampur, Mautara, Balarampur, Malkuriya, Kotmadanmohanpur, Majuddagara, Gobindapur, Kallapur, Jharia, Jemua, Balijora, Dandulya, Bihar Jurya, Amthia, Gosainpur, Belut, Bhatla Para, Menjua, Nityanandapur
	High	Pabayan, Khanrari, Mandarbani, Numuigarya, Kelai, Gururbad, Balikhun, Radhaballavpur, Sagarya, Nutangram, Gobinda Dham, Bhairabpur, Khidirpur, Madhabpur, Radhakrishnapur, Radhashyampur, Gopalpur, Jambedya, Palsana, Bhiringi, Arjunpur, Hare Krishnapur, Piraboni, Radhakrishapur, Gopinathpore, Tentuliyadanga, Simlanagar, Aviirampur, Bhalukapahari, Rajmadhabpur, Gangabandh, Dhulai, Churamanipur, Nanchanhati, Bneshe, Parulia, Brindaban Pur, Panch Para, Mamudpur, Bishnubati, Arbetal
2011	Very High	Chhotalalpur, Numuigarya, Kotalpukur, Arjuni, Krishnabati, Keshiara, Belianarayanpur, Dharampur, Mautara, Balarampur, Malkuriya, Kotmadanmohanpur, Majuddagara, Gobindapur, Kallapur, Jharia, Basu Chandanpur, Khopaganj, Jemua, Balijora, Gopalpur, Bhiringi, Malkonra, Dandulya, Bihar Jurya, Dhabani Gobindapur, Radha Krishnapur, Kantabani, Amthia, Gopinathpur, Gosainpur, Belut, Bhatla Para, Menjua, Nityanandapur,
	High	Saharjora, Muktatar, Beleshola, Pabayan, Khanrari, Mandarbani, Kelai, Gururbad, Balikhun, Radhaballavpur, Baradihi, Nutangram, Bamundiha, Hanri Bhanga, Shuabasa, Nutangram, Gobinda Dham, Bhairabpur, Mandi, Chhotakumira, Ekarya, Khidirpur, Kapishtha, Radharamanpur, Madhabpur, Ramnagar, Lalbazar, Radhakrishnapur, Radhashyampur, Sonagara, Sankara, Jambedya, Palsana, Barajuri, Arba, Arjunpur, Hare Krishnapur, Maldanga, Tentulia Danga, Shimlagar, Abhirampur, Srirampur, Bhalukapahari, Krishnapur, Rajmadhabpur, Gangabandh, Dhulai, Paschim Dubrajpur, Dubrajhati, Kamardanga, Ratnapur, Churamanipur, Sapuradihi, Nanchanhati, Ban Paruliya, Bneshe, Dhan Simla, Rampur, Asanbani, Parulia, Brindaban Pur, Benda,

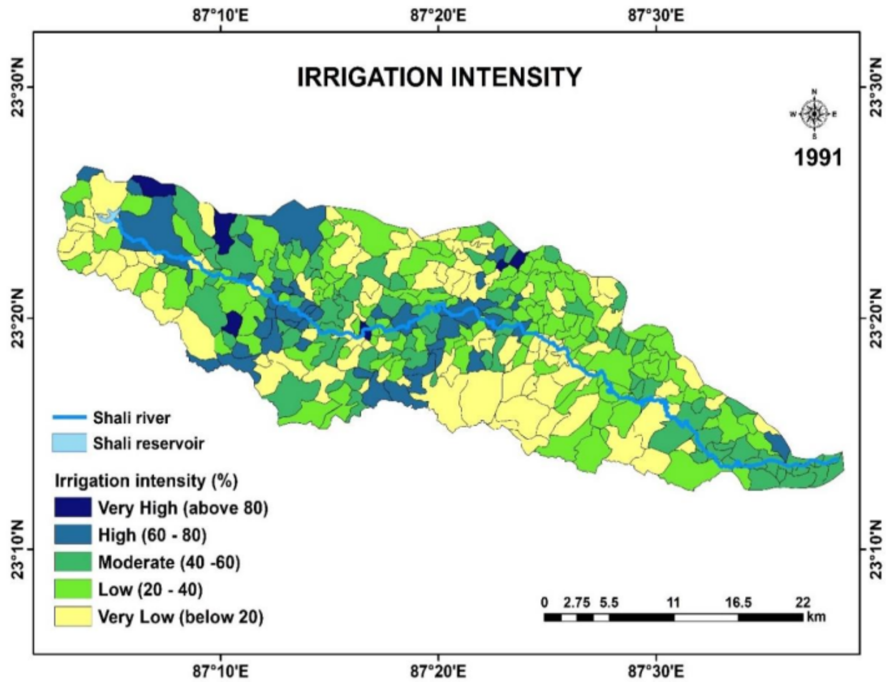

Figure 8.5 Village-wise IRINST of Shali River basin in 1991

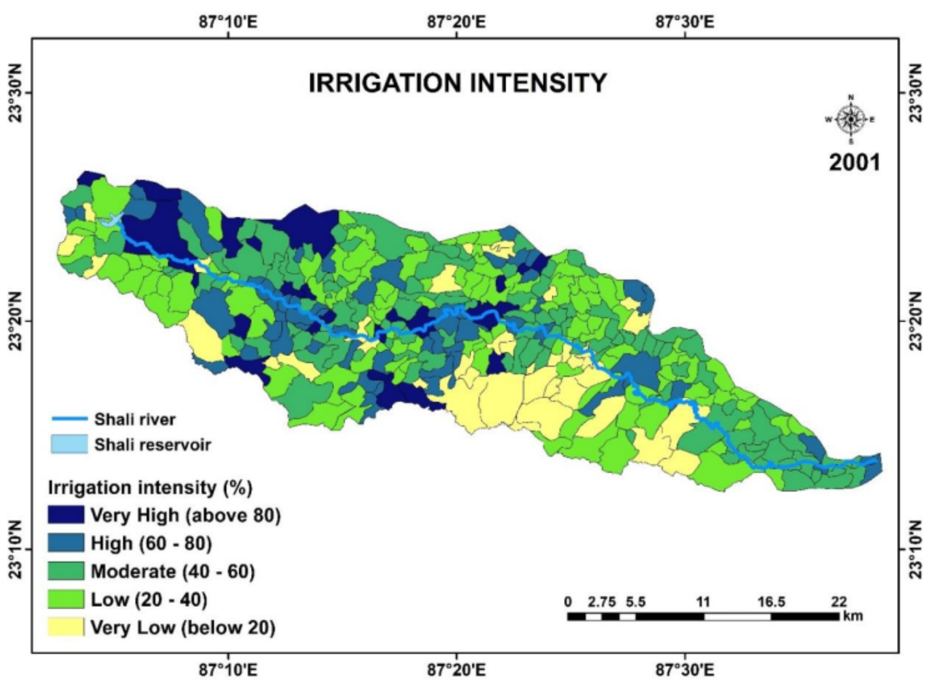

Figure 8.6 Village-wise IRINTST of Shali River basin in 2001

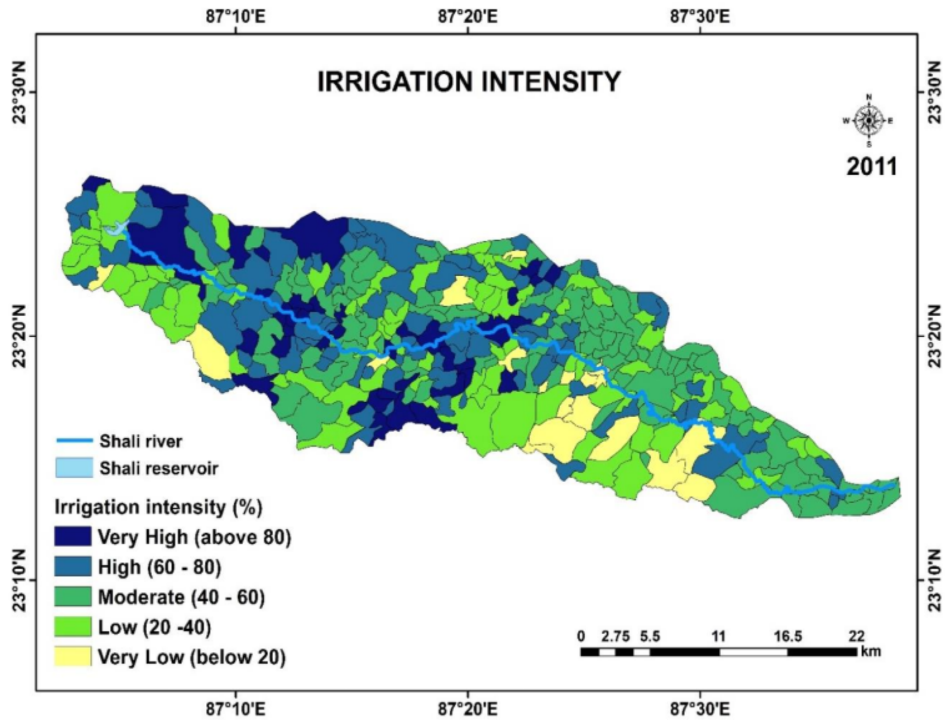

Figure 8.7 Village-wise IRINTST of Shali River basin in 2011

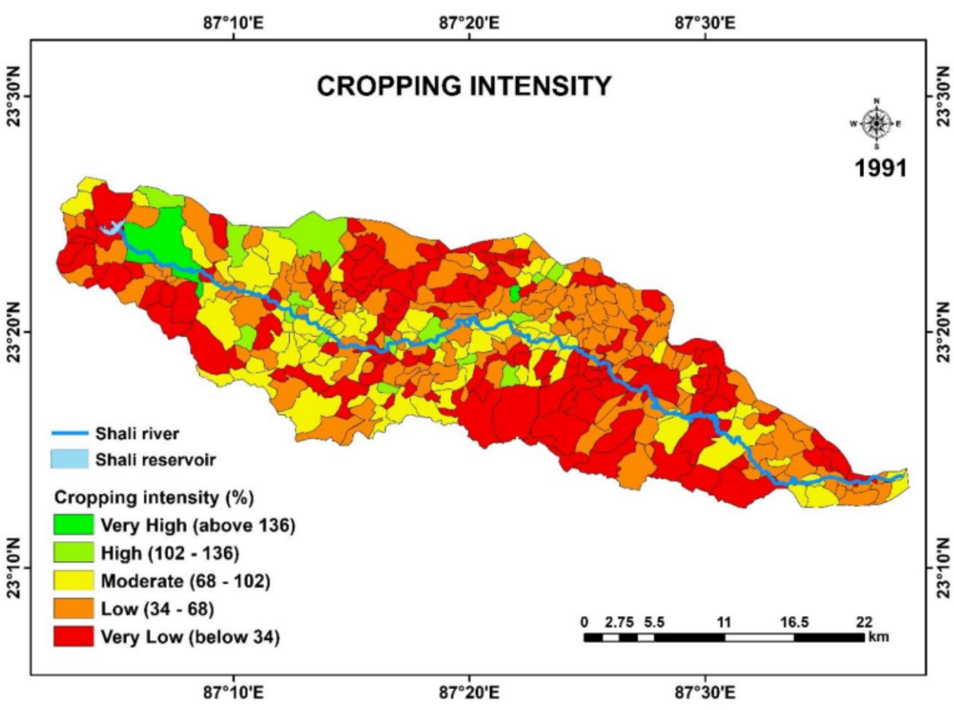

Figure 8.8 Village-wise CRPINTST of Shali River basin in 1991

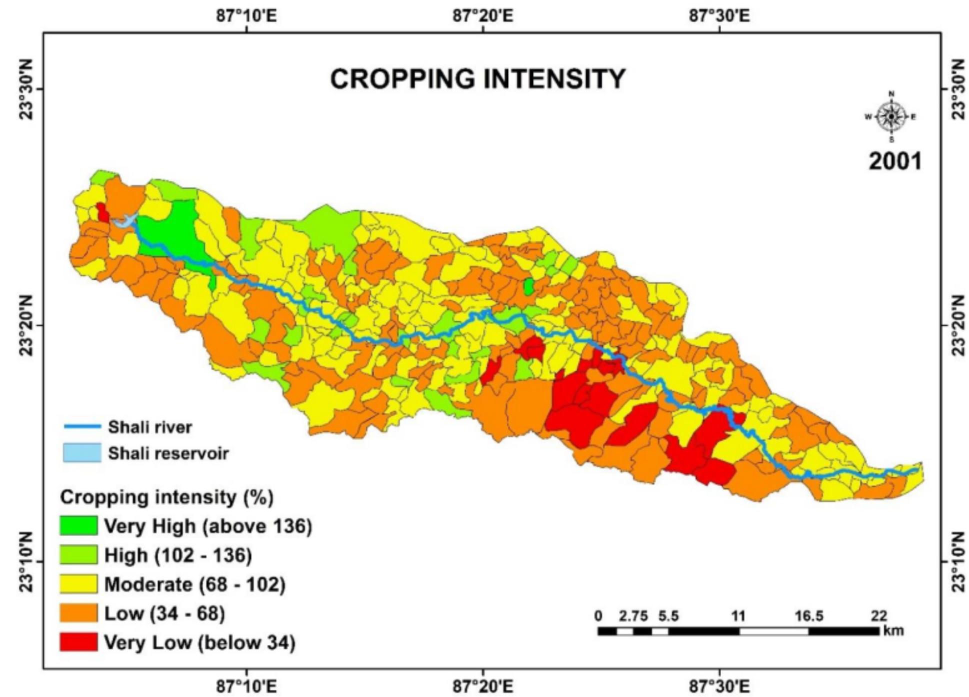

Figure 8.9 Village-wise CRPINTST of Shali River basin in 2001

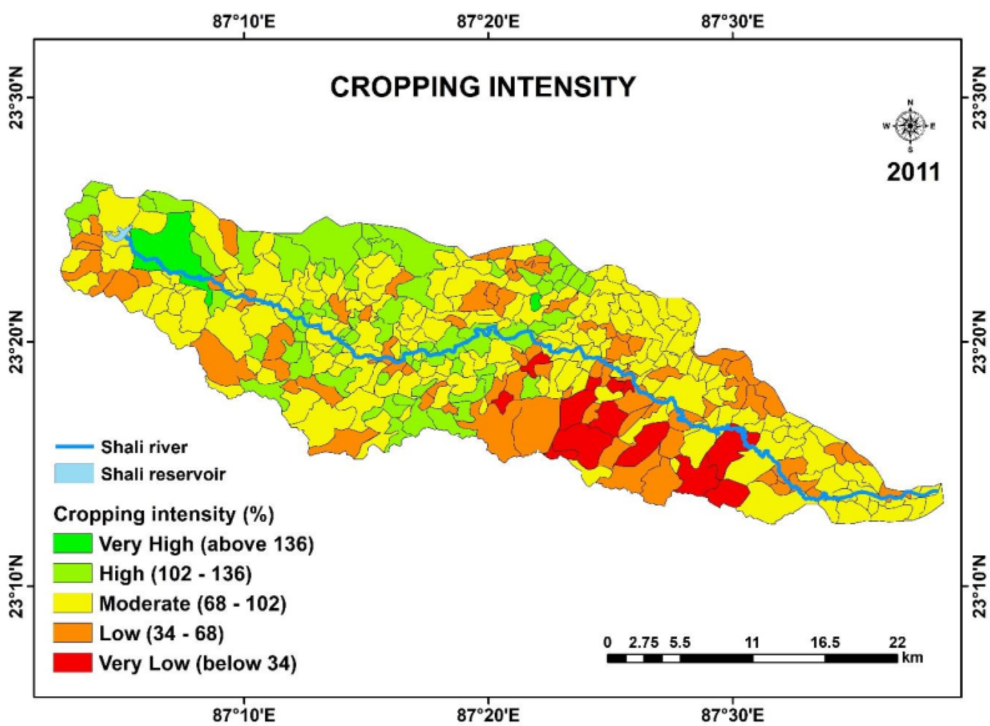

Figure 8.10 Village-wise CRPINTST of Shali River basin in 2011

8.9 Village-wise cropping intensity

In cropping intensity, the village-wise cropping intensity values are arranged into five groups: Very High (above 136%), High (102-136%), Moderate (68-102%), Low (34-68%) and Very Low (below 34%). In 1991, the maximum and minimum cropping intensities were around 156% and 1.75% and the mean was around 45% in the Shali River basin. In 1991, only one village was observed under the very high category. In the high and moderate categories, 9 and 56 villages were noticed. While around 151 and 121 villages were observed in the low and very low categories (Figure 8.8).

In 2001, 159% and 1.47% were the maximum and minimum cropping intensities of the Shali River basin. The village-wise mean cropping intensity value was around 66%. In 2001, around 2 villages were counted in under the Very High cropping intensity category and 28 villages were under the high category. In the moderate category, 130 villages were found. Lastly, in low and very low categories 147 and 32 villages were distinguished (Figure 8.9).

In 2011, the Shali River basin was around 168% and 6% maximum and minimum cropping intensity. The mean cropping intensity value was around 77%. During 2011, 3 and 55 villages were under the very high and high categories. Around 158 villages were under the moderate category. Finally, around 106 and 17 villages were found under the low and very low categories (Figure 8.10).

The result discloses that after the creation of the Shali reservoir irrigation project village wise gross cropped area has been increased throughout the Shali. The village-wise mean of cropping intensity has increased (around 32%) from 1991 to 2011. Mainly the villages near to reservoir and Shali River has good cropping intensity than the other villages. Villages of Gangajalghati and Barjora blocks have the maximum number of very high and high-intensity villages than Sonamukhi and Patrasayer blocks. The cropping intensity also signifies that both the kharif and rabi season crops are cultivated in villages of Shali River basin after the creation of the Shali reservoir project (A1. Ch. 8.5).

Table 8.2 Year wise very high and high cropping intensity village names

Year	Cropping intensity type	Village names
1991	Very High	Keshiara
	High	Kotalpukur, Arjuni, Belianarayanpur, Mautara, Balarampur, Gobindapur, Balijora, Dandulya, Kantabani
2001	Very High	Keshiara, Mautara
	High	Chhotalalpur, Numuigarya, Kotalpukur, Radhaballavpur, Arjuni, Krishnabati, Belianarayanpur, Dharampur, Balarampur, Malkuriya, Majuddagara, Gobindapur, Kallapur, Jharia, Basu Chandanpur, Radhashyampur, Balijora, Dandulya, Bihar Jurya, Dhabani Gobindapur, Kantabani, Amthia, Gosainpur, Belut, Shimlagar, Bhatla Para, Menjua, Nityanandapur
2011	Very High	Keshiara, Mautara, Amthia

High	Saharjora, Muktatar, Beleshola, Pabayan, Khanrari, Chhotalalpur, Mandarbani, Dewangarya, Numuigarya, Kelai, Gururbad, Kotalpukur, Rajamela, Radhaballavpur, Arjuni, Baradihi, Krishnabati, Nutangram, Shuabasa, Belianarayanpur, Dharampur, Dhwajamanipur, Nutangram, Thumkonra, Balarampur, Malkuriya, Ekarya, Majuddagara, Gadardihi, Radharamanpur, Madhabpur, Gobindapur, Kallapur Jharia, Ramnagar, Radhakrishnapur, Basu Chandanpur, Radhashyampur, Khopaganj, Jemua, Balijora, Gopalpur, Malkonra, Dandulya, Bihar Jurya, Pirrabani, Dhabani Gobindapur, Radha Krishnapur, Kantabani, Gosainpur, Belut, Shimlagar, Bhatla Para, Menjua, Nityanandapur

8.10 Village-wise agricultural labour intensity

The village-wise agricultural labour intensity values are arranged into five groups: very high, high, moderate, low and very low. In 1991, the maximum and minimum agricultural labour intensities were around 86% and 0.71% and the mean was around 28% in the Shali River basin. In 1991, only three villages were observed under the very high category. In the high and moderate categories, 18 and 42 villages were noticed. While around 141 and 135 villages were observed in the low and very low categories (Figure 8.11).

In 2001, 96% and 1.16% were the maximum and minimum agricultural labour intensities of the Shali River basin. The village-wise mean agricultural labour intensity value was around 42%. In 2001, around 22 villages were counted in under the very high cropping intensity category and 47 villages were under the high category. In the moderate category, 61 villages were found. Lastly, in low and very low categories, 120 and 89 villages were distinguished (Figure 8.12).

In 2011, the Shali River basin was around 98% and 1.16% maximum and minimum agricultural labour intensity. The mean agricultural labour intensity value was around 54%. During 2011, 58 and 64 villages were under the very high and high categories. Around 85 villages were under the moderate category. Finally, around 132 villages were found under low and very low categories (Figure 8.13).

The result discloses that after the creation of the Shali reservoir irrigation project, the village-wise number of agricultural labours has increased throughout the Shali River basin. The village-wise mean of agricultural labour intensity has increased (around 26%) from 1991 to 2011. Villages of Gangajalghati and Barjora blocks have the maximum number of very high and high-intensity villages than Sonamukhi and Patrasayer blocks. Mainly, the villages having very high and high irrigation and cropping intensity have very high and high agricultural labour intensity (A1. Ch. 8.6).

Table 8.3 Year wise very high and high agricultural labour intensity village names

Year	Labour intensity type	Village names
1991	Very High	Garjuria, Kalpaini, Banshol,

	High	Uara, Gururbad, Kotalpukur, Balikhun, Radhaballavpur, Bishanpur, Nadihi, Keshiara, Jam Bedya, Taljhitka, Ekchala, Ranganathpur, Amjor, Mautara, Kalberia, Balarampur, Belut, Ratnapur,
2001	Very High	Chak Keshya, Shitla, Deucha, Mandarbani, Kelai, Balikhun, Bishanpur, Nadihi, Kantabad, Keshiara, Jam Bedya, Taljhitka, Kalpaini, Banshol, Ranganathpur, Mautara, Thumkonra, Nabasan, Rampur, Gopalpur, Bhiringi, Belut
	High	Manjmura, Kanchanpur, Uara, Chhotalalpur, Gururbad, Radhaballavpur, Krishnabati, Shuabasa, Harekrishnapur, Garjuria, Ukhradihi, Purunia, Sangrampur, Amjor, Gobinda Dham, Oltara, Ranbahal, Kanchchala, Selera, Balarampur, Khidirpur, Kotmadanmohanpur, Gadardihi, Saltora, Kallapur, Ramnagar, Lalbazar, Kalla, Charadihi, Bhabarkola, Sirsa, Malkonra, Asan Chua, Hare Krishnapur, Harishpur, Amthia, Saldanga, Abhirampur, Muktapur, Bandarkoda, Bhairabpur, Basu Nandanpur, Katnia, Ratnapur, Churamanipur, Baharpur, Dhamsa
2011	Very high	Saharjora, Muktatar, Chak Keshya, Shitla, Manjmura, Uara, Deucha, Chhotalalpur, Mandarbani, Kelai, Kotalpukur, Rajamela, Balikhun, Radhaballavpur, Metia Narayanpur, Krishnabati, Bishanpur, Nadihi, Kantabad, Shuabasa, Keshiara, Harekrishnapur, Garjuria, Ukhradihi, Jam Bedya, Taljhitka, Kalpaini, Banshol Ekchala, Ranganathpur, Gobinda Dham, Mautara, Thumkonra, Oltara, Selera, Kalberia, Balarampur, Khidirpur, Nabagram, Kotmadanmohanpur, Gadardihi, Saltora, Kallapur, Ramnagar, Lalbazar, Kalla, Brahmanara, Charadihi, Rampur, Chandaibot, Gopalpur, Bhiringi, Belut, Bhairabpur, Ratnapur, Baharpur
	High	Kanchanpur, Gururbad, Baradihi, Ashuria Madhabpur, Hanri Bhanga, Talanjuri, Belianarayanpur, Gopkande, Purunia, Sangrampur, Lakhyara, Dhwajamanipur, Phulberrya, Dangarpara Amjor, Madhabpur, Ranbahal, Kanchchala, Bhairabpur, Ekarya, Gadardi, Salbedya, Jharia, Talanda, Bhabarkola, Paschim Brindabanpur, Sirsa, Jambedya, Saluka, Arba, Asan Chua, Hare Krishnapur, Harishpur, Pirrabani, Shyamdaspur, Kantabani, Amthia, Gosainpur, Saldanga, Abhirampur, Asansola, Muktapur, Tilasuli, Bandarkoda, Bayermara, Rautara, Barkura, Gangabandh, Radharamanpur, Paschim Nandapur, Basu Nandanpur, Shitaljor, Katnia, Jashra, Mathurabati, Churamanipur, Tiura, Bhedomushal, Salda, Chaitanpur, Ban Paruliya, Bneshe, Jaljala, Dhamsa, Mamudpur

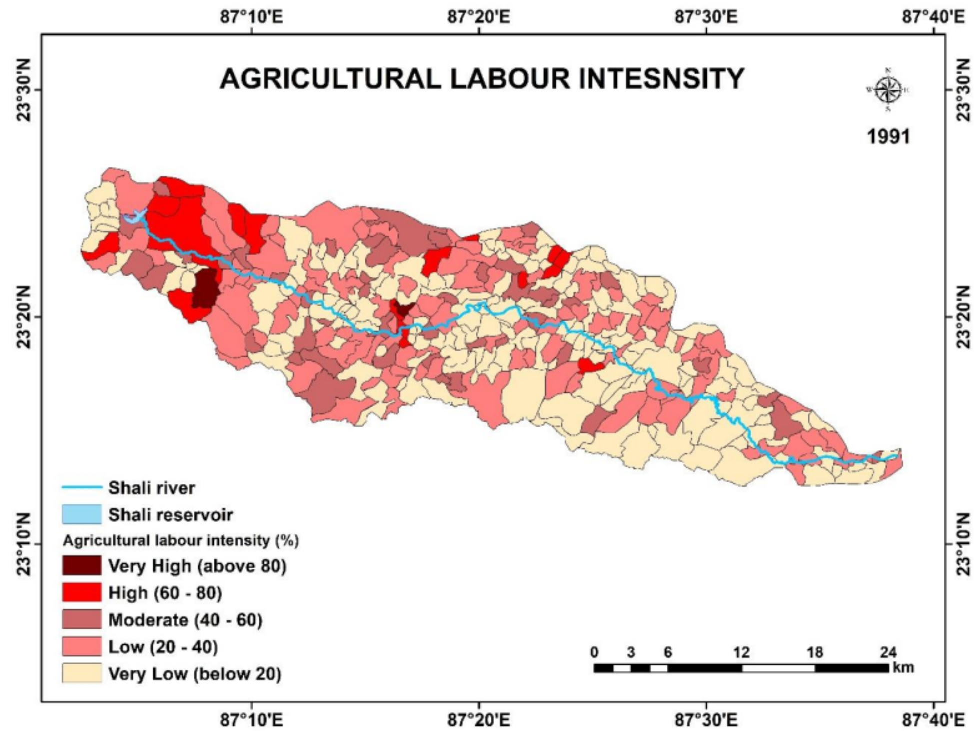

Figure 8.11 Village-wise AGLBINTST of Shali River basin in 1991

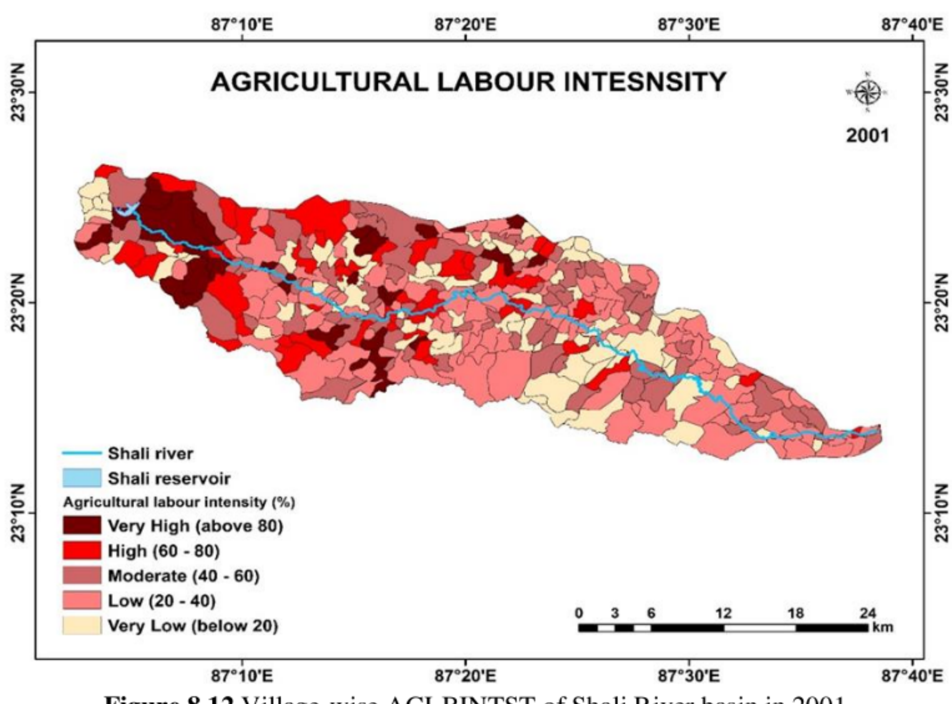

Figure 8.12 Village-wise AGLBINTST of Shali River basin in 2001.

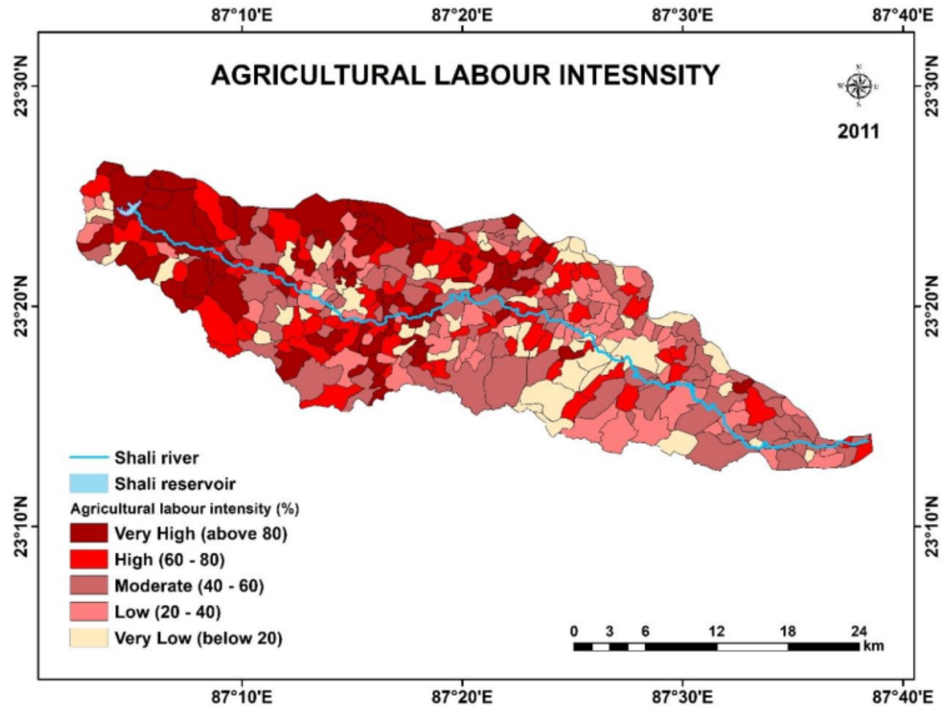

Figure 8.13 Village-wise AGLBINTST of Shali River basin in 2011

8.11. Correlation analysis

Correlation analysis has been performed using the LR method between IRINTST and CRPINTST. Both the village and block-wise IRINTST and CRPINTST analysis reveal that after the creation of the Shali reservoir irrigation project, positive changes have occurred in IRINTST and CRPINTST. The LR approach has been used to identify the association between IRINTST and CRPINTST. For the analysis village wise IRINTST and CRPINTST datasets were used. Here, IRINTST is considered an independent value (*X*-axis) and CRPINTST is considered a dependent value (*Y*-axis) respectively.

In 1991, an upward trend line has been observed which signifies a positive association-between IRINTST and CRPINTST and R^2 value is 0.70 which means the IRINTST and CRPINTST values are 70% correlated (Figure 8.14).

In 2001, again a high positive relationship has been observed between IRINTST and CRPINTST with an R^2 value of 0.79. the correlation value has improved from 1991 to 2011. It signifies that the CRPINTST of the Shali River basin is highly dependent on IRINTST (Figure 8.15).

In 2011, a positive association between IRINTST and CRPINTST has been observed but the R^2 value is reduced to 0.72. it indicates that the percentage of relationships is decreasing and, therefore dependency is reducing. The main reason would be the use of high-yield seeds, fertilizer, and modern types of machinery which enhances the crop production area (Figure 8.16).

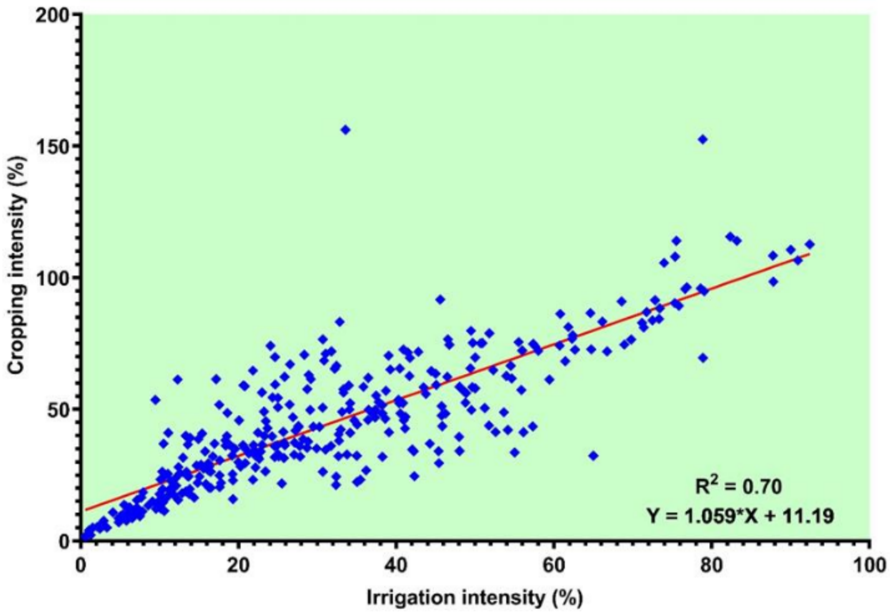

Figure 8.14 LR between IRINTST and CRPINTST in 1991

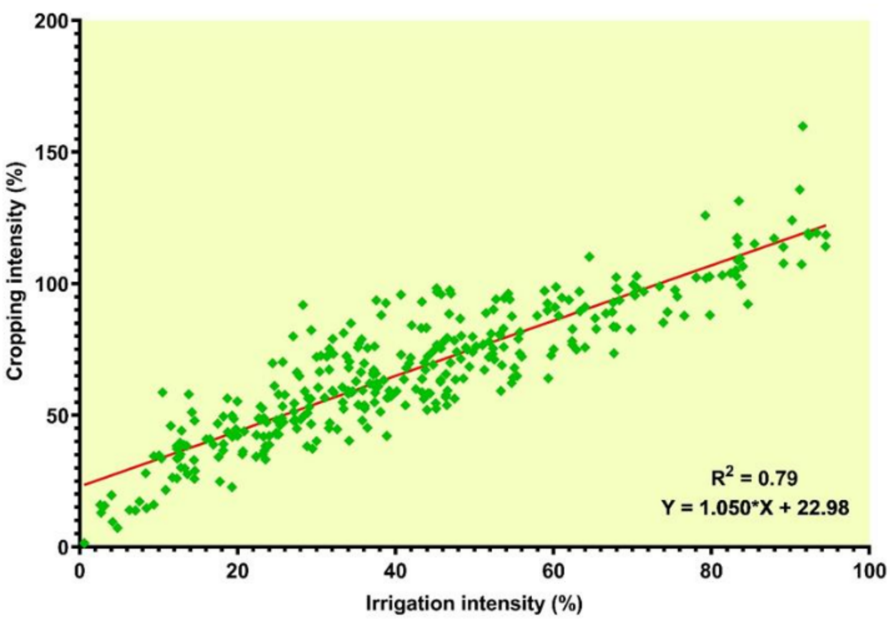

Figure 8.15 LR between IRINTST and CRPINTST in 2001

MLR has been executed to analyse the correlation between IRINTST, CRPINTST and ARLBINTST. Here, IRINTST and CRPINTST are used as independent variables (*X*-axis) and the agricultural labour intensity is considered as the dependent variable (*Y*-axis). Block-wise IRINTST, CRPINTST and ARLBINTST data sets are used for MLR. Figure 17 shows a block-wise temporal change in correlation. The correlation coefficient values are classified into four categories: Very high positive, high positive, moderate positive and low positive.

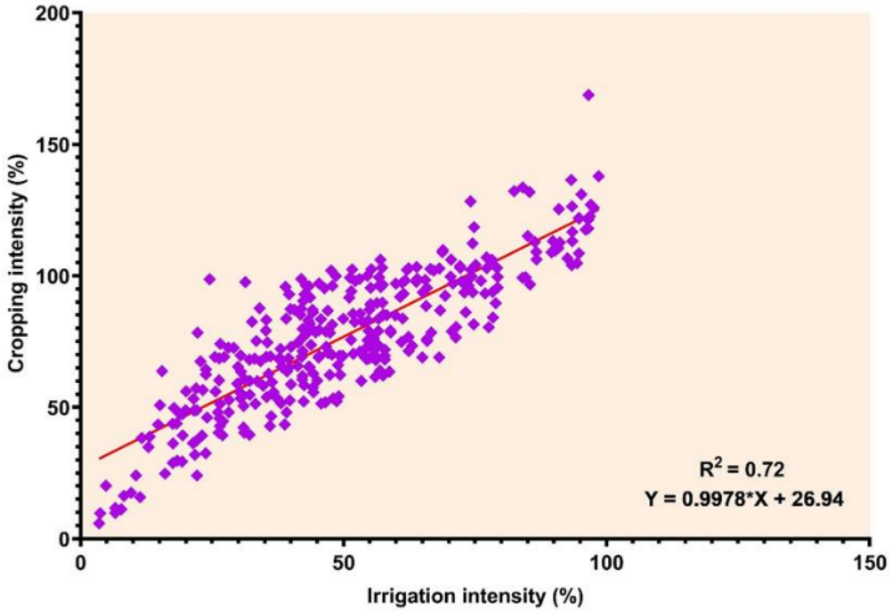

Figure 8.16 LR between IRINTST and CRPINTST in 2011

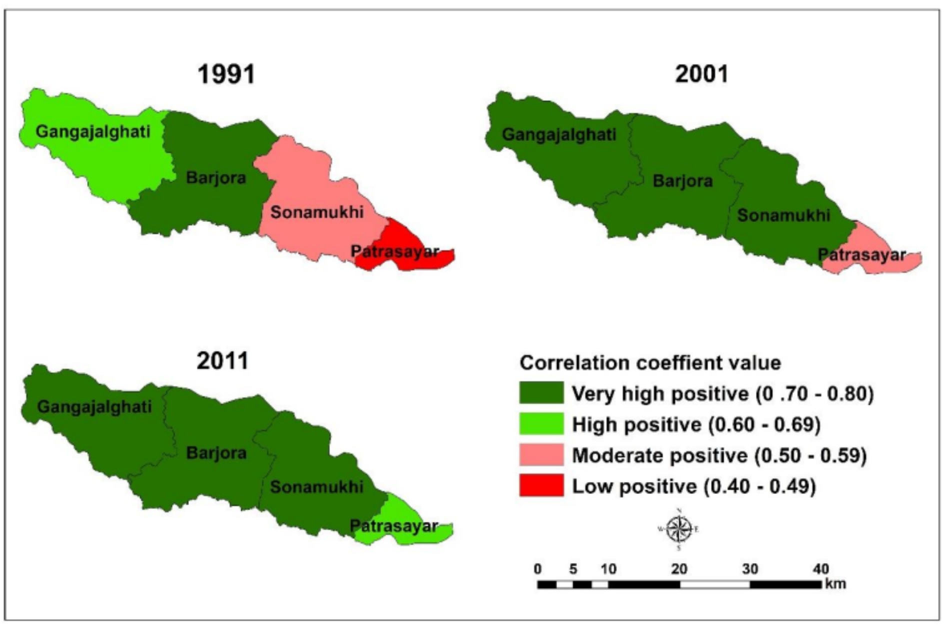

Figure 8.17 MLR analysis between IRINST, CROINTST and ARLBINTST

In 1991, the Barjora block was in the very high positive category with an R^2 value of 0.72. Gangajalghati block was in the high positive category. The R^2 value of the Gangajalghati block was 0.64. In the moderate positive category, the Sonamukhi block was observed. The R^2 value of the Sonamukhi block was 0.58. whereas, the Patrasayer block was in the low positive category with an R^2 value of 0.35.

In 2001, the correlation between IRINTST, CRPINTST and ARLBINTST have been improved. Gangajalghati, Barjora and Sonamukhi blocks were included under the very high positive category with R^2 values of 0.73, 0.75 and 0.71. In 2001, in Sonamukhi block sharp change has been noticed. It includes under very high positive category from the moderate positive category. A gentle rise in correlation value is also noticed in the Patrasayer block. It was under the moderate positive category with an R^2 value of 0.50.

In 2011, very high positive category comprised Gangajalghati, Barjora and Sonamukhi blocks with R^2 values of 0.79, 0.77, and 0.75. all the correlation coefficient values were increased from 1991 to 2011. In 2001, the Barjora block had a maximum R^2 value but in 2011 Gangajalghati block has a maximum. The correlation coefficient value of the Patrasayer block also improved in 2011. Patrasayer block was in the high positive category with the R^2 value of 0.63.

The MLRn approach discovers that block-wise number of agricultural labour is positively correlated with gross cropped and irrigated areas in the Shali River basin. Though the intensity is not the same in every block. Gangajalghati and Barjora blocks have the maximum correlation with the Sonamukhi and Patrasayer blocks (Figure 8.17).

8.12 Conclusion

This chapter addresses the impact of the Shali reservoir irrigation project on irrigation, cropping and agricultural labour intensity. A temporal analysis from 1991 to 2011 has been done to identify the change in irrigation, cropping and agricultural labour intensity in the Shali River basin. Both LR and MLR methods are applied to identify the association between IRINTST, CRPINTST and ARLBINTST.

The study reveals that temporal positive change has occurred from 1991 to 2011 in IRINTST, CRPINTST and ARLBINTST but not at the same intensity. IRINTST has increased by 19%, CRPINTST by 32% and ARLBINTST by 26%. The Shali reservoir project helps to increase irrigated areas which boosts the irrigation intensity. Whereas, the irrigation intensity increases the gross cropped area. before the Shali reservoir project only kharif crops were cultivated in the Shali River basin area but after the creation of the Shali reservoir project both the kharif and rabi crops are cultivating. So, IRINTST and CRPINTST are positively correlated. Whereas the correlation analysis identifies that in 2011 the correlation between IRINTST and CRPINTST is declining which may be the result of fertilizer, high-yield seeds and modern types of machinery. Therefore, the rise in the gross cropped area is not dependent on irrigation intensity. The number of agricultural labours also increased from 1991 to 2011 and the correlation between IRINTST AND CRPINTST intensified over time. The economy of Shali River basin is rural, therefore the maximum number of people of Shali River basin are engaged in agricultural activities and the growth of IRINTST AND CRPINTST has generated huge employment which intensified the agricultural labour intensity over time. Gangajalghati and Barjora blocks have a maximum intensity than the Sonamukhi and Patrasayer block.

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Overall conclusions

The present thesis depicts that the Shali reservoir plays a significant role in the agricultural development of the Shali River basin area. After the construction of the reservoir farmers are getting irrigational water throughout the season. The Shali reservoir helps to cultivate both the Kharif (summer) and Rabi (Winter) crops. It also increases the number of irrigated areas and reduces rural-to-urban migration which helps to increase the number of agricultural labours. Nonetheless, the agricultural development is not equitable because the villages near to reservoir and river are getting more water than the other villages. Therefore, the maximum number of irrigated lands is observed along the Shali riverside.

9.1 Major findings

Shali reservoir is a medium irrigation project governed by the Irrigation and Waterways Department, Government of West Bengal, situated in Gangajalghati Block, Bankura district of West Bengal. This man-made reservoir was formed at the origin of the Shali River. Shali reservoir stores rainfall and provides irrigational water through the Shali River using the river lift irrigation technique in the Shali River basin area. The Shali River basin comprises part of four blocks i.e., Gangajalghati, Barjora, Sonamukhi and Patrasayer. The Shali River basin area gets a minimum amount of rainfall than the other parts of the Bankura district, thus Shali reservoir was made to store rainfall. Uneven topography is another important factor behind the construction of the Shali reservoir. Before the construction of the Shali reservoir due to high elevation and slope maximum amount of water flowed as surface runoff. The Shali River basin area is covered with lateritic uplands which have low water holding capacity, So, reservoir construction is necessary and the groundwater level is poor in the Shali River basin than in other parts of the Bankura district. These are the main factors behind the erection of the Shali reservoir.

The water level of the Shali reservoir is dependent on rainfall. the water level trend from 1990 to 2021 of the Shali reservoir shows a positive trend which signifies that the water level has increased in the Shali reservoir. The Shali reservoir area gets a minimum amount of rainfall during winter and pre-monsoon seasons. So, the water level reduces this time. The average water level in the winter season is around 8.85 m. The MK trend Z value of winter water level is around 1.57 which represents a very low increasing trend. In pre-monsoon season average water level reduces to 8.81 m. During monsoon, it gets the maximum amount of rainfall. So, the water level also increases. The average water level is around 8.91 m. the MK trend z value is around 2.71 which indicates a high increasing trend from 1990 to 2021. In post-monsoon, the amount of rainfall decreases, so the water level also reduces in post-monsoon. The average water level in post-monsoon is around 8.89 m. the MK trend analysis z value is around 1.96 which determines an increasing trend. In the Shali reservoir, a high-water level trend has been observed in monsoon and post-monsoon, and a low positive trend was observed in pre-monsoon and winter. Study reveals that the Shali reservoir can provide irrigation water throughout the season.

Supervised classification with a random forest algorithm has been used to determine the transformation in LULC after the creation of the Shali reservoir irrigation project from 1986 to 2021. The study reveals a huge transformation in the LULC of the Shali River basin area. After the construction of the Shali reservoir around 52% growth in agricultural land has been observed from 1986 to 2021 in the Shali River basin area. between 2006 to 2021, maximum transformation in LULC has been observed. A huge number of forest areas and barren lands are transformed into agricultural land. Along with the agricultural development, built-up areas also increased. Block-wise agricultural development was also analysed. The Shali reservoir is constructed in the Gangajalghati block. In 1986, the Gangajalghati block was covered with dense forest covers and 0.23% was under agricultural land. In 2021, around 50% of the Gangajalghati block is under agricultural land. The block-wise agricultural land comparison reveals that from 1986 to 2021, around 29% of agricultural land has been increased in Gangajalghati block. In the Barjora block, only 5% of agricultural land has been increased. Whereas around 47% of agricultural land decreased in the Sonamukhi block and 8% increased in the Patrasayer block. Shali reservoir is in Gangajalghati block, so maximum agricultural development has occurred in Gangajalghati block. The predicted LULC map of 2031, also shows that the amount of agricultural land will be increased by around 57%. Thus, it has been proven that the Shali reservoir plays a vital role in agricultural development in the Shali River basin area.

The AHP has been applied to discover suitable irrigation lands for the Shali River basin. AHP is a multi-criteria decision-making process which needs several criteria, so 12 criteria are selected: slope, relief, soil group, soil texture (clay, sand, silt), soil properties (nitrogen, pH, organic carbon), LULC, rainfall and distance from the river. A normalized pairwise matrix has been created to generate the criteria weightage of each factor. The result shows that the Shali River basin has around 64% irrigation-suitable land. These suitable lands are observed along the Shali River and north, north-eastern, and north-western portions because these portions are covered with fertile luvisols which are widely used for cropping and rich in nitrogen and organic carbon. Block-wise suitability analysis shows that Sonamukhi block has the maximum amount of very high irrigation suitable land but Gangajalghati and Barjora blocks have the maximum amount of high irrigation suitable land. These two blocks are situated near the reservoir (upper portion of the Shali River basin); therefore, they are getting more irrigational water than the other two blocks. The village-wise irrigational suitability reveals that the villages near the river have high irrigation-suitable lands. So, it can be said that the distance to the river is playing a major role because it determines the irrigation water availability.

The Z score method has been applied to identify the village-wise distribution of irrigated areas. The analysis shows that the number of low-irrigated villages has been reduced from 1991 to 2011. In 1991, around 78% of villages have low irrigated areas but in 2001 it reduced to 64%. But in 2011 around 51% of villages have low irrigated areas. Thus, it can be considered that after the construction of the Shali reservoir the number of irrigated areas has increased in the Shali River basin area but maximum development has been discovered near the Shali riverside villages.

The major crops of the Shali River basin are rice, potato, wheat, and mustard. After the creation of the Shali reservoir around 640 ha of crop production area has increased from 1995 to 2020. Rice is the dominant crop and three types of seasonal rice (Aus, Aman and Boro) have been cultivated, around 585 ha of rice production area has been increased from 1995 to 2020. The MK trend analysis of crops shows that potato has the maximum trend which means potato production area has increased more than other crops. Both Kharif and Rabi production areas have been increased in the Shali River basin area. Rice mapping also shows a positive change in the rice production area. It can be said that after the creation of the Shali reservoir crop production area has increased especially in the Rabi season.

The study reveals a positive change between irrigation, cropping and agricultural labour intensity from 1991 to 2011 in the Shali River basin area. Irrigation intensity has increased by around 19%, cropping intensity by around 32% and agricultural labour intensity by around 26%. Prior to the Shali reservoir irrigation project only kharif crops were cultivated but after the creation of the Shali reservoir irrigation project both the kharif and rabi crops are cultivating. The correlation analysis shows a positive correlation between irrigation and cropping intensity. In 2001, the correlation is 0.79 and in 2011 is 0.72 which indicates a declining correlation between irrigation and cropping intensity. It signifies that the dependency of cropping intensity on irrigation is reducing. The main reason would be the use of high-yield seeds, fertilizer and modern types of machinery which enhances the crop production area. the number of agricultural labours also increased from 1991 to 2011 and the correlation between irrigation and cropping intensity also intensified over time. The economy of the Shali River basin area is rural, maximum people of the Shali River basin are engaged in agricultural activities and the growth of irrigation and cropping intensity has generated huge employment which intensified the agricultural labour intensity over time. Gangajalghati and Barjora blocks are situated upper portion of the Shali River basin, thus they get more irrigation water than Sonamukhi and Patrasayer blocks.

The overall study discloses that after the creation of the Shali reservoir villages of Gangajalghati and Barjora blocks are getting maximum benefit than the other two blocks.

9.3 Recommendations

It is proved that the Shali reservoir has a great impact on the Shali reservoir area. It acts like a life saviour to the people of the Shali River basin area. There are some suggestions and recommendations made for prospects.

- After the creation of the Shali reservoir, irrigation intensity has been accelerated in the Shali River basin area but the villages of Gangajalghati and Barjora blocks are getting more irrigation water due to their location than the other two blocks i.e., Sonamukhi and Patrasayer. These two blocks yielded more quick flow than Gangajalghati and Barjora blocks. Therefore, it is advisable to imply rainwater collecting structures to store monsoonal rainfall that will help to increase irrigation intensity in future. The rainwater harvesting structures known as Hapa have already been implemented in the Hirbandh and Khatra blocks of the Bankura district. Hapa is a rainwater collecting arrangement which is financed by the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS).

- During the study period, it has been observed that there is a communication gap between the reservoir authority and farmers. The reservoir authority does not inform the farmers before the water is discharged from the reservoir. Therefore, huge misuse of water has been observed. The Shali reservoir maintenance officials should inform the villagers before water is released from the reservoir. Social media can be a good option for this purpose.
- The reservoir authority has no idea about the amount of water that farmers are getting for irrigation. Thus, each farmer is not getting an equal amount of irrigation water. Affluent farmers have modern types of machinery, so they are collecting more irrigation water from the Shali river than poor farmers.
- The farmers do not know about crop water requirement (CWR), therefore, sometimes crops are affected due to over-irrigation. Hence, the I&W Dept. should implement awareness programs which will help farmers to learn the proper usage of irrigation water.
- Reservoir sedimentation is a big problem. It reduces the water holding capacity of the reservoir. In the case of the Shali reservoir, no sedimentation analysis has been found. The I&W Dept. should implement desilting programme in the Shali reservoir.
- The reservoir site has no proper electric lights, so electrification of the reservoir site is compulsory. Solar lights can be a good option for this purpose.
- In the reservoir site, only one rain gauge station is available which is very old. Therefore, modern meteorological data collection systems are needed.
- The reservoir site has the potential to convert into a tourist spot. According to villagers' opinion, many seasonal birds visit here. This place is already used as a picnic spot during the winter. So, the beautification program along the reservoir site should be launched with the help of the Irrigation and Tourism department. The irrigation and tourism department should start boating facilities in the Shali reservoir which will boost tourism.
- The Shali reservoir's water is also used for drinking purposes; therefore, water quality monitoring of reservoir water is necessary.
- The Shali reservoir can be used for pisciculture. It will enhance the economic growth of the villagers of Shali reservoir.
- The Shali reservoir is situated in a very remote place which is inaccessible to tourists. Therefore, it is advisable to provide public transport facilities for tourists.
- The Shali River basin is comprised of five protected forests but vegetation cover trend analysis reveals that the amount of dense vegetation cover has decreased over time from the period 1995 to 2020. The dense vegetation covers are transformed into agricultural lands that reduce annual rainfall and increase land surface temperature and air quality. Whereas, after 2015, a slight improvement in the total area of vegetation cover has been noticed which may have been due to the yearly afforestation programme such as National Afforestation Programme (2009) by the Indian Government. Lastly, it can be said that the Shali reservoir increases agricultural development. Simultaneously, it affects the environmental balance. So, it is advisable that Government should implement awareness schemes to balance this situation.

9.4 Limitations

The foremost limitation to conducting the study is data availability. The water level data of the reservoir is available but the water usage data is not available. There is no proper data regarding the water discharge of the reservoir and reservoir sedimentation level. Farmers also have no idea how much water they are using from irrigation. Therefore, to generate data geospatial techniques have been incorporated into this study. Due to Covid 19 pandemic, it was impossible to collect data from the farmers, thus secondary data sets were used. A guide curve is needed to be prepared to regulate the gates of the Shali dam.

9.5 Future research scopes

There are certain future research scopes on the Shali reservoir and Shali River basin which are listed below.

- A perception study of the villagers on the Shali reservoir irrigation project.
- Determining the area and volume of the Shali reservoir by comparing digital elevation models.
- Water quality analysis of the Shali reservoir.
- Climate change impact on the Shali reservoir performance
- Analysis of siltation in the Shali reservoir and Shali river
- Life period analysis of the Shali reservoir

Appendix A1

Chapter 2

Ch. 2.1 Climograph of Shali River basin

Year	Annual mean		Year	Annual mean	
	Rainfall (cm)	Temperature (°C)		Rainfall (cm)	Temperature (°C)
1981	124.80	24.8	2001	111.61	25.41
1982	104.58	25.36	2002	92.72	25.47
1983	61.96	26.38	2003	94.04	25.48
1984	103.27	25.38	2004	100.19	25.33
1985	90.52	25.82	2005	83.49	25.85
1986	87.01	25.62	2006	121.28	25.62
1987	81.73	26.1	2007	146.77	24.85
1988	83.05	26.08	2008	115.57	24.82
1989	71.19	26	2009	109.42	25.61
1990	111.62	25.52	2010	77.78	26.15
1991	88.33	25.96	2011	149.85	25.22
1992	71.19	25.95	2012	108.54	24.87
1993	94.92	25.75	2013	148.09	24.7
1994	110.74	25.51	2014	94.92	25.08
1995	91.40	25.46	2015	103.71	25.64
1996	75.58	25.79	2016	123.48	26.08
1997	112.50	25.57	2017	162.59	25.63
1998	105.47	25.28	2018	104.14	24.96
1999	109.86	25.38	2019	96.67	25.73
2000	82.17	25.09	2020	111.62	24.71
			2021	158.05	25.33

Chapter 3

Ch. 3.1 Block-wise rainfall and temperature in Bankura district

Block name	Rainfall (mm)	Temperature (°C)	Block name	Rainfall (mm)	Temperature (°C)
Bankura-I	1349.5	27.27	Jaypur	1425.9	26.69
Bankura-II	1398.2	27.12	Khatra	1425.6	27.11
Barjora	1402.7	26.76	Kotulpur	1384.7	26.775
Bishnupur	1421.9	26.96	Mejhia	1386.2	26.84
Chhatna	1354.7	27.01	Onda	1382.7	27.07
Gangajalghati	1390.4	26.84	Patrasayer	1425.4	26.71
Hirbandh	1415.7	26.92	Saltora	1373.8	26.73
Indpur	1386	27.09	Simlapal	1412.6	27.23
Indus	1412.5	26.71	Sonamukhi	1420.7	26.66

Ch. 3.2 Seasonal groundwater level of Bankura district

Locations	Winter (m)	Pre-monsoon (m)	Monsoon (m)	Post-monsoon (m)
Gangajalghati	0	7.28	5.72	2.6
Gholkund	4.23	5.76	2.94	2.68
Gorabari	0	7.94	3.97	3.69
Gauripur	5.13	5.93	4.83	2.78
Habib pushkarini	0	0.85	0	3.08
Hatasuria	2.65	2.75	1.98	1.28
Hatirampur	5.5	6.66	4.22	3.24
Hazra bandh	13.7	12.94	0	12.27
Indpur	0	6.36	1.03	2.07
Jagadalla	0	6.73	2.75	2.47
Jayrampur	0	2.16	0.92	1.63
Jhilmili	0	4.72	8.99	2.41
Joypur	2.6	2.25	0.61	1.64
Kamalpore	5.14	7.43	4.66	3.48
Kashtora	5	6.43	2.08	2.73
Kenjakura	3.2	8.02	3.24	2.55
Kharka suli	4.83	16	19.84	8.23
Khatra	0	5.38	4.22	3.41
Kotulpur	10	16.21	0	3.41
Kusthalia	0	7.65	1.9	2.16
Lakhanpur	0	7.48	3.84	2.38
Lokpur	0	3.85	0	5.52
Mejia	2.2	6.01	5.69	4.04
Moyra	8.38	7.23	2.17	5.54
Natungram	0	3.9	1.32	1.69
Partasayer	4.4	2.07	1.14	1.91
Radhanagar	0	1.7	1.3	0.55
Raipur	6.69	8.38	1.67	4.85
Ranibandh	8	11.08	3.98	6.74
Saltora	1.6	3.03	3.8	1.51
Sonamukhi	8.9	9.16	9	8.87
Dhansimla	2.85	1.64	0.77	0.53
Dhaban	0	4.44	2.31	1.34
Dakshin sole	0	5.63	2.25	2.73
Chunpara	3.89	7.19	4.24	4.46
Chhatna	2.44	2.64	1.6	0.99
Bhagabanpur	5.6	7.74	0	5.18
Bishnupur	4.6	4.55	2.92	2.66
Bishnupur2	0	4.69	2.87	3.99
Chandai	5.6	7.23	7.11	4.39
Barjora	2.53	2.02	1.54	1.7
Beliatore	0	8.64	4.07	4.45
Basudevpur	6.4	11	5.58	5.15
Aima	2.8	2.12	1.29	0

Ch. 3.3 Estimation of sediment level of the Shali reservoir (SRS method)

Year	Area (m^2)	Area Difference	Water level (m)	Water Level Difference	Reservoir Volume	Sediment Volume	Sediment Level (m)
1991	1328400	0	8.98	0	11929032	0	
1996	1069200	259200	9	0.02	9622800	23929.16	0.16
2001	956699	112501	9.09	0.09	8696393	91118.56	0.61
2006	894600	62099	9.1	0.01	8140860	9254.75	0.06
2011	850500	44100	9.11	0.01	7748055	8724.57	0.05
2016	835200	15300	9.13	0.02	7625376	16856.76	0.11
2021	712800	122400	9.15	0.02	6522120	15463.84	0.10

Ch. 3.4 Water level and rainfall in the Shali reservoir

Year	Water level (m)	Rainfall (mm)	Year	Water level (m)	Rainfall (mm)
1990	8.82	938.91	2006	9.03	997.33
1991	8.82	956.70	2007	9.03	970.00
1992	8.83	994.41	2008	9.03	907.80
1993	8.84	988.7	2009	9.01	1005.60
1994	8.82	1037.0	2010	9.01	1073.83
1995	8.87	939.50	2011	9.03	1019.41
1996	8.85	874.25	2012	8.99	1086.75
1997	8.48	1041.58	2013	8.99	1102.00
1998	8.47	927.83	2014	9.01	1139.58
1999	8.45	862.91	2015	9.03	1209.33
2000	8.48	962.66	2016	9.02	1163.37
2001	8.48	1122.41	2017	9.03	1167.72
2002	9.03	1139.91	2018	9.04	1171.12
2003	9.00	1065.25	2019	9.04	1175.40
2004	9.01	857.91	2020	9.04	1182.93
2005	9.00	879.00	2021	9.04	1290.03

Ch. 3.5 Seasonal water level trend of Shali reservoir

Year	Winter (m)	Pre-monsoon (m)	Monsoon (m)	Post-monsoon (m)
1990	8.85	8.84	8.97	8.95
1991	8.88	8.86	8.96	8.94
1992	8.81	8.87	8.87	8.84
1993	8.82	8.86	8.95	8.91
1994	8.82	8.85	8.93	8.90
1995	8.85	8.84	8.98	8.92
1996	8.87	8.85	8.93	8.92
1997	8.44	8.43	8.48	8.47
1998	8.46	8.47	8.52	8.48
1999	8.45	8.43	8.53	8.53
2000	8.49	8.42	8.51	8.51
2001	8.42	8.37	8.50	8.52
2002	9.03	8.96	9.06	9.08
2003	9.01	8.94	9.06	9.05
2004	8.91	8.93	9.00	9.04
2005	8.95	8.98	9.04	9.04
2006	8.94	8.94	9.05	9.04
2007	9.01	8.97	9.08	9.07
2008	9.03	8.96	9.06	9.03
2009	8.93	8.96	9.02	9.06
2010	9.01	8.98	8.94	8.93
2011	8.95	8.93	9.05	9.05
2012	8.95	8.90	8.97	9.00
2013	8.96	8.93	9.01	9.03
2014	8.98	8.91	8.93	8.92
2015	8.88	8.85	8.97	8.95
2016	8.91	8.86	8.97	9.00
2017	8.97	8.89	9.05	9.01
2018	8.99	8.93	8.96	9.00
2019	8.91	8.87	8.92	9.03
2020	9.00	8.95	9.03	9.02
2021	8.93	8.88	9.04	9.03

Ch. 3.6 Satellite images used for Shali reservoir and river NDWI analysis

Year	Month-wise Image ID	
1990	LT5-L01TP-P&R139044-DA19900105-DPG2200916-2-T01	LT5-L01TP-P&R139044-DA19900716-DPG2200916-2-T01
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	LT5-L01TP-P&R139044-DA19900310-DPG2200916-2-T01	LT5-L01TP-P&R139044-DA1990092-DPG2200916-2-T02
	LT5-L01TP-P&R039034-DA19900426-DPG2200820-2-T01	LT5-L01TP-P&R139044-DA1990120-DPG2200915-2-T01
	LT5-L01TP-P&R031036-DA19900504-DPG2200820-2-T01	LT5-L01TP-P&R139044-DA19901120-DPG2200915-2-T01
	LT5-L01TP-P&R031035-DA19900504-DPG2200820-2-T01	LT5-L01TP-P&R139044-DA19901223-DPG2200915-2-T01
1991	LT5-L01TP-P&R139044-DA19910124-DPG2200915-2-T01	LT5-L01TP-P&R139044-DA19910719-DPG2200915-2-T02
	LT5-L01TP-P&R139044-DA1991209-DPG2200915-2-T01	LT5-L01TP-P&R139044-DA19910820-DPG2200915-2-T01
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	LT5-L01TP-P&R139044-DA20070426-DPG2DA200730-2-T01	LT5-L01TP-P&R139044-DA20071003-DPG2DA200729-2-T01
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	LT5-L01TP-P&R139044-DA20070613-DPG2DA200730-2-T02	LT8-L01TP-P&R139044-DA20071222-DPG2200912-2-T01
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	LT5-L01TP-P&R139044-DA20070310-DPG2200911-2-T01	LT5-L01TP-P&R139044-DA2007092-DPG2200911-2-T01
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	LT5-L01TP-P&R139044-DA20090415-DPG2008200728-2-T01	LT5-L01TP-P&R139044-DA2009124-DPG200800725-2-T01
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	LT5-L01TP-P&R139044-DA2010207-DPG2200911-2-T01	LT5-L01TP-P&R139044-DA20100801-DPG2200911-2-T02
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	LT8-L01TP-P&R139044-DA20160621-DPG2200906-2-T01	LT8-L01TP-P&R139044-DA20161230-DPG2200905-2-T01
2017	LT8-L01TP-P&R139044-DA20170115-DPG2200905-2-T01	LT8-L1GT-P&R139044-DA20170710-DPG2200903-2-T02
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	LT8-L01TP-P&R139044-DA20170421-DPG2200904-2-T01	LT8-L01TP-P&R139044-DA20171014-DPG220092-2-T01
	LT8-L01TP-P&R139044-DA20170523-DPG2200903-2-T01	LT8-L1GT-P&R139044-DA20171115-DPG220092-2-T02
	LT8-L01TP-P&R139044-DA20170608-DPG2200903-2-T01	LT8-L01TP-P&R139044-DA20171217-DPG220092-2-T01
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	LT8-L01TP-P&R139044-DA2018219-DPG220092-2-T01	LT8-L01TP-P&R139044-DA20180830-DPG2DA200731-2-T01
	LT8-L01TP-P&R139044-DA20180307-DPG2200901-2-T01	LT8-L01TP-P&R139044-DA20180915-DPG2DA200730-2-T01
	LT8-L01TP-P&R139044-DA20180424-DPG2200901-2-T01	LT8-L01TP-P&R139044-DA20181017-DPG2DA200730-2-T01
	LT8-L01TP-P&R139044-20180526-DPG2200901-2-T01	LT8-L01TP-P&R139044-DA20181118-DPG2DA200730-2-T01
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2019	LT8-L01TP-P&R139044-DA20190105-DPG2DA200730-2-T01	LT8-L01TP-P&R139044-DA20190716-DPG2DA200727-2-T01
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	LT8-L01TP-P&R139044-DA20190310-DPG2DA200729-2-T01	LT8-L01TP-P&R139044-DA20190918-DPG2DA200726-2-T01
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2020	LT8-L01TP-P&R139044-DA2020108-DPG2DA200724-2-T01	LT8-L01TP-P&R139044DA202072-DPG2200913-2-T01
	LT8-L01TP-P&R139044-DA2020209-DPG2DA200723-2-T01	LT8-L01TP-P&R139044-DA2020703-DPG2200914-2-T01
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	LT8-L01TP-P&R139044-DA2020515-DPG2DA200720-2-T01	LT8-L01TP-P&R139044-DA20201107-DPG2201111-2-T01
	LT8-L01TP-P&R139044-DA2020616-DPG2DA200723-2-T01	LT8-L01TP-P&R139044-DA20211123-DPG2210315-2-T01
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	LT8-L01TP-P&R139044-DA2021227-DPG2210304-2-T01	LT8-L01TP-P&R139044-DA20210822-DPG2210827-2-T01
	LT8-L01TP-P&R139044-DA20210315-DPG2210328-2-T01	LT8-L01TP-P&R139044-DA20210923-DPG2211003-2-T01
	LT8-L01TP-P&R139044-DA2021042-DPG2210508-2-T01	LT8-L01TP-P&R139044-DA2021125-DPG2211103-2-T01
	LT8-L01TP-P&R139044-DA20210518-DPG2210525-2-T01	LT8-L01TP-P&R139044-DA20211117-DPG2220119-2-T01
	LT8-L01TP-P&R139044-DA20210603-DPG2210608-2-T01	LT8-L01TP-P&R139044-DA20211220-DPG2220122-2-T01

where, L5 = Landsat 5, L8 = Landsat 8, L01 = Level one, P&R = Path and Row, DA = Date of acquisition, DPG = Date of product generation (Source: Earthexplorer)

Ch. 3.7 Year-wise annual mean NDWI values

Year	Shali Reservoir NDWI	Shali River NDWI	Year	Shali Reservoir NDWI	Shali River NDWI
1990	0.2	0.25	2006	0.25	0.34
1991	0.21	0.26	2007	0.36	0.37
1992	0.18	0.23	2008	0.2	0.3
1993	0.24	0.28	2009	0.37	0.4
1994	0.23	0.28	2010	0.2	0.3
1995	0.27	0.3	2011	0.23	0.29
1996	0.24	0.29	2012	0.23	0.24
1997	0.28	0.3	2013	0.37	0.4
1998	0.14	0.15	2014	0.34	0.38
1999	0.22	0.25	2015	0.21	0.3
2000	0.23	0.28	2016	0.21	0.31
2001	0.26	0.27	2017	0.26	0.33
2002	0.25	0.28	2018	0.36	0.4
2003	0.22	0.29	2019	0.22	0.27
2004	0.21	0.29	2020	0.31	0.36
2005	0.29	0.31	2021	0.35	0.39

Chapter 4

Ch. 4.1 Images of January used for LULC classification

Year	Image ID
1986	LT5-L01TP-P&R139044-DA19860105-DPG20200916-2-T01
1991	LT5-L01TP-P&R139044-DA19910124-DPG20200915-2-T01
1996	LT5-L01TP-P&R139044-DA19960122-DPG20200912-2-T01
2001	LT5-L01TP-P&R139044-DA20010119-DPG20200906-2-T01
2006	LT5-L01TP-P&R139044-DA20060102-DPG20201008-2-T01
2011	LT5-L01TP-P&R139044-DA20110131-DPG20200823-2-T01
2016	LC8-L01TP-P&R139044-DA20160129-DPG20200907-2-T01
2021	LC8-L1TP-P&R139044-DA20210110-DPG20210307-2-T01

Ch. 4.2 Temporal variations in LULC

Year	Dense forest cover	Light forest cover	Water bodies	Barren land	Agricultural land	Built up areas
1986	40.735	4.318	0.380	49.398	3.132	2.039
1991	14.373	33.609	1.323	40.519	7.011	3.165
1996	16.633	16.836	0.589	49.957	12.403	3.582
2001	29.037	5.132	0.326	14.612	46.971	3.922
2006	26.022	6.796	1.179	36.587	24.931	4.484
2011	33.199	8.596	0.589	18.893	33.594	5.129
2016	16.263	9.083	0.840	15.248	53.180	5.387
2021	28.501	1.732	0.469	8.006	55.446	5.847

Ch. 4.3 Area change in LULC

LULC types	1986 to 2006	2006 to 2021
	Change (km^2)	
Dense forest cover	-106.96	18.02
Light forest cover	18.02	-36.82
Water bodies	5.81	-5.16
Barren land	-93.13	-207.79
Agricultural land	158.48	221.84
Built up areas	17.78	9.91

Ch. 4.4 Area-wise temporal modification in LULC (km^2)

Year	Dense forest cover	Light forest cover	Water bodies	Barren land	Agricultural land	Built up areas
Gangajalghati block						
1986	74.679	20.985	1.531	120.408	0.522	1.898
1991	11.675	79.083	4.138	114.114	7.424	3.587
1996	18.527	35.387	2.024	112.888	46.157	5.038
2001	35.314	0.201	1.082	37.420	139.730	6.274
2006	20.194	34.167	1.722	119.550	38.893	5.496
2011	36.223	33.981	0.973	53.858	88.355	6.632

2016	11.138	39.517	2.630	17.510	143.519	5.880
2021	63.078	9.770	1.360	8.348	127.586	10.709
			Barjora block			
1986	96.737	6.743	0.560	123.134	3.275	9.643
1991	52.844	68.994	3.153	95.691	11.024	8.385
1996	59.675	32.740	1.085	115.687	15.377	15.527
2001	62.301	5.591	0.388	43.323	121.900	6.590
2006	84.407	7.721	2.383	94.289	37.142	14.148
2011	101.226	13.216	0.836	40.502	70.788	13.523
2016	60.447	14.770	1.725	47.294	96.858	18.996
2021	91.116	1.106	0.878	21.090	103.166	22.734
			Sonamukhi block			
1986	94.655	2.587	0.424	81.172	15.662	5.161
1991	32.320	70.289	1.609	57.644	31.349	6.452
1996	37.317	40.654	0.883	97.524	15.456	7.827
2001	74.783	11.868	0.801	15.540	88.371	8.300
2006	66.774	4.904	3.512	32.296	81.509	10.667
2011	82.038	11.949	1.368	37.947	53.203	13.159
2016	43.911	2.152	1.321	48.756	92.099	11.442
2021	37.004	0.866	1.130	23.952	121.055	15.673
			Patrasayer block			
1986	26.943	2.285	0.240	20.099	0.583	0.638
1991	1.371	18.527	0.627	24.790	3.865	1.308
1996	0.470	12.642	0.281	32.026	2.315	2.754
2001	13.631	16.634	0.096	1.266	17.377	1.484
2006	5.715	0.512	0.908	14.448	25.941	2.964
2011	14.152	0.740	1.080	3.618	27.142	3.756
2016	2.572	0.022	0.379	3.033	43.058	1.433
2021	0.375	0.036	0.038	5.364	39.856	4.827

Ch. 4.5 Areal coverage of LULC in 2031

LULC type	Predicted year 2031 (km^2)
Forest	198.96
Shrub	8.47
Water bodies	3.34
Barren land	35.84
Agricultural land	422.23
Built up areas	58.16

Ch. 4.6 Block-wise comparison in agricultural land area (km^2)

Block names	Year							
	1986	1991	1996	2001	2006	2011	2016	2021
Gangajalghati	2.550	6.598	61.293	37.160	18.799	35.652	37.223	31.488
Barjora	22.663	22.251	21.051	33.239	20.147	30.011	25.569	28.067
Sonamukhi	73.442	63.720	14.379	24.958	46.795	23.015	25.858	25.616
Patrasayer	1.346	7.431	3.277	4.643	14.258	11.322	11.350	9.829

Ch. 4.7 Temporal change in the village-wise distribution of agricultural land

Year	Number of villages	Year	Number of villages
1981	42	2006	143
1991	61	2011	161
1996	103	2016	178
2001	289	2021	310

Chapter 5

Ch. 5.1 The influence percentages of each criterion and their sub-criteria with scores

Criteria	Weightage	Influence	Sub-criteria	Score
Distance to river	0.22	22%	1	5
			3	4
			6	3
			8	2
			10	1
Rainfall	0.16	16%	0-1368	3
			1369-1386	3
			1387-1404	3
			1405-1422	4
			1423-1439	5
Clay	0.12	12%	0-223	1
			224-238	2
			239-253	3
			254-339	4
			above 339	5
Sand	0.11	11%	0-433	1
			434-474	2
			475-497	3
			498-567	4
			above 567	5
Silt	0.09	9%	0-269	1
			270-290	2
			291-315	3
			316-439	4
			above 439	5
Nitrogen	0.09	9%	0-119	1
			120-127	2
			128-136	3
			137-268	4
			above 268	5
Organic carbon	0.05	5%	0-167	1

			168-176	2
			177-187	3
			188-467	4
			above 467	5
pH	0.05	5%	0	3
			61	3
			62	4
			63	4
			66	5
Soil group	0.04	4%	Ferralsols	2
			Gypsisols	4
			Fluvisols	3
			Luvisols	5
			Vertisols	1
LULC	0.04	4%	Dense forest	2
			Medium forest	4
			Barren land	4
			Water body	3
			Built-up	1
			Agricultural land	5
Slope	0.02	2%	0-12	5
			13-25	3
			above 25	2
Elevation	0.01	1%	0-39	5
			40-68	4
			69-98	3
			99-127	2
			128-156	1

Ch. 5.2 Block-wise irrigation suitability area of the Shali River basin

Block	Very High (ha)	High (ha)	Moderate (ha)	Low (ha)
Gangajalghati	1775.13	9913.2	854.029	8512.88
Barjora	3819.25	11258.8	737.285	7849.08
Sonamukhi	10587	3998.98	626.385	5531.98
Patrasayer	3899.36	163.88	185.7	655.96

Ch. 5.3 Village-wise irrigation suitable land

Village names	Very High (ha)	High (ha)	Moderate (ha)	Low (ha)	Total (ha)
Saharjora	0.00	449.92	42.39	277.47	769.78
Muktatar	0.00	165.71	0.00	175.34	341.05
Beleshola	0.00	74.18	0.00	61.66	135.84
Chak Keshya	0.00	77.07	20.23	36.61	133.92

Shitla	0.00	263.02	12.52	63.59	339.13
Koch Kunda	0.00	211.95	0.00	103.09	315.04
Manjmura	0.00	43.35	0.00	17.34	60.70
Monoharbati	0.00	53.95	0.00	42.39	96.34
Kanchanpur	0.00	96.34	0.00	82.85	179.20
Pabayan	0.00	84.78	0.96	184.98	270.72
Dakaisini	0.00	57.81	0.96	94.42	153.19
Khanrari	0.00	239.89	0.00	154.15	394.04
Uara	0.00	205.21	0.00	89.60	294.81
Deucha	0.00	131.99	0.00	34.68	166.67
Dejuri	0.00	47.21	0.00	8.67	55.88
Chhotalalpur	0.00	86.71	0.00	28.90	115.61
Hatashuria	0.00	99.23	1.93	31.79	132.95
Mandarbani	3.85	42.39	5.78	26.01	78.04
Dewangarya	0.00	91.53	0.00	5.78	97.31
Sarali	0.00	70.33	6.74	9.63	86.71
Madanhati	0.00	146.44	9.63	1.93	158.00
Numuigarya	23.12	114.65	0.00	0.00	137.77
Kelai	0.00	45.28	0.00	58.77	104.05
Gururbad	32.76	49.13	0.00	0.00	81.89
Kotalpukur	40.46	142.59	3.85	179.20	366.10
Balikhun	54.92	148.37	5.78	230.26	439.32
Arjuni	3.85	52.03	0.00	0.00	55.88
Metia Narayanpur	0.00	381.52	11.56	360.32	753.40
Baradihi	5.78	329.49	7.71	117.54	460.52
Bararampur	0.00	56.84	0.00	47.21	104.05
Sagarya	0.00	48.17	0.00	24.09	72.26
Nutangram	0.00	174.38	3.85	40.46	218.70
Khajuri	0.00	131.99	0.00	29.87	161.86
Payermohan	0.00	100.20	26.01	1.93	128.14
Jamshala	0.00	155.11	3.85	73.22	232.19
Chhotalacchipur	0.00	118.50	17.34	10.60	146.44
Nadihi	0.00	242.78	5.78	77.07	325.64
Bamundiha	0.00	248.56	7.71	81.89	338.16
Chholabaid	0.00	68.40	0.00	43.35	111.76
Hanri Bhanga	0.00	575.17	8.67	271.69	855.52
Shuabasa	8.67	360.32	105.98	210.03	685.00
Keshiara	237.97	913.33	209.06	616.59	1976.96
Harekrishnapur	55.88	330.46	84.78	181.12	652.24
Ita Dangra	25.05	184.98	47.21	48.17	305.41
Gopkande	0.00	249.53	6.74	71.29	327.57
Purunia	0.00	303.48	10.60	110.79	424.87
Sangrampur	0.00	292.88	0.00	52.99	345.87
Lakshminarayanpur	0.00	263.98	0.00	44.32	308.30
Shirsha	8.67	120.43	0.00	60.70	189.80
Gangadharpur	0.00	61.66	2.89	131.03	195.58
Kalpaini	0.00	185.94	3.85	148.37	338.16

Banshol	0.00	236.04	0.96	399.82	636.83
Dharampur	2.89	207.14	5.78	277.47	493.28
Dhwajamanipur	45.28	80.93	13.49	36.61	176.31
Phulberrya	111.76	27.94	16.38	12.52	168.60
Damodarpur	41.43	0.00	17.34	14.45	73.22
Dangarpara	65.51	488.46	16.38	364.18	934.53
Nutangram	0.00	16.38	36.61	14.45	67.44
Bahadurpur	4.82	467.26	16.38	441.25	929.71
Madhabpur	56.84	161.86	11.56	193.65	423.91
Thumkonra	141.62	414.27	110.79	199.43	866.12
Kanchchala	113.68	173.42	16.38	138.73	442.21
Selera	80.93	248.56	20.23	171.49	521.22
Dhabani	46.24	487.50	69.37	393.08	996.19
Ramchandrapur	0.00	175.34	0.00	307.33	482.68
Bhairabpur	185.94	308.30	2.89	373.81	870.94
Mandi	52.03	141.62	18.31	65.51	277.47
Nomoghonsara	96.34	0.00	16.38	0.00	112.72
Karuriya	22.16	9.63	0.00	2.89	34.68
Bolarampur	106.94	252.42	16.38	96.34	472.08
Malakuriya	10.60	83.82	5.78	113.68	213.88
Ekariya	78.04	333.35	3.85	387.30	802.54
Majudagara	4.82	88.64	0.00	84.78	178.23
Kapishtha	235.08	382.48	74.18	214.84	906.59
Gadardhi	0.00	59.73	0.00	29.87	89.60
Nischintapur	64.55	188.83	35.65	122.36	411.38
Radharomonpur	19.27	111.76	9.63	131.03	271.69
Salbedya	1.93	117.54	1.93	87.67	209.06
Gobindopore	8.67	261.09	1.93	209.06	480.75
Kallapur	44.32	453.78	14.45	954.76	1467.30
Ramnagar	183.05	121.39	14.45	101.16	420.06
Suara	100.20	276.50	6.74	151.26	534.70
Sonagara	59.73	117.54	9.63	35.65	222.55
Sankara	237.97	56.84	5.78	26.98	327.57
Nabasan	80.93	25.05	5.78	15.41	127.17
Charadihi	68.40	157.04	6.74	50.10	282.28
Gobindapur	46.24	85.75	14.45	9.63	156.08
Khopaganj	112.72	50.10	7.71	7.71	178.23
Pataspur	72.26	132.95	12.52	69.37	287.10
Jemua	66.48	157.04	11.56	155.11	390.19
Chandaibot	105.01	71.29	21.20	39.50	237.00
Gopalpur	51.06	244.71	11.56	234.11	541.45
Palsana	52.03	106.94	26.98	30.83	216.77
Bhiringi	33.72	10.60	32.76	20.23	97.31
Malkonra	26.98	281.32	10.60	324.68	643.57
Barajuri	14.45	330.46	0.00	541.45	886.35
Dandulya	0.00	119.47	0.96	83.82	204.25
Ramkanali	0.00	193.65	1.93	180.16	375.74

Kenduabari	0.00	98.27	0.00	109.83	208.10
Arba	8.67	70.33	0.96	26.01	105.98
Asan Chua	0.00	79.00	0.96	71.29	151.26
Arjunapur	0.00	89.60	0.00	55.88	145.48
Biharjuriya	30.83	321.79	19.27	285.18	657.06
Harekrishnpur	0.00	69.37	0.00	50.10	119.47
Swargabati	0.00	102.12	3.85	911.40	1017.38
Gobordhonpur	19.27	100.20	0.96	29.87	150.29
Piraboni	12.52	216.77	0.00	223.52	452.81
Birndabanpur	62.62	194.61	0.00	134.88	392.12
Radhakrishnpur	64.55	79.96	0.00	2.89	147.40
Amthia	121.39	68.40	2.89	2.89	195.58
Gopinathpore	139.70	68.40	5.78	11.56	225.44
Bankurardanga	131.99	59.73	15.41	28.90	236.04
Tentuliyadaga	171.49	399.82	5.78	77.07	654.17
Saldanga	4.82	76.11	4.82	31.79	117.54
Batlapara	198.47	196.54	28.90	35.65	459.56
Purushottampur	73.22	89.60	0.00	25.05	187.87
Abhirampore	150.29	40.46	0.00	11.56	202.32
Muktapur	141.62	52.03	5.78	21.20	220.63
Telashuli	168.60	153.19	5.78	38.54	366.10
Bhalukapahari	131.99	51.06	0.00	33.72	216.77
Krishnapur	106.94	124.28	0.96	124.28	356.47
Benachapara	205.21	206.17	28.90	164.75	605.03
Mathuaberia	31.79	52.03	0.00	32.76	116.57
Bhairabdanga	127.17	21.20	11.56	3.85	163.78
Bhairabpur	112.72	0.00	0.00	0.00	112.72
Rautara	82.85	7.71	0.00	0.00	90.56
Barkura	32.76	19.27	0.00	0.00	52.03
Mathuradanga	110.79	0.00	0.00	0.00	110.79
Rajmadhabpur	0.00	22.16	0.00	30.83	52.99
Radhakantapur	69.37	83.82	0.00	13.49	166.67
Srikrishnapur	1.93	52.03	0.00	80.93	134.88
Kantabeshe	100.20	32.76	0.00	97.31	230.26
Nityanandapur	74.18	72.26	0.00	38.54	184.98
Gangabandh	5.78	12.52	0.00	77.07	95.38
Dulai	131.03	49.13	10.60	0.00	190.76
Pathanpalasi	69.37	26.01	0.00	0.00	95.38
Manusmari	109.83	193.65	0.00	0.00	303.48
Bankshimla	4.82	36.61	0.00	0.00	41.43
Belagaria	54.92	36.61	0.00	0.00	91.53
Pashchimdubrajpore	0.00	50.10	0.00	0.00	50.10
Krishnanagar	0.00	62.62	0.00	0.00	62.62
Belut	69.37	30.83	0.00	0.00	100.20
Harishchandrapur	181.12	1.93	2.89	0.00	185.94
Radharamanpur	234.11	140.66	0.96	0.00	375.74
Ulai	113.68	52.99	0.00	0.00	166.67

Pear Bera	70.33	70.33	0.00	0.00	140.66
Prayagpur	126.21	97.31	0.00	0.00	223.52
Paschim Nandapur	72.26	6.74	3.85	0.00	82.85
Basu Nandanpur	105.01	8.67	0.00	0.00	113.68
Shitaljor	118.50	5.78	10.60	19.27	154.15
Kubir Bandh	61.66	6.74	2.89	1.93	73.22
Dubrajhati	131.03	8.67	0.96	0.00	140.66
Shibdanga	79.00	3.85	1.93	0.00	84.78
Kamardanga	196.54	7.71	0.00	0.00	204.25
Jaypur	48.17	0.00	0.00	0.00	48.17
Katnia	117.54	0.00	0.00	0.00	117.54
Birsingpur	197.50	4.82	0.00	0.00	202.32
Paschim Patrahati	168.60	1.93	0.00	0.00	170.53
Ruppal	128.14	0.00	0.00	0.00	128.14
Karjbani	63.59	0.00	0.00	0.00	63.59
Palshare	244.71	19.27	23.12	7.71	294.81
Aligang	86.71	14.45	4.82	9.63	115.61
Baikunthapur	50.10	0.00	0.96	2.89	53.95
Rupat Ganj	140.66	0.00	12.52	6.74	159.93
Jambani	38.54	27.94	10.60	66.48	143.55
Patjor	101.16	1.93	5.78	0.00	108.87
Parbbatia	75.15	4.82	8.67	48.17	136.81
Bahulia	179.20	166.67	2.89	81.89	430.65
Shalchaturia	79.96	11.56	5.78	5.78	103.09
Shyamsundarpur	164.75	0.00	12.52	7.71	184.98
Hamirhati	56.84	3.85	5.78	0.00	66.48
Basumara	163.78	65.51	0.00	125.25	354.54
Rampur	165.71	0.96	0.96	0.00	167.64
Khausa	31.79	80.93	5.78	10.60	129.10
Basumara	47.21	101.16	5.78	327.57	481.71
Jashra	3.85	373.81	3.85	475.93	857.45
Patsol	5.78	52.03	0.00	113.68	171.49
Ratnapur	41.43	30.83	4.82	32.76	109.83
Mathurabati	78.04	32.76	28.90	166.67	306.37
Bara Narayanpur	1.93	47.21	0.00	233.15	282.28
Bhula	28.90	216.77	5.78	361.29	612.74
Kesheshol	19.27	131.03	0.00	133.92	284.21
Khayrakura	0.00	20.23	0.00	37.57	57.81
Churamanipur	172.45	102.12	18.31	192.69	485.57
Tiura	35.65	9.63	5.78	16.38	67.44
Kalyanpur	95.38	0.00	0.00	0.00	95.38
Bhedomushal	65.51	81.89	41.43	94.42	283.25
Dakshinsol	66.48	0.00	0.00	8.67	75.15
Indkata	110.79	0.00	0.00	1.93	112.72
Amghata	131.99	0.00	0.00	0.00	131.99
Sapuradihi	93.45	0.00	0.00	0.00	93.45
Sonamukhi	63.59	0.00	0.00	0.00	63.59

Kshertamohanpur	99.23	0.00	0.00	0.00	99.23
Salda	135.84	0.00	0.00	0.00	135.84
Siltiya	81.89	0.00	0.00	0.00	81.89
Rautara	272.65	5.78	12.52	1.93	292.88
Saheb Ganj	147.40	3.85	0.00	9.63	160.89
Maheshpur	38.54	0.00	3.85	0.00	42.39
Madanmohanpur	57.81	0.96	0.00	0.00	58.77
Goltor	142.59	15.41	2.89	10.60	171.49
Chaitanpur	72.26	0.00	0.00	0.96	73.22
Khuldanga	218.70	0.00	0.00	9.63	228.33
Amshol	126.21	0.00	0.00	0.00	126.21
Nanchanhati	197.50	21.20	8.67	0.00	227.37
Purbopotrahati	340.09	84.78	35.65	299.63	760.15
Bhalukhan	73.22	0.00	11.56	10.60	95.38
Jaga Mohanpur	171.49	0.00	6.74	14.45	192.69
Shonadwipa	172.45	0.00	0.00	0.00	172.45
Banparulia	232.19	0.00	0.00	0.00	232.19
Beneshe	49.13	0.96	0.00	0.00	50.10
Rajada	118.50	0.00	28.90	0.00	147.40
Janshara	85.75	0.00	9.63	3.85	99.23
Narula	115.61	3.85	0.00	0.00	119.47
Nischinapur	614.67	105.01	109.83	181.12	1010.64
Ramchandrapur	0.00	57.81	0.00	62.62	120.43
Kundopushkorini	0.00	34.68	0.00	193.65	228.33
Kasipore	0.00	91.53	0.00	503.87	595.40
Kuchiyagopalpore	3.85	193.65	0.00	409.46	606.96
Bahaarpur	0.00	69.37	0.00	551.08	620.45
Dhonsimla	18.31	135.84	20.23	259.16	433.54
Kanduya	78.04	0.00	0.00	0.00	78.04
Rampur	451.85	0.00	0.00	3.85	455.70
Machdoba	81.89	0.00	0.00	0.00	81.89
Karachmani	285.18	3.85	0.00	16.38	305.41
Ranibandh	76.11	15.41	11.56	10.60	113.68
Chakdhoyakure	207.14	3.85	13.49	48.17	272.65
Dhagaria	85.75	0.00	0.00	3.85	89.60
Hamirpur	78.04	0.00	0.00	0.00	78.04
Anandapur	151.26	0.00	0.00	0.00	151.26
Kendgare	270.72	6.74	9.63	1.93	289.03
Lalpur	123.32	0.00	3.85	0.00	127.17
Muktapur	217.73	0.00	0.00	0.00	217.73
Khosalpur	201.36	0.00	21.20	0.00	222.55
Khamardihi	110.79	2.89	14.45	0.00	128.14
Hadal	70.33	0.00	8.67	0.00	79.00
Ram Nagar	18.31	0.00	0.00	0.00	18.31
Dhamsa	143.55	0.00	8.67	0.00	152.22
Sonatikri	79.00	0.00	0.96	0.00	79.96
Balarampur	318.90	0.00	0.00	0.00	318.90

Telsanra	149.33	0.00	31.79	0.00	181.12
Parulia	52.03	0.00	3.85	0.00	55.88
Keshabpur	57.81	0.00	3.85	0.00	61.66
Brindaban Pur	64.55	0.00	0.00	0.00	64.55
Benda	233.15	0.00	19.27	0.00	252.42
Dayalpur	123.32	152.22	20.23	552.04	847.82
Chak Patrasayer	24.09	0.00	0.00	0.00	24.09
Panch Para	82.85	0.00	0.96	0.00	83.82
Mamudpur	507.73	113.68	105.01	49.13	775.56
Arbetal	21.20	80.93	3.85	12.52	118.50
Saulia	80.93	246.64	0.00	843.00	1170.57

Chapter 6

Ch. 6.1 Block-wise mean and SD of irrigated areas of the Shali River basin

Block name	Year 1991		Year 2001		Year 2011	
	Mean	SD	Mean	SD	Mean	SD
Gangajalghati	58.9	60.51	63.31	68.52	66.52	75.05
Barjora	19.63	26.95	24.59	31.67	28.27	34.07
Sonamukhi	46.4	45.53	69.11	73.31	68.3	73.23
Patrasayar	83.1	67.27	90.06	69.49	86.22	66.24

Ch. 6.2 Village-wise Z-scores values of irrigated areas

Village names	Z-score			Village names	Z-score		
	1991	2001	2011		1991	2001	2011
Saharjora	0.395	0.450	1.066	Pirrabani	1.333	0.632	0.931
Muktatar	-0.567	-0.570	-0.146	Gopinathpur	-0.552	-0.597	-0.487
Beleshola	-0.718	-0.762	-0.368	Dhabani Gobindapur	0.493	0.294	0.541
Chak Keshya	-0.548	-0.570	-0.363	Birndabanpur	-0.681	-0.787	-0.708
Shitla	-0.465	-0.081	0.171	Radhakrishnopur	0.051	-0.407	-0.268
Koch Kunda	-0.369	-0.353	0.105	Shyamdaspur	-0.729	-0.841	-0.771
Manjmura	-0.626	-0.638	-0.469	Kantooani	-0.031	-0.004	0.197
Monoharbati	-0.617	-0.734	-0.600	Amthia	-0.435	-0.461	-0.331
Kanchanpur	-0.752	-0.875	-0.487	Gopinathpore	1.136	-0.298	-0.143
Pabayan	-0.503	-0.359	-0.669	Gosainpur	0.491	0.642	0.943
Dakaisini	-0.729	-0.761	-0.672	Maldaga	0.011	-0.394	-0.253
Khanrari	-0.497	-0.352	-0.143	Bankurardanga	-0.593	-0.679	-0.582
Uara	-0.603	-0.705	-0.301	Tentuliyadaga	0.589	0.324	0.575
Deucha	-0.595	-0.679	-0.396	Belut	0.726	1.388	-0.363
Dejuri	-0.612	-0.679	-0.425	Simlagaar	-0.425	-0.625	-0.520
Chhotalalpur	-0.010	-0.168	0.008	Saldanga	-0.714	-0.817	-0.742
Hatasuriya	-0.452	-0.426	0.036	Batlapara	-0.181	0.055	0.265
Mandarboni	-0.399	-0.489	-0.270	Jagannathpur	-0.599	-0.668	-0.569

Dewangarya	-0.356	-0.325	-0.158	Manjua	-0.119	-0.325	-0.174
Saroi	-0.654	-0.734	-0.645	Purushottampur	-0.707	-0.802	-0.725
Madnahati	-0.681	-0.734	-0.642	Abhirampur	-0.378	-0.570	-0.456
Numugariya	-0.059	-0.034	0.163	Asansola	-0.734	-0.828	-0.754
Kelai	-0.121	-0.403	-0.264	Shrirampore	-0.244	-0.559	-0.444
Gorurbnad	-0.100	-0.028	0.171	Muktapur	-0.590	-0.672	-0.574
Katalpukur	0.176	0.246	0.530	Telasuli	0.627	-0.134	0.046
Rajamela	1.846	0.085	0.485	Kodma	-0.575	-0.625	-0.520
Balikhun	1.102	-0.318	-0.166	Bhalukapahari	0.140	-0.168	0.008
Radhabollabhpur	-0.083	-0.024	0.174	Bandarkoda	-0.714	-0.809	-0.732
Arjunii	-0.451	-0.434	-0.300	Bayermara	0.570	0.241	-0.520
Matianarayanpur	-0.714	-0.727	-0.638	Krishnapur	-0.759	-0.869	-0.802
Lachhmanpur	6.142	-0.157	1.292	Raniara	3.504	1.388	1.804
Baradihi	0.472	-0.466	-0.300	Benachapara	-0.759	-0.859	-0.751
Mahidhara	-0.630	-0.609	-0.408	Mathuaberia	-0.718	-0.761	-0.462
Krishnabati	-0.362	-0.359	-0.672	Bhairobdaga	-0.643	-0.700	-0.576
Bararampur	0.179	-0.869	-0.740	Bhairobpur	-0.647	-0.734	-0.632
Sagarya	-0.213	-0.614	-0.407	Raautara	-0.671	-0.766	-0.577
Nutangram	0.187	-0.353	0.045	Berkura	-0.650	-0.732	-0.324
Naykona	-0.695	-0.787	-0.694	Mathuradaga	-0.644	-0.732	-0.324
Khajuri	1.032	-0.507	-0.309	Rajamadhabpur	-0.720	-0.825	-0.751
Payermohan	-0.672	-0.761	-0.645	Radhakantopore	-0.713	-0.787	-0.625
Radhanagar	-0.714	-0.836	-0.745	Shrikrisnapur	-0.712	-0.787	-0.676
Shushunia	-0.700	-0.814	-0.734	Kantobeshe	-0.714	-0.814	-0.676
Jamshala	0.166	-0.837	-0.627	Nityanondopur	1.377	1.650	-0.607
Chhotalacchipur	0.000	-0.755	-0.670	Gangabadh	-0.741	-0.864	-0.796
Sahebdihi	-0.720	-0.841	-0.740	Dhulai	0.917	2.100	2.626
Bishanpur	-0.684	-0.787	-0.703	Pathan Palashi	0.259	1.107	1.474
Nadihi	1.078	-0.539	-0.421	Manush Mari	1.356	2.893	3.542
Bamundiha	0.261	-0.648	-0.385	Bank Simla	-0.772	0.649	-0.833
Ashuria Madhabpur	-0.503	-0.597	-0.452	Belgaria	-0.439	0.247	0.361
Chholabaid	0.125	-0.769	-0.616	Paschim Dubrajpur	-0.772	0.931	-0.833
Hanri Bhanga	0.949	-0.273	-0.113	Krishnanagar	-0.401	0.345	-0.833
Talanjuri	-0.065	-0.081	0.191	Belut	0.194	1.388	1.804
Kantabad	-0.631	-0.720	-0.605	Harischandropore	-0.074	0.153	0.281
Harirampur	-0.704	-0.814	-0.692	Radharamonpur	-0.559	-0.187	-0.833
Shuabasa	0.539	-0.403	-0.126	Ulaai	-0.772	0.179	-0.833
Keshiara	5.508	4.801	7.296	Peerbera	0.387	0.832	0.665
Belianarayanpur	-0.695	-0.787	-0.676	Prayagpore	-0.500	-0.145	-0.276
Harekrishnapur	-0.624	-0.707	-0.605	Paschim Nandapur	-0.304	-0.090	-0.244
Ita Dangra	-0.072	-0.628	-0.492	Basunandapore	-0.230	0.013	0.000
Mallikdihi	0.415	-0.520	-0.337	Shitoljar	-0.259	0.009	-0.160
Dadhimukha	-0.413	-0.477	-0.191	Kubirband	-0.412	-0.275	-0.224
Gopkande	-0.597	-0.672	-0.528	Dubrajati	-0.527	-0.413	-0.523
Garjuria	0.498	-0.507	-0.337	Shibdaga	-0.442	-0.219	-0.206
Ukhradihi	2.182	-0.519	-0.391	Kamardaga	-0.369	0.676	-0.545
Purunia	-0.218	-0.224	0.408	Jaypur	-0.203	0.176	0.374

Sangrampur	-0.677	-0.761	-0.521	Katnia	0.370	0.813	0.582
Lakshminarayanpur	-0.656	-0.748	-0.663	Birsingpur	-0.540	0.066	-0.343
Jam Bedya	1.422	-0.198	0.051	Pashchimpatrohati	0.370	0.374	0.617
Shirsha	-0.100	-0.645	-0.500	Rupal	0.792	1.758	2.231
Bahara Khuliya	-0.670	-0.734	-0.645	Karajboni	0.581	0.614	0.897
Gangadharpur	-0.721	-0.843	-0.569	Palashare	0.409	0.390	0.651
Taljhitka	0.031	-0.626	-0.506	Aligaang	0.001	0.000	0.132
Lakhyara	0.288	-0.707	-0.590	Boikunthopur	0.503	1.778	-0.213
Kalpaini	-0.731	-0.841	-0.770	Rupotganj	-0.658	-0.130	-0.647
Banshol	-0.680	-0.787	-0.692	Jambani	-0.238	0.300	0.191
Ekchala	0.679	-0.868	-0.743	Patjor	-0.273	0.515	0.175
Ranganathpur	3.597	0.179	0.641	Parbatiya	-0.177	1.254	0.191
Dharampur	0.475	0.520	1.059	Bohuliya	-0.197	0.058	-0.026
Dhwajamanipur	-0.554	-0.636	-0.461	Shalchaturia	-0.006	0.945	0.206
Phulberrya	-0.613	-0.625	-0.442	Shyamsundarpur	-0.753	-0.692	-0.802
Damodarpur	-0.682	-0.787	-0.708	Hamirhati	-0.224	1.146	-0.120
Dangarpara	-0.721	-0.814	-0.714	Boshumara	-0.728	-0.026	-0.756
Amjor	3.198	0.743	1.533	Rampore	-0.611	0.676	-0.554
Macha Parulia	3.524	3.069	3.745	Khousha	-0.727	-0.305	-0.701
Gobinda Dham	5.178	3.194	3.889	Basumara	-0.731	-0.026	-0.756
Bahadurpur	-0.337	-0.224	0.296	Jasahra	-0.688	-0.130	-0.678
Madhabpur	-0.362	-0.359	-0.213	Patsal	-0.255	0.931	-0.554
Mautara	0.596	0.442	0.712	Ratnopur	-0.254	0.164	-0.445
Thumkonra	1.540	0.245	0.515	Mothuraboti	-0.636	0.353	-0.647
Oltara	-0.670	-0.762	-0.599	Boronarayanpur	-0.691	1.442	-0.089
Ranbahal	0.358	-0.774	-0.661	Bula	-0.652	1.320	-0.583
Kanchchala	-0.627	-0.716	-0.625	Kashesol	-0.772	-0.515	-0.833
Selera	-0.201	-0.774	-0.694	Khayrakura	-0.772	0.134	-0.833
Samantamara	-0.676	-0.761	-0.366	Churamonipur	-0.772	-0.277	-0.833
Konra	0.529	-0.271	-0.050	Teura	-0.640	-0.065	-0.633
Dhoboni	-0.305	-0.325	-0.034	Kalyanpore	-0.731	1.079	-0.771
Ramchandropore	0.951	1.009	-0.237	Bedomushol	-0.772	1.294	-0.833
Bhairabpur	3.043	2.159	2.695	Daxhinshol	-0.662	-0.712	-0.633
Chala	-0.522	-0.570	-0.442	Indakata	-0.036	2.020	0.516
Kaalberiya	-0.731	-0.841	-0.720	Aamghata	-0.490	-0.318	-0.321
Mandi	0.290	-0.187	-0.014	Sopurodihi	0.253	0.417	0.454
Nomoghonshara	-0.772	-0.896	-0.833	Shonamukhi	-0.515	-0.196	-0.492
Karuriya	-0.682	-0.787	-0.669	Kshertamohanpur	-0.772	0.150	-0.833
Bolorampore	-0.175	-0.095	0.091	Saalda	0.164	0.193	0.425
Chhotakumira	0.482	-0.747	-0.542	Siltiya	0.741	0.771	1.092
Kenduadihi	1.576	0.219	0.571	Raautara	0.076	0.160	0.386
Maalkuria	-0.704	-0.814	-0.703	Shahebganj	-0.130	0.016	0.220
Eakariya	-0.729	-0.841	-0.757	Maheshpur	0.536	0.778	1.100
Nabagram	2.825	0.454	0.788	Madnamohonpur	0.159	0.677	0.982
Kotmadanmohanpur	-0.580	-0.727	-0.203	Galtor	-0.371	-0.148	0.015
Majudagora	-0.656	-0.734	-0.644	Chaaitanpur	1.053	1.989	2.482
Kapishtha	-0.580	2.050	2.578	Khuldanga	0.163	0.153	0.378

Saragara	-0.600	-0.679	-0.577	Aamshal	-0.359	0.505	0.754
Godhardi	-0.549	-0.611	-0.490	Nanchanhati	-0.323	-0.286	-0.036
Nischintapur	-0.122	-0.638	-0.517	Purbopatrohati	-0.213	0.212	0.447
Godordihi	-0.570	-0.611	-0.475	Bhalakkhan	0.363	0.958	0.852
Saltora	1.754	0.242	0.544	Jaga Mohanpur	-0.072	0.333	0.540
Radharomanpore	-0.606	-0.654	-0.483	Shonadwipa	-0.212	1.361	1.661
Salbedya	0.718	-0.353	-0.144	Banparulia	-0.442	-0.426	-0.290
Birsingapur	-0.747	-0.869	-0.739	Bnese	-0.165	1.200	0.811
Madhabpur	-0.047	-0.345	-0.197	Raajda	-0.660	2.451	-0.585
Gobindopore	-0.119	-0.157	0.020	Junsara	-0.513	-0.050	0.074
Kallapur	1.001	-0.122	0.281	Naruliya	-0.280	1.052	1.168
Jhoriya	-0.064	-0.048	0.051	Nischinapur	-0.228	0.034	0.163
Ramnagar	-0.083	-0.543	-0.425	Ramchandrapur	0.820	1.009	1.367
Lalbazar	-0.613	-0.693	-0.523	Kundopushkorini	-0.451	0.766	0.586
Suara	1.275	-0.367	-0.098	Kashipore	-0.046	0.732	0.735
Kalla	-0.734	-0.841	-0.694	Kuchiyagopalpore	-0.078	0.395	0.658
Radhashyampur	-0.140	-0.734	-0.419	Baharpore	-0.513	0.892	1.180
Sonagara	-0.631	-0.734	3.635	Dhonshimla	2.698	7.503	6.852
Sankara	0.161	-0.462	-0.332	Kenduya	-0.741	-0.124	-0.779
Talanda	-0.641	-0.734	-0.559	Rampur	-0.772	-0.664	-0.833
Brahmanara	-0.316	-0.693	-0.579	Machdoba	-0.643	-0.343	-0.659
Nabasan	-0.772	-0.896	0.408	Karachmani	-0.411	0.724	-0.358
Charadihi	0.327	-0.353	-0.199	Ranibandh	-0.708	1.430	-0.616
Chhandar	-0.586	-0.652	-0.394	Chakdhoyakure	-0.759	1.321	-0.740
Rampur	0.083	-0.544	-0.421	Rampur	-0.183	-0.207	-0.228
Gobindapur	-0.691	-0.787	-0.683	Jaljala	-0.183	-0.095	3.418
Khopaganj	-0.130	-0.869	-0.784	Asanbani	-0.593	-0.238	-0.182
Murakata	-0.478	-0.570	-0.456	Nahala	1.047	1.926	1.416
Birra	1.146	0.004	-0.458	Parashia	-0.554	-0.211	-0.721
Pataspur	-0.759	-0.869	-0.647	Chapabani	-0.273	-0.009	-0.120
Jemua	0.016	0.071	0.284	Dhagaria	0.470	0.777	-0.538
Bhabarkola	-0.718	-0.814	-0.588	Hamirpur	1.277	1.563	1.696
Balijora	0.202	0.353	0.616	Anandapur	-0.452	0.004	-0.368
Chandaibot	-0.727	-0.841	-0.678	Kendgare	-0.234	-0.077	-0.042
Gopalpur	0.435	0.300	-0.099	Lalpur	0.368	0.649	0.889
Paschim Brindabanpur	-0.721	-0.832	-0.625	Muktapur	0.272	0.251	0.408
Sirsa	-0.676	-0.787	-0.645	Khosalpur	1.008	1.227	1.494
Jambedya	1.328	0.098	0.315	Khamardihi	0.150	0.664	0.408
Palsana	-0.554	-0.625	-0.442	Hadal	-0.644	-0.386	-0.585
Bhiringi	-0.111	-0.203	-0.033	Ram Nagar	-0.490	0.636	-0.352
Saluka	-0.772	-0.896	-0.833	Damasa	-0.362	-0.261	-0.290
Malkonara	0.525	0.462	0.740	Shonatikiri	0.060	0.259	0.253
Borojuri	2.752	0.825	1.219	Bolorampore	-0.260	0.394	-0.120
Jaykrishnapur	-0.721	-0.841	-0.771	Telesanara	-0.145	-0.141	-0.026
Dhanduliya	0.368	0.235	0.473	Paruliya	0.624	0.833	1.339
Ramkonali	4.490	0.489	0.768	Kesabpore	-0.004	0.112	0.330

Kendhuabari	0.410	-0.196	-0.011	Brindabonpore	-0.388	-0.191	-0.290
Arba	0.301	-0.054	-0.112	Bendha	3.096	4.241	-0.151
Ashancua	0.456	-0.480	-0.268	Dayalpore	1.034	1.178	1.556
Arjnpur	0.018	-0.339	-0.127	Chak Patrasayer	1.546	5.943	2.130
Biharjuriya	1.716	1.670	2.130	Panch Para	0.393	0.679	0.641
Kushma	-0.397	-0.413	-0.275	Mamudpur	1.603	1.698	2.161
Harekrshnapur	-0.203	-0.461	-0.320	Bishnubati	-0.337	-0.106	0.079
Swargabati	-0.706	-0.787	-0.708	Arbetal	0.477	-0.271	-0.112
Harishpur	-0.682	-0.761	-0.676	Saulia	-0.175	0.039	0.254
Gobordhanpore	-0.192	-0.560	-0.445				

Chapter 7

Ch. 7.1 Crop production area trend of the Shali River basin

Year	Total crop (ha)	Year	Total crop (ha)
1995	504.3	2008	804.7
1996	517.9	2009	872.2
1997	593.25	2010	958.91
1998	773.1	2011	994.83
1999	585.5	2012	1016.37
2000	502	2013	951.8
2001	825.55	2014	923.8
2002	708.6	2015	993.8
2003	706.3	2016	1042.69
2004	734.3	2017	1064.17
2005	749.5	2018	1081.67
2006	802.81	2019	1104.35
2007	809.2	2020	1144.23

Ch. 7.2 District-wise rice production area in West Bengal

District	Production area (ha)	District	Production area (ha)
Purba Bardhaman	1930147	Nadia	723032
Medinipur West	1739539	Dinajpur Uttar	713283
Birbhum	1334010	Parganas North	667791
Medinipur East	1092049	Maldah	665346
Parganas South	1017645	Dinajpur Dakshin	555446
Murshidabad	1001925	Jharghram	492048
Bankura	997336	Jalpaiguri	353436
Hooghly	891622	Howrah	273731
Coochbehar	835353	Alipurduar	193773
Purulia	796725	Paschim Bardhaman	127472
		Darjeeling	66682

Ch. 7.3 Rice production area trend in the Shali River basin

Year	Rice production area (ha)	Year	Rice production area (ha)	Year	Rice production area (ha)
1995	501	2004	720	2013	908
1996	513	2005	729	2014	878
1997	585	2006	783	2015	944
1998	762	2007	787	2016	995
1999	576	2008	779	2017	1014
2000	488	2009	844	2018	1029
2001	809	2010	924	2019	1049
2002	692	2011	954	2020	1086
2003	690	2012	975		

Ch. 7.4 Boro, Aus, and Aman rice production trend in the Shali River basin

Year	Boro	Aus	Aman
1995	233	194	74
1996	217	185	111
1997	245	205	135
1998	350	236	176
1999	266	189	121
2000	108	199	181
2001	489	169	151
2002	328	233	131
2003	279	214	197
2004	293	219	208
2005	350	147	232
2006	304	221	258
2007	213	284	290

Year	Boro	Aus	Aman
2008	310	249	220
2009	322	276	246
2010	323	251	350
2011	323	257	374
2012	319	262	394
2013	315	269	324
2014	326	281	271
2015	326	289	329
2016	337	284	374
2017	339	290	385
2018	336	295	398
2019	333	303	413
2020	343	313	430

Ch. 7.5 District-wise potato production area in West Bengal (2019-20)

District names	Production area (ha)	District names	Production area (ha)
Hooghly	95165	Maldah	7567
Medinipur west	70004	Howrah	6990
Purba bardhaman	63571	Darjeeling	4834
Bankura	34474	Nadia	4717
Coochbehar	33220	Jhargram	3572
Jalpaiguri	30742	Medinipur east	3006
Birbhum	16094	Purulia	1212
Alipurduar	14346	Kalimpong	880
Murshidabad	11696	Paschim bardhaman	468
Dinajpur uttar	14486	24 paraganas south	4441
Dinajpur dakshin	7642	24 paraganas north	8550

Ch. 7.6 Potato production area trend in the Shali River basin

Year	Potato Production Area (ha)	Year	Potato Production Area (ha)
1995	1.1	2008	15.3
1996	2.6	2009	17.2
1997	4.9	2010	23
1998	6.5	2011	29.6
1999	4.9	2012	29
2000	7.8	2013	30.2
2001	8.3	2014	31.7
2002	8.9	2015	33.2
2003	8.3	2016	31.99
2004	7.9	2017	33.89
2005	10	2018	35.86
2006	10.11	2019	38.02
2007	12	2020	40.32

Ch. 7.7 District-wise wheat production in West Bengal

District names	Production area (ha)	District names	Production area (ha)
Birbhum	30904	24 paraganas north	1511
Dinajpur dakshin	26271	24 paraganas south	1145
Dinajpur uttar	15147	Purulia	833
Maldah	10697	Jhargram	726
Jalpaiguri	6705	Darjeeling	500
Coochbehar	4680	Paschim bardhaman	478
Alipurduar	4389	Medinipur east	237
Medinipur west	3670	Hooghly	164
Bankura	2254	Kalimpong	137
Purba bardhaman	1596	Howrah	103

Ch. 7.8 Year-wise wheat production area in the Shali River basin

Year	Wheat Production Area (ha)	Year	Wheat Production Area (ha)
1995	2	2008	9
1996	2	2009	10
1997	3	2010	10.8
1998	4.2	2011	10
1999	4	2012	11
2000	5	2013	11.3
2001	7	2014	11.5
2002	6.5	2015	12
2003	6.9	2016	13
2004	5	2017	13.5
2005	8.9	2018	13.9
2006	8.4	2019	14.3
2007	9	2020	14.8

Ch. 7.9 District-wise mustard production area in West Bengal

District names	Production area (ha)	District names	Production area (ha)
Murshidabad	127044	Hooghly	10810
Nadia	87654	Jhargram	6547
Dinajpur uttar	72383	Alipurduar	5517
Dinajpur dakshin	70202	Jalpaiguri	4600
Maldah	45729	Purulia	3278
24 paraganas north	36809	24 paraganas south	3245
Birbhum	36717	Medinipur east	2057
Purba bardhaman	32985	Howrah	1878
Coochbehar	31257	Paschim bardhaman	1209
Bankura	14586	Darjeeling	427
Medinipur west	10907	Kalimpong	92

Ch. 7.10 Mustard production area trend in the Shali River basin

Year	Mustard (ha)	Year	Mustard (ha)	Year	Mustard (ha)
1995	0.2	2004	1.4	2013	2.3
1996	0.3	2005	1.6	2014	2.6
1997	0.35	2006	1.3	2015	4.6
1998	0.4	2007	1.2	2016	2.6
1999	0.6	2008	1.4	2017	2.73
2000	1.2	2009	1	2018	2.85
2001	1.25	2010	1.11	2019	2.96
2002	1.2	2011	1.23	2020	3.07
2003	1.1	2012	1.376		

Ch. 7.11 Trend rate comparison of major crops of the Shali River basin

Crop type	MK trend
Rice	5.82
Wheat	6.7
Potato	6.79
Mustard	5.25

Ch. 7.12 Seasonal rice cropped area in the Shali River basin

Village	2015		2021	
	Kharif	Rabi	Kharif	Rabi
Sohorjara	275.95	284.04	354.13	394.73
Mukatator	139.30	166.42	156.79	204.67
Balesola	29.50	71.49	58.79	83.88
Chakkeshiya	19.45	59.60	50.90	74.30
Shitala	81.44	97.90	102.42	107.16
Kachkunda	72.83	78.78	105.10	104.70
Monjimura	16.07	13.54	17.39	16.95
Monahorboti	14.83	10.16	23.77	22.20

Kanchanpur	46.50	74.50	78.39	85.10
Pabayan	89.79	84.18	101.30	112.94
Dakaisini	42.39	51.98	44.04	65.62
Khanrari	136.91	110.20	147.35	131.18
Uara	141.72	99.57	138.54	125.31
Deucha	77.25	75.42	89.54	88.78
Dejuri	29.03	33.45	33.94	28.98
Chhotalalpur	38.58	41.67	42.56	47.58
Hatasuriya	130.70	64.42	125.81	43.27
Mandarboni	91.73	41.92	79.26	22.91
Dewangarya	73.49	40.48	59.23	16.09
Sorali	81.99	37.24	71.77	20.52
Madnahati	121.14	66.64	111.19	35.79
Numugariya	115.92	42.21	97.46	37.40
Kelai	33.77	48.96	52.45	70.89
Gururbad	61.52	15.84	53.51	16.07
Kotalpukur	173.13	126.99	190.37	171.39
Balikhun	210.41	182.68	214.83	201.94
Arjune	50.07	23.02	37.51	16.83
Metianarayanpore	285.03	264.52	320.19	365.74
Baradihi	220.86	157.80	237.54	190.63
Bararampur	28.35	29.61	35.11	41.61
Sagarya	27.81	34.28	32.79	46.83
Nutangram	122.98	86.15	127.30	80.73
Khajuri	63.31	72.93	75.53	104.45
Payermohan	75.95	33.59	92.98	48.66
Jamshala	117.91	131.44	137.80	143.59
Chhotalacchipur	89.27	81.34	121.21	83.25
Nadihi	157.74	158.89	180.67	191.09
Bamundiha	195.54	155.66	197.88	176.52
Chholabaid	92.94	133.25	110.06	141.21
Hanri Bhanga	451.08	296.17	444.14	384.57
Shuabasa	325.06	211.46	335.87	303.75
Keshiara	824.23	1102.03	1091.97	1350.19
Harekrishnapur	311.71	244.53	336.53	318.93
Ita Dangra	174.43	110.88	169.49	145.33
Gopikanda	216.25	150.02	223.79	198.70
Puraniya	203.08	233.29	239.14	296.64
Shangrampore	235.50	72.63	216.22	100.16
Laxminarayanpore	86.69	106.62	98.39	122.28
Shirsha	93.46	74.31	90.11	88.03
Gangadhorpore	86.62	46.42	84.68	63.24
Kalpaeni	73.60	86.17	102.43	136.99
Bansal	137.84	187.73	192.02	294.19
Dharampur	119.66	194.56	170.94	256.85
Dhwajamonipore	46.14	65.70	80.64	104.32
Phulberrya	86.74	56.64	97.77	83.98
Damodorpore	29.04	15.17	31.16	28.51
Dagarpara	346.52	304.11	412.86	474.65
Nutongraam	25.40	29.57	39.36	32.67
Bahadurpore	366.38	329.80	394.82	462.10
Madhabpore	200.51	128.71	216.30	170.73
Thumkonra	339.59	389.30	438.45	523.92
Kanchchala	127.07	116.88	170.59	191.72
Selera	97.45	68.11	151.99	133.19

Dhaboni	308.56	253.41	359.84	372.12
Ramchandrapore	98.81	65.59	141.46	106.34
Bhairabpur	247.45	384.84	378.37	526.05
Mandi	65.01	97.50	111.51	148.96
Nomoghanshara	55.29	40.30	59.06	58.65
Karuria	22.09	8.14	20.24	13.51
Balarampore	161.66	269.29	256.26	363.85
Malkhuria	62.86	96.10	111.32	139.04
Ekariya	311.37	392.59	423.89	496.03
Mejudagara	54.05	109.56	94.72	135.05
Kapishtha	303.15	363.17	428.49	539.26
Godardi	50.34	19.07	57.65	28.76
Nischintapur	170.25	101.49	201.93	195.27
Radharomanpore	81.61	65.60	116.45	134.39
Salbedya	85.91	77.28	101.13	120.56
Gobindopore	284.78	127.78	258.93	158.24
Kallapur	215.38	102.00	394.40	390.87
Ramnagar	224.18	103.52	212.52	155.29
Suara	203.58	134.13	224.84	128.25
Sonagara	84.63	46.45	83.52	71.77
Sankara	105.60	46.78	108.04	80.93
Nabasan	32.71	10.44	38.27	22.38
Charadihi	32.91	20.67	61.29	33.83
Gobindapur	32.67	25.31	42.81	44.26
Khopaganj	32.76	15.43	49.08	30.28
Pataspur	58.79	83.42	83.22	109.96
Jemua	58.43	40.19	87.62	54.10
Chandaibot	45.28	60.26	77.34	78.83
Gopalpur	114.86	120.38	164.96	148.79
Palsana	74.95	79.28	102.43	105.39
Bhiringi	38.22	52.35	60.26	76.02
Malkonra	150.02	110.65	203.22	185.95
Barajuri	313.11	281.58	359.14	357.45
Dandulya	101.85	95.88	107.27	118.09
Ramkanali	165.49	164.70	197.22	217.84
Kenduabari	70.29	41.96	88.66	70.67
Arba	57.00	56.04	49.20	79.47
Ashanchuya	60.10	51.29	62.98	76.88
Arjunpore	42.87	19.87	51.46	35.44
Biharjuriya	109.50	65.93	166.31	120.18
Harekrishnapore	57.82	56.04	63.53	75.07
Swargabati	255.88	110.05	279.09	167.99
Gobardhonpore	38.50	22.24	49.06	38.51
Piraboni	122.80	81.99	132.20	113.25
Birndabanpur	83.76	66.39	103.98	91.54
Radhakrishnapore	31.68	29.55	54.99	50.82
Amthia	53.23	52.12	77.61	79.38
Gopinathpore	86.25	67.24	106.26	100.39
Bankurardanga	74.14	55.47	88.13	91.38
Tentuliyadaga	296.43	205.61	338.53	322.58
Saldanga	62.46	44.29	64.42	51.53
Batlapara	287.15	124.48	268.02	201.71
Purushottampur	119.04	44.08	113.08	64.18
Avirampore	138.49	61.05	125.74	86.39
Muktapur	128.11	66.90	118.63	88.45

Tilashuli	175.50	107.23	171.56	147.51
Bhalukapahari	124.83	87.28	127.84	111.59
Krishnapur	164.33	96.27	154.07	100.56
Benachapara	224.00	156.30	246.69	225.23
Mathuaberia	85.43	28.78	75.64	53.21
Bhairabdanga	94.29	44.56	76.26	75.30
Bhairobpore	57.78	34.73	48.83	50.57
Routara	40.19	28.06	33.70	37.03
Baarkura	20.55	10.13	18.80	17.22
Mathuradaga	25.20	12.01	30.02	19.29
Rajmadhabpore	4.86	2.04	10.72	2.28
Radhakantopore	22.72	9.21	40.27	26.77
Shrikrishnapore	24.16	12.59	27.73	21.61
Kantabeshe	87.96	49.42	67.23	86.96
Nityanondopur	116.24	88.30	97.08	120.08
Gangabadh	64.25	21.88	50.13	34.11
Dhulae	107.83	20.35	101.24	40.28
Pathanpalasi	61.04	11.02	48.97	20.12
Manusmari	172.96	54.53	139.04	60.03
Bankshimla	49.40	29.97	41.85	11.92
Belgaraja	80.61	8.97	63.86	8.28
Paschimdubrajpore	76.77	57.37	59.78	17.96
Krishnanagar	72.76	36.88	64.22	26.14
Belut	74.32	26.51	60.89	21.07
Harishchandropore	142.27	55.49	123.07	51.68
Radharamanpore	281.78	136.12	237.53	79.83
Ulae	126.17	29.70	99.48	30.37
Peerbera	84.80	19.17	71.07	33.68
Prayagpore	175.95	68.55	152.00	58.89
Paschim Nandapur	69.59	10.92	43.52	14.25
Basunandanpur	99.94	10.42	69.74	28.61
Shitaljar	120.11	33.88	101.06	67.68
Kubeerbadh	63.96	19.50	45.98	29.77
Dubrajhati	125.98	17.43	76.69	30.11
Shibdanga	61.05	20.71	50.52	25.03
Kamardanga	169.83	43.80	121.44	65.67
Jaypur	29.28	8.27	24.06	11.56
Kataniya	111.89	63.18	89.62	32.94
Birshingapore	152.10	57.75	121.35	44.73
Pashchimpotrahati	164.28	77.09	110.09	25.89
Rupal	116.01	31.52	78.50	23.48
Karjaboni	52.60	12.07	42.42	16.19
Palasare	217.26	88.64	172.64	100.56
Aliganj	88.37	24.64	67.61	22.77
Baikunthopore	46.98	12.04	37.91	13.12
Rupat Ganj	138.64	44.50	90.20	25.88
Jambone	75.17	27.03	55.64	49.78
Patjor	60.51	29.55	57.69	35.69
Parbatiya	65.89	29.14	63.39	38.16
Bohuliya	166.86	50.44	149.54	103.81
Salchaturiya	43.00	26.79	39.13	39.22
Shyamsundarpur	58.45	31.98	46.42	40.65
Hamirhatti	33.15	19.37	29.37	26.72
Basumara	180.19	85.38	170.34	128.02
Rampore	60.33	32.37	47.27	48.47

Kausha	35.44	14.92	35.38	30.87
Basumara	141.66	79.12	128.75	124.22
Jashara	326.30	151.55	280.71	254.11
Patsal	94.77	34.14	78.01	55.33
Ratnapore	80.97	30.71	61.80	40.47
Mathuraboti	128.78	46.09	106.45	76.64
Boronarayanpur	34.50	12.84	55.37	44.01
Bhulaa	71.60	22.54	100.50	55.91
Keshashal	66.15	32.49	65.71	63.28
Khayrakura	17.54	8.58	19.67	20.53
Churamonipore	200.30	101.85	175.90	98.33
Teura	30.83	7.93	27.46	14.21
Kalyanpore	44.41	9.18	34.27	23.58
Bedomushol	178.91	47.51	135.49	75.37
Daxhinsol	48.26	11.04	26.11	22.55
Indakata	81.82	15.33	31.98	16.68
Aamghata	89.23	24.15	55.68	31.97
Sapuradighi	58.86	13.63	55.61	24.40
Shonamukhi	40.57	14.35	38.91	18.20
Kshertamohanpur	67.22	25.09	59.44	25.37
Saldiya	97.31	37.17	82.53	43.15
Siltiya	49.70	16.20	35.17	21.90
Reutara	198.27	28.77	187.54	69.33
Shahebganj	66.89	16.20	62.38	27.26
Maheshpur	47.72	7.59	47.56	17.98
Madnamahanpur	31.35	11.78	29.19	16.11
Galtar	107.74	33.12	98.18	50.10
Chaitonpore	168.59	87.05	153.39	101.33
Khuldanga	159.40	19.10	97.41	28.67
Aamshol	96.47	8.68	36.72	9.99
Nanchanhati	155.34	27.03	99.58	77.50
Purba Patrahati	442.36	93.85	359.58	200.55
Bhaluk Khan	54.46	16.67	43.92	24.54
Jaga Mohanpur	124.32	20.43	76.15	38.65
Sona Dwipa	137.56	57.07	135.20	92.81
Ban Paruliya	137.28	45.14	120.08	68.13
Bneshe	39.37	16.82	34.80	25.19
Rajda	82.32	40.30	79.61	65.62
Junshara	72.37	34.67	69.31	59.45
Naruala	82.63	35.90	73.07	60.12
Nischinapur	680.46	288.14	546.58	430.81
Ramchandrapur	13.75	5.44	28.80	12.19
Kundopushkorini	47.17	15.65	51.23	38.13
Kasipore	107.43	41.14	153.86	102.84
Kuchiyagopalpore	172.00	70.11	221.64	168.38
Baharpore	126.82	45.88	161.83	160.65
Dhonsimla	153.85	43.39	136.60	138.65
Kendhuya	74.20	50.25	71.44	57.07
Rampur	322.61	182.42	310.86	204.21
Machdoba	69.15	44.38	67.52	51.20
Karachmani	229.40	119.31	213.58	164.37
Ranibandh	76.53	11.87	37.35	30.33
Chakdhoyakure	206.29	94.01	154.90	119.27
Dhagaria	71.92	23.30	64.91	39.26
Hamirpur	68.74	32.45	58.16	41.22

Anandapur	110.65	30.36	88.36	45.52
Kendgare	184.64	54.11	142.79	78.03
Lalpur	84.61	16.63	76.98	32.84
Muktapur	159.53	63.16	151.88	92.11
Khosalpur	186.03	108.44	180.60	122.72
Khamardihi	95.11	65.55	91.21	61.93
Hadal	37.32	22.06	38.75	21.95
Ram Nagar	35.79	6.71	32.70	17.71
Dhamasha	106.61	10.36	84.64	29.09
Shonatikiri	53.99	9.41	52.57	25.26
Balorampore	231.91	105.01	229.76	150.31
Telesanra	107.72	43.69	109.42	75.52
Paruliya	95.83	51.65	91.14	64.36
Keshabpore	41.78	14.11	40.89	25.36
Brindabonpore	46.28	13.81	45.62	20.98
Bendha	190.08	34.32	131.65	46.18
Dayalpore	476.53	139.79	316.51	290.09
Chak Patrasayer	30.82	7.71	27.53	14.89
Panch Para	49.00	9.33	38.31	15.60
Mamudpur	503.50	249.17	326.96	144.86
Arbetal	43.88	44.54	66.87	61.27
Saulia	396.15	164.07	398.14	321.92

Chapter 8

Ch. 8.1 Block-wise comparison in IRINTST

Blockk	1991	2001	2011
Gangajalghati	55	62	65
Barjora	47	49	54
Sonamukhi	22	32	35
Patrasayer	24	26	28

Ch. 8.2 Block-wise comparison in CRPINTST

Block	1991	2001	2011
Gangajalghati	67	72	76
Barjora	50	57	65
Sonamukhi	25	35	45
Patrasayer	26	30	35

Ch. 8.3 Block-wise comparison in AGLBINTST

Block	1991	2001	2011
Patrasayar	13	30	53
Sonamukhi	16	29	64
Barjora	22	48	80
Gangajalghati	32	52	86

Ch. 8.4 Village-wise IRINTST in the Shali River basin

Village	Year			Village	Year		
	1991	2001	2011		1991	2001	2011
Sahorjara	23.31	46.94	78.27	Asan Chua	22.65	32.63	36.25
Mukatatar	17.79	30.00	66.48	Bihar Jurya	75.84	83.98	95.98
Belasola	21.90	43.64	62.38	Kushma	24.62	28.80	38.80
Chakkeshia	20.88	48.59	53.11	Hare Krishnapur	62.68	69.81	73.23
Shitola	19.20	34.60	47.78	Swargabati	12.38	16.53	26.53
Kochkundo	22.81	35.60	46.66	Harishpur	16.28	19.80	29.80
Monjimurra	23.43	48.32	53.52	Pirrabani	66.73	73.44	79.16
Kanchanpur	10.69	22.69	32.19	Gopinathpur	32.76	36.44	42.50
Pabayan	45.84	60.32	68.18	Birndabanpur	14.94	18.20	28.20
Dakaisini	16.75	31.62	45.69	Radha Krishnapur	71.37	75.68	85.00
Khanrari	55.01	75.39	77.17	Shyamdaspur	13.88	24.44	29.13
Uara	10.16	24.93	27.31	Kantabani	75.53	79.24	82.38
Deucha	16.24	38.20	45.34	Amthia	33.59	83.48	98.48
Dejuri	13.78	47.03	51.24	Gopinathpur	37.46	70.32	84.60
Chhotalalpur	71.16	83.09	91.09	Gosainpur	87.80	93.32	97.00
Hatasuriya	20.64	33.79	42.22	Bankurardanga	15.41	17.49	21.49
Mondarboni	50.69	64.01	70.40	Tentulia Danga	64.73	68.22	70.77
Sorali	5.09	16.96	19.96	Belut	14.82	23.36	45.00
Madnahati	7.23	19.79	25.63	Belut	71.73	87.95	93.47
Nemuigariya	62.37	78.08	86.67	Shimlagar	64.63	70.54	74.54
Kelai	62.30	70.10	75.10	Saldanga	15.90	17.77	23.77
Garurband	57.63	63.27	72.15	Bhatla Para	73.33	83.19	90.19
Kotalpukor	90.02	92.37	94.82	Jagannathpur	8.58	10.50	15.50
Rajamela	36.45	40.68	55.28	Menjua	79.05	83.33	86.35
Balikhun	27.60	67.45	72.94	Purushottampur	5.97	7.58	17.58
Radhaballabhpore	60.79	67.96	74.11	Abhirampur	68.93	73.90	78.90
Metianarayonpore	5.53	23.31	34.03	Asansola	5.36	8.36	18.36
Lachhmanpur	9.95	24.92	43.91	Muktapur	25.00	35.73	41.77
Baradihi	32.85	54.47	78.09	Tilasuli	50.94	51.88	54.67
Maahidara	16.97	32.12	39.93	Kodma	16.49	19.98	29.96
Krishnaboti	27.66	91.43	93.46	Bhalukapahari	66.13	70.12	76.12
Nutangram	53.96	67.94	72.13	Bandarkoda	10.42	13.83	23.83
Naykonra	17.65	25.61	39.52	Bayermara	19.31	54.73	79.27
Khajuri	15.59	20.61	23.21	Raniara	49.42	51.05	56.65
Shushuniya	10.53	14.22	22.26	Mathuaberia	5.73	12.33	42.15
Jamshala	6.08	11.54	26.36	Bhairabdanga	7.14	9.40	10.55
Chhotalacchipur	10.40	23.41	37.41	Bhairabpur	24.32	25.19	26.32
Sahebdihi	22.47	29.08	33.06	Rautara	28.21	27.53	33.59
Bishanpur	12.41	25.20	36.40	Barkura	22.51	27.11	57.85
Nadihi	13.70	28.42	30.44	Mathuradanga	23.26	27.11	57.85

Bamundiha	24.67	43.91	63.84	Rajmadhabpur	54.67	62.35	78.41
Ashuria Madhabpur	12.90	25.72	30.31	Radhakantapur	9.11	14.49	21.93
Hanri Bhanga	30.67	52.31	64.02	Srikrishnapur	13.54	18.20	21.72
Talanjuri	10.61	18.19	21.58	Kantabeshe	20.09	22.89	30.51
Kantabad	10.00	28.52	35.30	Nityanandapur	78.59	89.12	90.82
Harirampur	6.58	18.76	22.08	Gangabandh	50.00	60.00	65.81
Shuabasa	30.72	45.80	68.74	Dhulai	13.55	67.55	73.56
Keshiara	78.88	91.58	96.54	Manush Mari	24.28	37.37	43.79
Belianarayanpur	73.95	89.09	93.45	Belut	31.73	35.37	40.63
Harekrishnapur	13.58	24.67	35.20	Harishchandrapur	12.31	30.38	41.93
Ita Dangra	25.81	33.33	35.48	Radharamanpur	34.09	37.42	45.37
Mallikdihi	19.57	25.69	28.09	Ulai	16.35	27.37	45.36
Dadhimukha	39.10	40.70	44.66	Pear Bera	37.34	45.12	55.12
Gopkande	12.60	24.91	27.09	Prayagpur	28.73	32.22	44.22
Garjuria	19.30	29.29	31.10	Paschim Nandapur	29.19	35.30	40.00
Ukhradihi	13.84	24.00	28.18	Basu Nandanpur	19.35	43.57	49.32
Puruniya	31.04	43.78	54.41	Shitaljor	21.35	34.39	43.39
Shangrampore	4.84	16.06	19.36	Kubir Bandh	38.71	41.06	56.13
Laxshminarayanpore	21.31	30.21	42.21	Dubrajhati	24.05	55.56	65.66
Jam Bedya	18.37	31.90	41.93	Shibdanga	34.16	40.16	51.06
Bahorakulia	18.60	30.54	43.00	Kamardanga	27.11	44.13	65.81
Taljhitka	29.11	32.06	43.65	Katnia	25.70	31.70	49.07
Lakhyara	15.06	27.05	32.60	Birsingpur	18.87	34.13	44.13
Kalapaini	18.39	28.86	35.31	Paschim Patrahati	28.70	38.94	48.94
Benshal	25.00	36.47	39.08	Ruppal	42.25	46.54	51.80
Ekchala	5.82	14.57	17.77	Karjbani	27.06	39.11	49.20
Ranganathpur	15.28	22.41	25.54	Palshare	37.78	42.57	55.39
Dhajamanipore	41.46	52.73	57.00	Aligang	48.04	53.25	57.25
Phulberrya	13.42	19.35	22.81	Baikunthapur	11.06	23.19	39.75
Damodarpur	26.92	37.84	42.40	Rupat Ganj	17.62	20.69	24.05
Dangarpara	5.33	17.61	19.41	Patjor	28.90	41.90	57.42
Amjor	39.25	48.26	54.91	Parbbatia	38.25	41.25	55.74
Nutangram	26.49	46.80	62.02	Bahulia	32.22	53.24	56.35
Gobinda Dham	55.52	60.66	65.01	Shalchaturia	17.18	48.91	52.12
Bahadurpur	40.48	51.81	59.87	Hamirhati	28.67	29.30	45.26
Madhabpur	45.07	55.38	57.85	Rampur	7.91	10.38	21.38
Mautara	83.19	91.17	93.26	Jashra	12.12	14.54	17.54
Thumkonra	39.04	42.04	47.62	Patsol	5.88	12.33	34.70
Oltara	6.56	12.78	18.24	Ratnapur	20.28	25.83	71.42
Ranbahal	9.68	12.31	20.05	Mathurabati	9.00	10.90	12.90
Kanchchala	11.46	12.84	14.76	Bara Narayanpur	4.10	14.60	22.12
Selera	15.78	31.59	42.59	Bhula	5.85	8.49	9.64

Samantamara	7.69	19.32	21.99	Tiura	18.55	20.84	23.84
Konra	41.74	45.77	47.82	Kalyanpur	1.56	2.72	3.72
Dhabani	16.49	37.65	41.34	Bhedomushal	34.00	28.00	31.00
Ramchandrapur	10.35	22.35	36.09	Dakshinsol	32.98	45.16	54.85
Bhairabpur	48.66	65.29	69.31	Indkata	30.88	31.33	35.58
Challa	24.90	35.86	37.69	Amghata	31.06	49.77	54.74
Kalberia	11.23	23.14	34.22	Sonamukhi	35.06	39.47	42.23
Kururiya	20.58	27.84	30.43	Salda	28.37	37.37	43.28
Balarampur	82.33	90.21	95.21	Siltiya	26.53	34.35	46.36
Chhotakumira	25.87	37.15	65.86	Rautara	44.27	53.35	56.45
Kenduadihi	41.17	45.23	47.38	Saheb Ganj	33.15	44.00	56.46
Ekarya	31.78	43.27	63.88	Madanmohanpur	46.74	57.91	59.91
Khidirpur	49.65	60.19	74.34	Goltor	38.21	48.20	52.20
Nabagram	33.78	44.78	46.68	Chaitanpur	11.11	19.53	24.53
Kotmadanmohanpur	61.42	83.78	84.00	Khuldanga	42.05	44.37	47.36
Kapishtha	42.82	55.73	73.78	Amshol	32.68	38.08	44.08
Saragara	41.13	46.40	51.88	Nanchanhati	57.32	63.36	71.32
Gadardi	22.17	36.11	44.29	Purba Patrahati	27.84	33.43	42.43
Gadardihi	20.82	36.04	57.34	Bhaluk Khan	38.26	43.35	45.75
Saltora	40.87	49.35	54.51	Sona Dwipa	25.53	35.24	39.26
Salbedya	32.70	45.71	56.88	Ban Paruliya	36.19	43.35	76.90
Birsingpur	11.76	23.53	26.41	Bneshe	45.43	67.95	77.60
Madhabpur	59.42	71.42	74.21	Rajda	4.82	6.32	8.25
Gobindapur	90.91	94.44	96.49	Junshara	24.63	38.78	42.86
Kallapur	76.63	83.62	84.05	Naruala	13.33	26.00	38.97
Jharia	78.89	81.38	85.38	Ramchandrapur	35.04	41.36	53.36
Ramnagar	48.88	58.88	68.88	Kunda Pushkarini	20.81	37.57	47.86
Lalbazar	28.84	43.33	61.73	Kashipur	21.85	33.42	43.42
Suara	24.62	37.19	39.64	Baharpur	19.31	27.52	33.38
Kalla	6.22	28.94	32.13	Dhan Simla	58.02	59.25	61.15
Basu Chandanpur	52.32	79.32	92.55	Machdoba	25.77	27.18	39.18
Radhashyampur	45.59	64.54	74.78	Karachmani	23.70	25.37	35.37
Sonagara	22.00	37.18	74.51	Ranibandh	2.94	4.04	7.77
Sankara	43.77	52.35	65.49	Rampur	46.47	47.59	49.83
Talanda	7.53	12.61	26.12	Jaljala	37.32	46.41	55.83
Brahmanara	40.54	52.42	54.57	Asanbani	33.33	36.73	72.41
Nabasan	11.00	20.00	27.00	Nahala	54.16	55.05	58.72
Charadihi	37.03	52.09	57.39	Parashia	17.60	39.22	43.56
Chhandar	16.20	28.29	31.33	Chapabani	53.64	54.70	36.67
Rampur	30.29	33.28	39.58	Dhagaria	22.17	29.51	31.12
Gobindapur	10.50	12.92	15.09	Hamirpur	44.46	49.07	51.43
Khopaganj	22.99	32.00	86.63	Kendgare	32.41	37.26	43.61
Murakata	35.85	38.51	41.27	Lalpur	40.91	45.24	48.52

Birra	16.10	35.79	46.53	Muktapur	49.49	53.68	58.19
Pataspur	7.14	11.76	32.17	Khosalpur	52.59	54.29	58.94
Jemua	73.42	84.61	94.74	Khamardihi	35.45	47.74	58.91
Bhabarkola	14.38	19.30	38.26	Hadal	27.78	31.58	38.10
Balijora	75.36	85.44	94.68	Ram Nagar	20.00	23.68	26.27
Chandaibot	2.80	13.18	17.49	Dhamsa	47.99	51.11	54.00
Gopalpur	55.98	74.42	94.38	Sonatikri	49.55	51.25	55.40
Paschim Brindabanpur	2.12	4.82	11.35	Balarampur	43.48	46.88	53.01
Sirsa	10.50	23.00	38.22	Telsanra	51.74	52.53	54.91
Jambedya	14.71	62.39	78.31	Parulia	65.00	66.64	68.16
Palsana	60.71	67.59	73.14	Keshabpur	42.31	46.15	48.46
Bhiringi	72.47	76.57	85.44	Brindaban Pur	51.22	65.42	66.67
Saluka	23.00	30.00	36.00	Benda	55.86	59.68	62.40
Malkonra	69.79	79.80	89.50	Dayalpur	40.38	46.58	49.74
Barajuri	29.50	36.12	68.36	Chak Patrasayer	32.37	37.52	47.01
Jaykrishnapur	3.33	13.30	33.23	Panch Para	49.70	61.06	56.73
Dandulya	92.43	94.50	96.50	Mamudpur	46.55	61.95	55.14
Ramkanali	25.11	38.91	48.02	Arbetal	45.77	67.64	57.57
Kenduabari	36.51	46.51	56.93	Saulia	9.97	12.72	32.14
Arba	45.77	59.35	74.73				

Ch. 8.5 Village-wise CRPINTST in the Shali River basin

Village	Year			Village	Year		
	1991	2001	2011		1991	2001	2011
Saharjora	39.92	69.96	106.02	Asan Chua	31.23	44.72	46.60
Muktatar	22.08	72.21	102.63	Bihar Jurya	89.33	106.60	117.53
Beleshola	36.40	69.96	102.82	Kushma	36.00	38.28	43.57
Chak Keshya	29.64	64.06	85.61	Hare Krishnapur	72.69	82.70	86.14
Shitla	32.46	59.15	70.03	Swargabati	15.63	41.03	51.26
Koch Kunda	33.95	66.39	78.88	Harishpur	20.26	44.73	59.05
Manjmura	26.48	80.14	82.63	Pirrabani	72.05	99.00	103.01
Kanchanpur	15.90	48.97	54.74	Gopinathpur	38.10	45.31	58.41
Pabayan	43.66	98.78	102.77	Birndabanpur	38.69	49.58	52.76
Dakaisini	32.16	75.30	83.57	Radha Krishnapur	81.17	95.15	115.13
Khanrari	33.65	97.69	106.96	Shyamdaspur	39.24	69.78	72.63
Uara	12.33	48.21	69.18	Kantabani	114.06	126.02	132.19
Deucha	26.76	88.06	97.13	Amthia	156.21	131.45	137.84
Dejuri	17.90	96.22	99.25	Gopinathpur	55.28	95.51	99.47
Chhotalalpur	82.89	105.12	112.65	Gosainpur	98.50	119.34	127.02
Hatashuria	59.17	72.53	79.82	Bankurardanga	40.86	46.88	53.27
Mandarbani	75.12	91.14	106.18	Tentulia Danga	72.85	97.78	97.09
Sarali	9.56	38.85	48.91	Belut	22.13	49.04	60.10

Madanhati	10.91	42.61	56.00	Belut	86.95	117.17	116.67
Numuigarya	78.10	102.39	106.26	Shimlagar	86.61	102.89	112.37
Kelai	76.86	99.67	104.20	Saldanga	21.63	24.90	32.53
Gururbad	73.91	97.04	103.00	Bhatla Para	84.40	102.88	109.67
Kotalpukur	110.64	118.30	121.91	Jagannathpur	13.46	58.71	63.79
Rajamela	62.01	95.86	102.52	Menjua	94.90	108.89	112.92
Balikhun	43.69	89.30	93.68	Purushottampur	12.87	17.33	36.23
Radhaballavpur	86.28	102.50	128.35	Abhirampur	74.66	85.24	89.63
Metia Narayanpur	13.69	41.94	87.69	Asansola	10.09	28.04	29.72
Lachhmanpur	15.43	43.50	79.89	Muktapur	54.38	78.95	85.27
Baradihi	83.29	94.01	105.97	Tilasuli	75.24	78.05	83.01
Mahidhara	36.98	73.35	87.34	Kodma	20.24	55.34	65.46
Krishnabati	43.42	107.38	113.24	Bhalukapahari	83.35	96.09	98.08
Nutangram	62.70	98.28	103.74	Bandarkoda	14.65	58.01	62.48
Naykona	30.66	48.98	68.69	Bayermara	23.07	87.62	99.60
Khajuri	27.60	35.24	56.57	Raniara	65.61	76.67	83.72
Shushunia	24.34	51.25	78.43	Mathuaberia	13.15	26.03	60.60
Jamshala	12.64	46.00	68.58	Bhairabdanga	12.68	16.11	24.09
Chhotalacchipur	19.62	36.58	53.30	Bhairabpur	54.56	57.98	60.26
Sahebdihi	41.18	53.24	68.49	Rautara	38.74	44.96	59.96
Bishanpur	28.16	42.75	59.62	Barkura	31.92	47.99	68.22
Nadihi	24.57	49.86	53.43	Mathuradanga	49.15	51.49	69.65
Bamundiha	59.44	83.24	97.72	Rajmadhabpur	61.75	78.24	84.19
Ashuria Madhabpur	18.26	70.31	55.74	Radhakantapur	15.10	33.06	37.15
Hanri Bhanga	50.67	73.38	98.83	Srikrishnapur	24.75	39.11	32.03
Talanjuri	11.46	36.68	48.75	Kantabeshe	45.86	53.35	63.53
Kantabad	17.85	59.13	69.26	Nityanandapur	95.92	107.72	110.53
Harirampur	10.76	43.65	48.97	Gangabandh	69.76	75.15	95.45
Shuabasa	76.61	96.01	109.04	Dhulai	24.74	92.87	95.87
Keshiara	152.57	159.88	168.69	Manush Mari	39.76	54.92	73.72
Belianarayanpur	105.67	114.00	126.39	Belut	36.10	77.22	87.10
Harekrishnapur	36.70	61.20	79.22	Harischandropore	61.38	66.59	87.44
Ita Dangra	37.31	55.03	74.69	Radharamonpore	49.96	58.61	69.55
Mallikdihi	34.98	53.43	72.68	Ulaai	28.35	48.26	79.37
Dadhimukha	41.36	73.04	78.57	Peerbera	49.80	54.67	89.22
Gopkande	25.83	42.87	44.72	Prayagpore	57.69	58.58	62.90
Garjuria	25.40	56.27	60.74	Paschim Nandapur	61.52	53.96	72.92
Ukhradihi	19.74	42.18	48.13	Bosunandapur	35.38	56.26	62.38
Puruniya	34.68	67.26	72.77	Shitalajar	33.10	58.78	65.43
Shangrampore	7.18	40.94	47.44	Kuberband	57.07	63.73	68.01
Laxminarayanpore	33.36	60.60	71.39	Dobraajhati	74.18	79.06	88.56
Jam Bedya	38.28	74.00	98.80	Sibdaga	41.11	59.22	91.67

Bahorakhulia	48.73	72.70	78.13	Kamardaga	37.39	58.46	75.85
Taljhitka	49.80	79.04	91.78	Katniya	41.52	47.09	54.24
Lakhyara	24.52	80.00	82.55	Birshingapore	36.57	40.42	57.57
Kalpajne	36.25	50.91	83.26	Pashchimpatrohati	35.43	56.67	66.05
Bansal	33.05	75.60	83.72	Rupal	34.03	79.47	85.57
Ekchala	7.75	47.98	49.82	Karajabani	32.81	56.81	69.61
Ranganathpur	29.03	42.48	69.13	Palashare	52.82	60.01	75.09
Dhajamanipore	71.60	94.14	106.10	Aliganga	34.19	80.33	97.02
Phulberrya	26.27	41.89	67.48	Baikunthopore	25.48	35.34	52.60
Damodarpur	47.04	61.02	76.93	Rupalgang	20.43	36.32	46.11
Dangarpara	9.41	34.19	39.33	Patjor	63.09	71.85	96.63
Amjor	65.12	71.49	87.10	Parbatiya	48.43	53.87	76.28
Nutangram	51.88	88.55	102.32	Bahuliya	65.49	80.97	89.63
Gobinda Dham	75.61	87.83	93.72	Salchaturiya	61.53	75.87	82.51
Bahadurpur	65.54	72.12	84.98	Hameerhati	35.48	46.73	68.89
Madhabpur	59.27	64.97	71.93	Rampur	18.53	33.63	36.38
Mautara	114.05	135.80	136.48	Jashra	21.03	25.89	28.84
Thumkonra	70.43	84.25	102.04	Patsol	8.74	37.24	58.28
Oltara	10.79	35.27	43.87	Ratnapur	28.27	47.50	80.54
Ranbahal	13.81	38.45	56.11	Mathurabati	15.25	21.72	34.92
Kanchchala	22.79	30.21	43.48	Bara Narayanpur	10.88	28.90	24.09
Selera	34.03	67.35	92.99	Bhula	9.68	14.76	17.50
Samantamara	16.59	49.87	57.24	Tirula	39.94	43.93	64.38
Konra	69.58	75.40	81.47	Kalyanpore	5.11	12.98	9.76
Dhabani	26.33	62.19	74.66	Bedhomusal	59.16	48.45	50.59
Ramchandrapur	26.42	34.26	69.40	Dakhinshol	42.37	52.54	68.66
Bhairabpur	56.70	86.88	92.37	Indokata	68.52	72.32	74.90
Challa	36.36	59.44	68.44	Aamghata	71.14	74.11	79.09
Kalberia	19.49	52.77	67.60	Shonamukhi	44.24	57.33	61.94
Kururiya	36.42	64.93	69.70	Saalda	70.77	76.24	83.10
Balarampur	115.65	124.10	131.03	Siltiya	67.10	85.04	95.27
Chhotakumira	36.39	61.65	75.25	Rautara	37.01	59.32	73.88
Kenduadihi	47.21	76.74	78.29	Saheb Ganj	49.12	52.12	68.83
Ekarya	72.03	83.15	103.32	Madanmohanpur	74.57	87.89	97.06
Khidirpur	58.48	91.12	99.79	Goltor	51.62	86.76	98.00
Nabagram	32.87	74.39	73.05	Chaitanpur	41.10	48.70	98.71
Kotmadanmohanpur	68.33	99.64	99.27	Khuldanga	34.79	58.37	62.37
Kapishtha	71.86	73.55	96.26	Amshol	32.26	51.41	87.10
Saragara	42.78	57.74	70.36	Nanchanhati	43.55	89.52	76.60
Gadardi	27.97	52.61	55.71	Purbopatrohati	32.09	52.48	52.20
Gadardihi	35.27	69.76	103.11	Bhalokhan	32.00	63.87	51.42
Saltora	52.41	68.51	99.98	Shonadipa	21.86	75.85	63.72
Salbedya	40.57	63.47	96.62	Banparulia	26.84	58.81	93.39

Birsingpur	17.71	33.25	45.79	Beneshe	29.66	83.47	80.49
Madhabpur	61.35	97.04	102.19	Rajada	8.65	14.05	16.31
Gobindapur	106.64	114.19	118.02	Jhunsaara	69.92	92.68	96.29
Kallapur	95.74	109.63	133.63	Naarula	18.83	57.83	95.78
Jharia	69.60	103.18	131.85	Ramchandrapur	22.42	67.98	60.04
Ramnagar	56.20	97.26	109.79	Kunda Pushkarini	58.78	93.74	96.19
Lalbazar	37.74	93.19	98.24	Kashipur	64.75	81.29	96.02
Suara	31.91	65.36	92.93	Baharpur	15.94	66.35	75.26
Kalla	12.77	56.44	68.16	Dhan Simla	72.24	92.54	97.38
Basu Chandanpur	64.91	102.12	106.61	Machdoba	31.55	54.56	48.12
Radhashyampur	91.73	110.24	118.51	Karachmani	42.85	46.20	53.89
Sonagara	34.55	66.16	93.74	Ranibandh	7.68	19.69	11.30
Sankara	55.87	75.47	98.43	Rampur	62.40	63.59	69.66
Talanda	9.43	34.16	48.11	Jaljala	46.97	65.70	71.82
Brahmanara	48.47	90.24	75.49	Asanbani	57.60	62.12	97.79
Nabasan	17.00	42.31	39.33	Nahala	42.17	68.10	63.52
Charadihi	48.35	81.08	89.78	Parashia	24.96	59.36	65.29
Chhandar	29.57	92.00	97.60	Chapabani	48.94	62.32	55.75
Rampur	43.38	60.76	65.19	Dhagaria	32.37	37.37	40.38
Gobindapur	36.97	44.22	50.80	Hamirpur	64.58	74.96	75.65
Khopaganj	56.48	59.38	109.11	Kendgare	66.60	67.17	81.78
Murakata	58.56	63.38	65.78	Lalpur	72.72	96.91	99.91
Birra	29.46	48.06	51.95	Muktapur	79.87	83.00	85.02
Pataspur	15.56	26.40	60.04	Khosalpur	41.41	96.28	78.46
Jemua	88.42	92.31	108.51	Khamardihi	23.32	74.18	79.23
Bhabarkola	16.46	22.78	67.99	Hadal	36.01	45.15	51.50
Balijora	108.04	115.12	121.88	Ram Nagar	29.91	47.33	40.39
Chandaibot	6.64	38.78	43.76	Dhomsha	39.56	77.00	69.19
Gopalpur	72.31	89.31	104.82	Shonatikiri	49.80	67.32	69.18
Saulia	14.39	39.58	39.58	Balarampore	58.43	97.59	98.84
Sirsa	15.89	48.37	65.35	Teleshanra	43.88	71.23	76.02
Jambedya	28.68	82.82	93.93	Paruliya	32.40	88.73	68.96
Palsana	74.24	83.74	97.65	Kesabppore	24.62	78.21	52.97
Bhiringi	83.80	87.87	96.78	Brindabonpore	50.48	82.90	78.40
Saluka	36.52	40.21	42.90	Bhenda	57.40	72.77	71.43
Malkonra	76.55	88.07	108.97	Dayalpur	52.43	59.45	69.28
Barajuri	43.48	53.69	86.90	Chak Patrasayer	21.32	65.95	70.68
Jaykrishnapur	5.12	29.91	51.39	Panch Para	75.31	94.72	99.48
Dandulya	112.71	118.51	121.37	Mamudpur	76.64	93.86	95.40
Ramkanali	32.18	42.21	53.44	Arbetal	47.67	73.63	85.32
Kenduabari	49.88	53.86	63.95	Paschim	5.45	7.22	15.84
Arba	51.25	64.12	81.61	Brindabanpur			

Ch. 8.6 Village-wise AGLBINTST in the Shali River basin

Village	Year				Year		
	1991	2001	2011	Village	1991	2001	2011
Sahajara	34.92	64.96	101.02	Birra	24.46	43.06	46.95
Mukatator	17.08	67.21	97.63	Pataspur	10.56	21.40	55.04
Beleshala	31.40	64.96	97.82	Jemua	83.42	87.31	103.51
Chakkeshia	24.64	59.06	80.61	Bhabarkola	11.46	17.78	62.99
Shitola	27.46	54.15	65.03	Balijora	103.04	110.12	116.88
Kochkundo	28.95	61.39	73.88	Chandaibot	1.64	33.78	38.76
Manjimura	21.48	75.14	77.63	Gopalpur	67.31	84.31	99.82
Kanchanpur	10.90	43.97	49.74	Paschim Brindabanpur	0.45	2.22	10.84
Pabayan	38.66	93.78	97.77	Sirsa	10.89	43.37	60.35
Dakaisini	27.16	70.30	78.57	Jambedya	23.68	77.82	88.93
Khanrari	28.65	92.69	101.96	Palsana	69.24	78.74	92.65
Uara	7.33	43.21	64.18	Bhiringi	78.80	82.87	91.78
Deucha	21.76	83.06	92.13	Saluka	31.52	35.21	37.90
Dejuri	12.90	91.22	94.25	Malkonra	71.55	83.07	103.97
Chhotalalpur	77.89	100.12	107.65	Barajuri	38.48	48.69	81.90
Hatashuriya	54.17	67.53	74.82	Jaykrishnapur	0.12	24.91	46.39
Mandarboni	70.12	86.14	101.18	Dandulya	107.71	113.51	116.37
Saroli	4.56	33.85	43.91	Ramkanali	27.18	37.21	48.44
Madnahat	5.91	37.61	51.00	Kenduabari	44.88	48.86	58.95
Numuigara	73.10	97.39	101.26	Arba	46.25	59.12	76.61
Kelai	71.86	94.67	99.20	Asan Chua	26.23	39.72	41.60
Gurubad	68.91	92.04	98.00	Bihar Jurya	84.33	101.60	112.53
Kotalpur	105.64	113.30	116.91	Kushma	31.00	33.28	38.57
Rajamela	57.01	90.86	97.52	Hare Krishnapur	67.69	77.70	81.14
Balikhun	38.69	84.30	88.68	Swargabati	10.63	36.03	46.26
Radhaballabhpore	81.28	97.50	123.35	Harishpur	15.26	39.73	54.05
Metiyanarayanpore	8.69	36.94	82.69	Pirrabani	67.05	94.00	98.01
Lachhmanpur	10.43	38.50	74.89	Gopinathpur	33.10	40.31	53.41
Baradihi	78.29	89.01	100.97	Birndabanpur	33.69	44.58	47.76
Mahidara	31.98	68.35	82.34	Radha Krishnapur	76.17	90.15	110.13
Krishnaboti	38.42	102.38	108.24	Shyamdaspur	34.24	64.78	67.63
Nutangram	57.70	93.28	98.74	Kantabani	109.06	121.02	127.19
Naykonra	25.66	43.98	63.69	Amthia	151.21	126.45	132.84
Khajuri	22.60	30.24	51.57	Gopinathpur	50.28	90.51	94.47
Sushuniya	19.34	46.25	73.43	Gosainpur	93.50	114.34	122.02
Jamshala	7.64	41.00	63.58	Bankurardanga	35.86	41.88	48.27
Chhotalacchipur	14.62	31.58	48.30	Tentulia Danga	67.85	92.78	92.09
Sahebdihi	36.18	48.24	63.49	Belut	17.13	44.04	55.10
Bishanpur	23.16	37.75	54.62	Belia	81.95	112.17	111.67

Nadihi	19.57	44.86	48.43	Shimlagar	81.61	97.89	107.37
Bamundiha	54.44	78.24	92.72	Saldanga	16.63	19.90	27.53
Ashuria Madhabpur	13.26	65.31	50.74	Bhatla Para	79.40	97.88	104.67
Hanri Bhanga	45.67	68.38	93.83	Jagannathpur	8.46	53.71	58.79
Talanjuri	6.46	31.68	43.75	Menjua	89.90	103.89	107.92
Kantabad	12.85	54.13	64.26	Purushottampur	7.87	12.33	31.23
Harirampur	5.76	38.65	43.97	Abhirampur	69.66	80.24	84.63
Shuabasa	71.61	91.01	104.04	Asansola	5.09	23.04	24.72
Keshiara	147.57	154.88	163.69	Muktapur	49.38	73.95	80.27
Belianarayanpur	100.67	109.00	121.39	Tilasuli	70.24	73.05	78.01
Harekrishnapur	31.70	56.20	74.22	Kodma	15.24	50.34	60.46
Ita Dangra	32.31	50.03	69.69	Bhalukapahari	78.35	91.09	93.08
Mallikdihi	29.98	48.43	67.68	Bandarkoda	9.65	53.01	57.48
Dadhimukha	36.36	68.04	73.57	Bayermara	18.07	82.62	94.60
Gopkande	20.83	37.87	39.72	Raniara	60.61	71.67	78.72
Garjuria	20.40	51.27	55.74	Mathuaberia	8.15	21.03	55.60
Ukhradihi	14.74	37.18	43.13	Bhairobdaga	7.68	11.11	19.09
Purunia	29.68	62.26	67.77	Bhairobpore	49.56	52.98	55.26
Sangrampur	2.18	35.94	42.44	Rauutara	33.74	39.96	54.96
Lakshminarayanpur	28.36	55.60	66.39	Barkira	26.92	42.99	63.22
Jam Bedya	33.28	69.00	93.80	Mathuradaga	44.15	46.49	64.65
Bahara Khuliya	43.73	67.70	73.13	Rajmadhobpore	56.75	73.24	79.19
Taljhitka	44.80	74.04	86.78	Radhakantopore	10.10	28.06	32.15
Lakhyara	19.52	75.00	77.55	Srikrishnopore	19.75	34.11	27.03
Kalpaini	31.25	45.91	78.26	Kantobeshe	40.86	48.35	58.53
Banshol	28.05	70.60	78.72	Nityanandopore	90.92	102.72	105.53
Ekchala	2.75	42.98	44.82	Gangabad	64.76	70.15	90.45
Ranganathpur	24.03	37.48	64.13	Dhulai	19.74	87.87	90.87
Dhwajamanipur	66.60	89.14	101.10	Manush Mari	34.76	49.92	68.72
Phulberrya	21.27	36.89	62.48	Belut	31.10	72.22	82.10
Damodarpur	42.04	56.02	71.93	Harischandropore	56.38	61.59	82.44
Dangarpara	4.41	29.19	34.33	Radharamonpore	44.96	53.61	64.55
Amjor	60.12	66.49	82.10	Ulaai	23.35	43.26	74.37
Nutangram	46.88	83.55	97.32	Pearberiya	44.80	49.67	84.22
Gobinda Dham	70.61	82.83	88.72	Prayagpore	52.69	53.58	57.90
Bahadurpur	60.54	67.12	79.98	Paschim Nandapur	56.52	48.96	67.92
Madhabpur	54.27	59.97	66.93	Basuanandanpur	30.38	51.26	57.38
Mautara	109.05	130.80	131.48	Shitolajor	28.10	53.78	60.43
Thumkonra	65.43	79.25	97.04	Kubirband	52.07	58.73	63.01
Oltara	5.79	30.27	38.87	Dubrajhati	69.18	74.06	83.56
Ranbahal	8.81	33.45	51.11	Shibdanga	36.11	54.22	86.67
Kanchchala	17.79	25.21	38.48	Kamardanga	32.39	53.46	70.85

Selera	29.03	62.35	87.99	Katnia	36.52	42.09	49.24
Samantamara	11.59	44.87	52.24	Birsinghapur	31.57	35.42	52.57
Konra	64.58	70.40	76.47	Pashchimpotrahati	30.43	51.67	61.05
Dhabani	21.33	57.19	69.66	Rupal	29.03	74.47	80.57
Ramchandrapur	21.42	29.26	64.40	Karjaboni	27.81	51.81	64.61
Bhairabpur	51.70	81.88	87.37	Palashare	47.82	55.01	70.09
Challa	31.36	54.44	63.44	Aliganj	29.19	75.33	92.02
Kalberia	14.49	47.77	62.60	Baikunthopore	20.48	30.34	47.60
Kururiya	31.42	59.93	64.70	Rupat Ganj	15.43	31.32	41.11
Balarampur	110.65	119.10	126.03	Patjor	58.09	66.85	91.63
Chhotakumira	31.39	56.65	70.25	Parbotia	43.43	48.87	71.28
Kenduadihi	42.21	71.74	73.29	Bahuliya	60.49	75.97	84.63
Ekarya	67.03	78.15	98.32	Salchaturiya	56.53	70.87	77.51
Khidirpur	53.48	86.12	94.79	Hamirhaati	30.48	41.73	63.89
Nabagram	27.87	69.39	68.05	Rampore	13.53	28.63	31.38
Kotmadanmohanpur	63.33	94.64	94.27	Jasra	16.03	20.89	23.84
Kapishtha	66.86	68.55	91.26	Patsal	3.74	32.24	53.28
Saragara	37.78	52.74	65.36	Ratnapore	23.27	42.50	75.54
Gadardi	22.97	47.61	50.71	Mathuraboti	10.25	16.72	29.92
Gadardihi	30.27	64.76	98.11	Boronarayanpore	5.88	23.90	19.09
Saltora	47.41	63.51	94.98	Bhuula	4.68	9.76	12.50
Salbedya	35.57	58.47	91.62	Teura	34.94	38.93	59.38
Birsingpur	12.71	28.25	40.79	Kalyanpore	0.11	7.98	4.76
Madhabpur	56.35	92.04	97.19	Bedomusal	54.16	43.45	45.59
Gobindapur	101.64	109.19	113.02	Dakhhinsal	37.37	47.54	63.66
Kallapur	90.74	104.63	128.63	Indokata	63.52	67.32	69.90
Jharia	64.60	98.18	126.85	Aamghata	66.14	69.11	74.09
Ramnagar	51.20	92.26	104.79	Sonamukhi	39.24	52.33	56.94
Lalbazar	32.74	88.19	93.24	Selda	65.77	71.24	78.10
Suara	26.91	60.36	87.93	Siltiya	62.10	80.04	90.27
Kalla	7.77	51.44	63.16	Raitara	32.01	54.32	68.88
Basu Chandanpur	59.91	97.12	101.61	Shahebganj	44.12	47.12	63.83
Radhashyampur	86.73	105.24	113.51	Madanmahonpore	69.57	82.89	92.06
Sonagara	29.55	61.16	88.74	Goltor	46.62	81.76	93.00
Sankara	50.87	70.47	93.43	Chaitanpur	36.10	43.70	93.71
Talanda	4.43	29.16	43.11	Khuldanga	29.79	53.37	57.37
Brahmanara	43.47	85.24	70.49	Amshol	27.26	46.41	82.10
Nabasan	12.00	37.31	34.33	Nanchanhati	38.55	84.52	71.60
Charadihi	43.35	76.08	84.78	Purba Potrohati	27.09	47.48	47.20
Chhandar	24.57	87.00	92.60	Bhalakkan	27.00	58.87	46.42
Rampur	38.38	55.76	60.19	Shonadwipa	16.86	70.85	58.72
Gobindapur	31.97	39.22	45.80	Banparulia	21.84	53.81	88.39
Khopaganj	51.48	54.38	104.11	Beneshe	24.66	78.47	75.49

Murakata	53.56	58.38	60.78	Rajada	3.65	9.05	11.31
Hadal	31.01	40.15	46.50	Junshera	64.92	87.68	91.29
Ram Nagar	24.91	42.33	35.39	Narula	13.83	52.83	90.78
Dhamsa	34.56	72.00	64.19	Ramchandrapur	17.42	62.98	55.04
Sonatikri	44.80	62.32	64.18	Kunda Pushkarini	53.78	88.74	91.19
Balarampur	53.43	92.59	93.84	Kashipur	59.75	76.29	91.02
Telsanra	38.88	66.23	71.02	Baharpur	10.94	61.35	70.26
Parulia	27.40	83.73	63.96	Dhan Simla	67.24	87.54	92.38
Keshabpur	19.62	73.21	47.97	Machdoba	26.55	49.56	43.12
Brindaban Pur	45.48	77.90	73.40	Karachmani	37.85	41.20	48.89
Benda	52.40	67.77	66.43	Ranibandh	2.68	14.69	6.30
Dayalpur	47.43	54.45	64.28	Rampur	57.40	58.59	64.66
Chak Patrasayer	16.32	60.95	65.68	Jaljala	41.97	60.70	66.82
Panch Para	70.31	89.72	94.48	Asanbani	52.60	57.12	92.79
Mamudpur	71.64	88.86	90.40	Nahala	37.17	63.10	58.52
Arbetal	42.67	68.63	80.32	Parashia	19.96	54.36	60.29
Saulia	9.39	34.58	34.58	Chapabani	43.94	57.32	50.75
Lalpur	67.72	91.91	94.91	Dhagaria	27.37	32.37	35.38
Muktapur	74.87	78.00	80.02	Hamirpur	59.58	69.96	70.65
Khosalpur	36.41	91.28	73.46	Kendgare	61.60	62.17	76.78
Khamardihi	18.32	69.18	74.23				

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