ASSESSMENT OF DROUGHT DYNAMICS IN PURULIA DISTRICTS, WEST BENGAL FOR APPROPRIATE ADAPTATION TO CLIMATE CHANGE IMPACTS

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CERTIFICATE FROM THE SUPERVISOR

This is certify that the thesis entitled "**Assessment of Drought Dynamics in Purulia Districts, West Bengal for appropriate adaptation to climate change impacts**" submitted by **Sabita Roy**, who got her name registered on **6th February 2017** for the award of Ph.D degree of Jadavpur University, is absolutely based upon her own work under the supervision **Prof. (Dr.) Sugata Hazra**, neither this thesis or any part of the thesis has been submitted for any degree/diploma nor other academic award anywhere before.

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This work is dedicated to my parents Mrs. Sachi Roy, Mr. Probhas Roy, my brother Mr. Prabir Roy and to the millions tribal people in the Purulia

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Abstract

The frequent occurrence of drought due to global warming has become one of the significant global issues. The developing short-term drought events accompanied by rising temperature, high evapotranspiration (ET), and low soil moisture occurred frequently around the world. In India warming has shown an increasing trend of frequent drought occurrences which mostly across the rice belt of northern and eastern India significantly impacted India's rice production. In West Bengal, the Purulia district experiences drought frequently due to monsoon irregularities. Rainfall is the major water resource used for agriculture in the red and laterite zone (RLZ). As a result, this district, with a large tribal population remains as the most underdeveloped and socially vulnerable regions in West Bengal. Despite having average rainfall around 1200 mm annually, incidences of crop failure in Purulia have been frequent during the recent decades. Therefore, a comprehensive geospatial analysis of the different drought incidences, it's characteristics including frequency, intensity, duration, it's spatial-temporal extent and influences on agricultural production in Purulia remained a prime concern of the present research. Attempts have been made to suggest appropriate drought risk reduction strategies through suitable water resources management which have been validated through a pilot action- research in few villages with the help of an established nongovernmental organisation.

The rainfall-based Standardized Precipitation Index (SPI) and evaporation-based Standardized Precipitation Evapotranspiration Index (SPEI) were computed over 1, 3 and 12-month time scales to explore variation in drought frequency, intensity, and duration in the RLZ over the last 120 years. Results indicated a minor change in the long-term droughts (12-months) condition while a major change is observed in short-term (1, 3-months) droughts characteristics. In the year 1998, 2002, 2005 and 2015, severe wet-drought could be detected during monsoon months but annually the rainfall did not depart much from the long-term annual mean. On the other hand in the years 1993, 1996, 2004, 2007, 2011 and 2012, annual rainfall was greater than normal yet drought condition prevailed for the pre and post-monsoon periods. The analysis brought out that the onset and monthly deficit of monsoon rainfall were the prime drivers of droughts in Purulia. Long-duration droughts of 8 to 10 months prevalent during 1930-1960, were found to be less frequent in the recent years. But after the 1990s, the area experienced more frequent short-term (of 4-5 month duration) droughts. The most extreme to severe (50%) droughts prevailed during the sowing months in monsoon seasons which could be attributed to rainfall variability and rising temperature due to climate change at a regional scale over the sub-humid RLZ.

In the present study, MODIS derived indices like NDVI anomaly, VCI, TCI, TVDI and Z_{PET} have been used for monthly drought assessment in monsoon seasons. Inconsistent temporal trends in drought variability were observed during the wet monsoon months in Purulia. Drought intensity was found to be variable, either peaking in June (2010) or in August (2015). Ground-level drought conditions during the monsoon months of June to September in 2015 could be further validated by SAR backscatter of multi-temporal data of 2015 to 2020. In 2015, higher backscatter values increased in June but decreased significantly in July and August due to rainfall deficit. The above mentioned temporal patterns of drought during each month were similar to the patterns obtained from agricultural drought assessment using MODIS-derived drought indices, indicating that SAR technique monitored monthly

droughts efficiently in sub-humid RLZ well, particularly during the monsoon seasons when multispectral satellite data are rare or unavailable.

Hydrological droughts were accessed from the ground water level data of 1256 wells of the Purulia. A good concurrence was observed among meteorological, agricultural, and hydrological drought indices. These three types of droughts in the sub-humid RLZ were of short duration though more frequent in the recent years. Extreme droughts mostly occurred in monsoon months. The Mann-Kendall (MK) trend test and Sen's slope estimator revealed that Purulia experienced a significant dry trend ($p < 0.05$) in the monsoon season, which indicated probability similar trend in future.

Areas more prone to extreme droughts with crop failure could be identified through spatial analysis. The droughts were found to be more frequent and severe in the western part of the district compared to eastern. The majority of the blocks have undergone drought incidences for once in 3 years during monsoon season. The prolonged (5 monsoon month) extreme drought in 2010 substantially (43%) affected Aman and other kharif crops productions. The short-term monsoon drought in 2015, 2005 and 2000 also extensively (20%) affected Aman and other kharif crops productions. Decadal declines of main agricultural working population were observed in the southern and eastern blocks.

Assessment the gap between irrigation water requirement and availability undertaken by the present study is significant for optimizing sustainable water resource management in the area. The total crop water requirement for different crops and availability from different water sources indicated significant deficiency of irrigation in dry even in normal years, often resulting in crop failure. The vulnerability and risk assessment through the IPCC AR 4 and 5 frameworks have been attempted. While the 'exposure' has been found to be higher in western blocks compared to eastern blocks, high 'sensitivity' and low adaptive capacity have made the eastern blocks more vulnerable to droughts. The Eastern blocks (Kashipur, Hura, and Purulia-I) were classified under high risk. Irrigation deficit, poor socio-economic condition of marginal farmers and limited livelihood options contribute to the high drought risk for these areas.

The research could suggest few adaptation strategies for drought risk reduction in the RLZ. These include: (a) suitable agricultural land use for sustainable agricultural (b) assessment of potential groundwater zones making micro-irrigation systems more efficient; (c) identification of optimum sites for rainwater harvesting structures for expanding the irrigation systems; (d) rural land use management including reforestation, e) using the traditional drip irrigation techniques in nutrition garden and use of less water-intensive crops. The strategies could be validated using a case study in few villages of Kashipur block with the help of a reputed NGO. It is observed from the analysis that these adaptations have helped the farmers in increasing their agricultural cropping intensity through supplementary micro-irrigation during short dry-spells and has a potential to reduce drought risk.

Considering the all results of the present study, it is concluded that inspite of adequate amount of annual rainfall, rising temperature and uncertain monsoon rainfall have resulted in frequent occurrence of short-term droughts in the sub humid RLZ with poor water retention capacity of soils. Both drought frequency and intensity have been found to increase, particularly in the wet months leading to frequent crop failures. The research argues for the need of meeting the irrigation water deficiency through micro-irrigation and appropriate cropping practices blending traditional methods and application of modern geoinformatic techniques for land and water use management for effective drought risk reduction

Table of Contents

Page No

CHAPTER I: ***Introduction*** **1-22**

CHAPTER II: ***Research Methodology*** **23-73**

CHAPTER III : ***Overview of The Study Area*** **74-100**

CHAPTER IV: ***Assessment of Meteorological, Agricultural and Hydrological Drought Characteristics in Purulia*** **101-132**

CHAPTER V: ***Evaluating the Impact of Drought on agricultural production and marginal farmers in Purulia*** **133-148**

CHAPTER VI: *Water Resource assessment to detect the optimum water management actions to deal with droughts in Purulia District* **149-164**

CHAPTER VII: *Drought vulnerability and risk assessment in rainfed agriculture of sub-humid RLZ for adaptation planning* **165-174**

CHAPTER VIII: *Drought Adaptation and Mitigation through Water, Agriculture and land use management in Purulia District* **175-221**

List of Figures

List of Tables

CHAPTER I

INTRODUCTION

[*This chapter introduces the background of the present thesis and gives a brief overview of the concept of drought phenomenon, its characteristics, impacts and the effects of changing climate on drought in recent times. The chapter also highlights the scope and necessity of the research along with a detailed review of the existing literature related to this study. Finally, the central queries and the aims & objectives of the present research are enumerated at the end of this chapter.]*

1.1 CONCEPTION OF DROUGHT

Drought is a kind of natural hazard which is acknowledged as a weather-related disaster and has magnetized the concentration of many streams such as environment, ecology, hydrology, meteorology, geology and agricultural science (Wilhite 1993; Mishra and Singh 2010; Wang et al. 2011). Drought appears in nearly all climatic zones, such as low as well as high rainfall areas and is mainly related to a decreased amount of rainfall acquired over an extended period in a specific area (Mishra and Singh 2010). During the last century, intensive droughts have been frequently observed in all continents such as North America (Cook et al. 2007), Europe (Feyen and Dankers 2009).), Asia (Fang et al. 2010; Chandrasekara et al. 2021) and Africa (Ahmadalipour and Moradkhani 2018).

1.1.1 Definition of Drought

Variances in meteorological, hydrological and socioeconomic influences as well as the stochastic nature of water requirement in different areas around the world have become a hindrance to define drought precisely. Although the term ‘drought’ is of meteorological origin which signifies a long and continued spell of dry weather due to insufficient rains. Drought can commonly be expressed as the intense persistence of a rainfall deficit over a certain region for a particular period (Beran and Rodier 1985; Correia et al. 1991; González and Valdés 2006). Drought can also be described as a deficient rainfall during crop growing season, resulting in deficit of crop produduction, yield and food security (Zargar et al. 2011; Wilhite 2016).

The Manual for Drought Management (2009) by the Union Ministry of Agriculture defines drought as a common and recurrent climatic feature that occurs in nearly all climatic regions and is generally characterized in terms of its, intensity, duration and spatial extension. Drought is a complex phenomenon with slow-onset and poses an ecological challenge (Gupta et al, 2011).

Some universally utilised definitions of drought are: (i) Gumbel (1963) described a ‘drought as the smallest annual value of daily streamflow.’ (ii) Palmer (1965) defined a ‘drought means various things to various people depending on their specific interest: To the farmer, drought means a shortage of moisture in the root zone of his crops. To the hydrologist, it suggests below-average water levels in the streams, lakes, reservoirs, and the like. To the economist, it means a shortage which affects the established economy' (iii) Linsley et al. (1982) assessed hydrological drought as a 'period during which streamflows are inadequate to supply established uses under a given water management system' (iv) The Food and Agriculture Organization (FAO 1983) of the United Nations states a drought as 'the percentage of years when crops fail from the lack of moisture.' (v) The World Meteorological Organization (WMO 1986) specifies 'drought means a sustained, extended deficiency in precipitation.' (vi) The UN Convention to Combat Drought and Desertification (UN Secretariat General 1994) denotes 'drought means the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems.' (vi) The encyclopaedia of climate and weather (Schneider 1996) identifies a drought as 'an extended period – a season, a year, or several years – of deficient rainfall relative to the statistical multi- year mean for a region.'

The difference between conceptual and operational definitions of drought is also significant (Wilhite and Glantz 1985). Conceptual definitions of drought are designed for overall understanding and formulating drought policy (NDMC 2006b). Operational definitions are (e.g., meteorological, hydrological or agricultural) objectively define criteria for drought start, end and intensity for a specific appliance.

1.1.2 Classification of drought

Like defining drought, classifying it is also difficult due to the diverse characteristics it possesses in different geographical and climatic conditions and all-encompassing nature. The droughts are usually categorised into four classes (Mishra and Singh 2010; GoI 2010; Rathore et al. 2014), which contain:

(i) Meteorological drought is outlined as a lack of precipitation over a particular region for specific time. Precipitation has been widely applied for meteorological drought analysis (Pinkeye 1966; Santos 1983; Chang 1991; Eltahir 1992). Considering drought as a precipitation deficit to long-term average values (Gibbs 1975), several studies have analysed drought intensity, duration and frequency concerning cumulative precipitation shortages (Chang and Kleopa 1991; Estrela et al. 2000).

(ii) Agricultural drought is related to a period with reducing soil moisture and resultant crop failure without any reference to surface water. A reduction of soil moisture depends on several components which affect meteorological and hydrological droughts along with potential evapotranspiration. Crop water demand varies on prevailing weather conditions, biological characteristics of the specific crops, stage of growth, and the properties of soil. Numerous drought indices, based on a combination of temperature, evaporation, soil moisture and vegetation, have been derived to analysis agricultural droughts (Mishra and Singh 2010).

(iii) Hydrological drought generally refers to a period with insufficient surface and subsurface water resources for established water uses of a given water resources management system. Streamflow data have been commonly used for widely applied for hydrologic drought analysis (Zelenhasic and Salvai, 1987; Zecharias and Brutsaert, 1988; Chang and Stenson, 1990; Frick et al., 1990; Mohan and Rangacharya, 1991; Vogel and Kroll, 1992; Clausen and Pearson, 1995).

(iv) Socioeconomic drought is connected with the demand and supply of economic goods with meteorological, hydrological and agricultural drought (Mishra and Singh 2010). Socioeconomic drought occurs when the need for economic goods (water, food, fish, forage, hydroelectricity, etc.) surpasses the supply as an outcome of a weather-related shortage in the water supply.

The National Commission on Agriculture in India classified drought in three groups: meteorological, agricultural and hydrological droughts. Meteorological drought is associted to a significant decrease in rainfall (i.e. more than 25 %) from normal precipitation over an area. Agricultural drought referes to inadequate soil moisture during the monsoon season to support crop growth to maturity and reults in crop stress and wilting. Hydrological drought may be associated with long-term meteorological droughts that consequence in drying up of reservoirs, lakes, streams and rivers, and decline the groundwater level. Different forms of droughts can get produced individually but are connected to each other through the water cycle (Bandyopadhyay and Saha 2016).

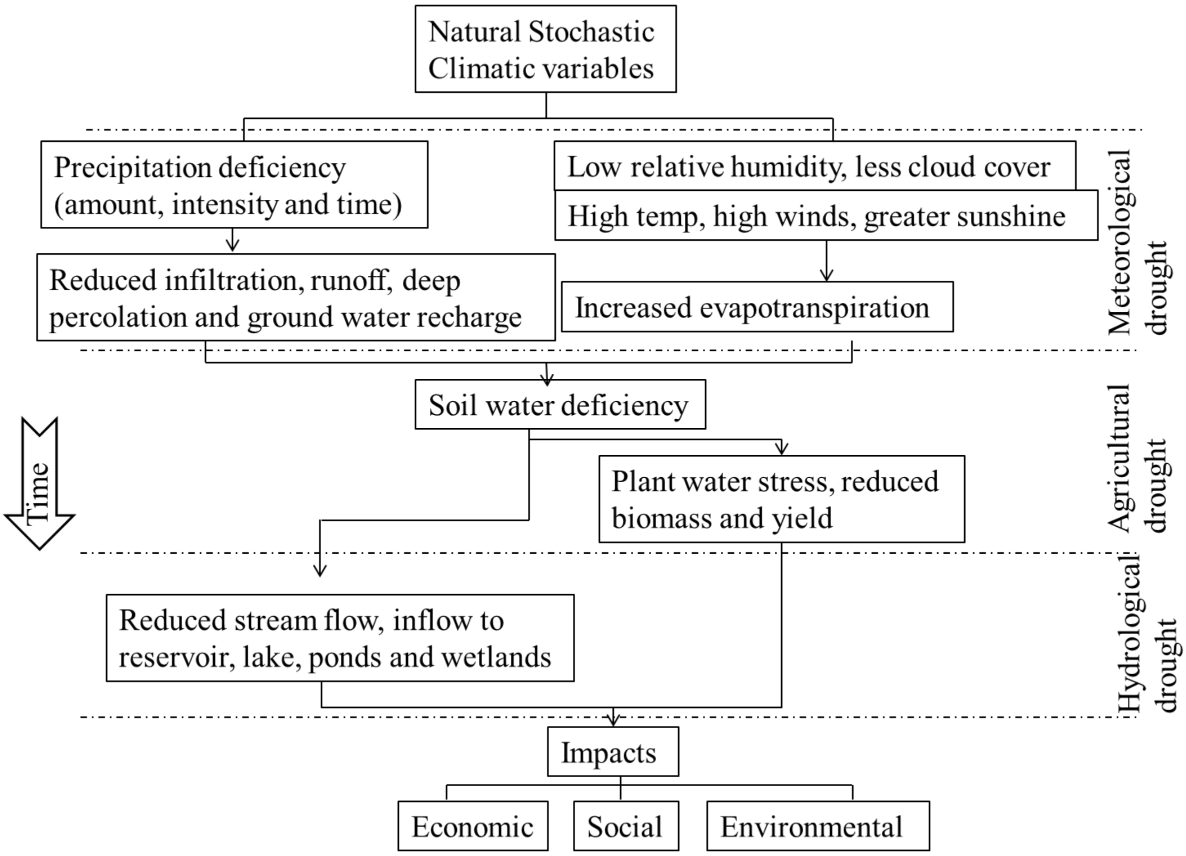

Fig. 1.1 The occurrence of different types of drought (NDMC 2006).

1.1.3 Impacts of Drought

The impact of droughts is recognized as ‘widespread crop loses leading to acute scarcities of food and fodder, adversely affecting human and livestock, health and nutrition accompanied by a shortage of drinking water accentuated by worsening groundwater quality and falling water tables leading to migration’ (Narain et al. 2000). Drought impact is all-encompassing and widespread due to its creeping nature (With no definite onset and end, precise definition and varying types) (Wilhite et al. 2007) and the drought-affected area has been increased globally since 1970 (IPCC 2007). IPCC (2007) reported that the impacts of drought are wide and depend on the vulnerability of those affected which further depends on their exposure and sensitivity to droughts and their capacity to respond and recover from it. Thus, the impact of drought also depends on local socioeconomic conditions (Gupta et al 2011). The impact of drought is regulated by the construction of the agricultural sector, management of water resources and prevailing economic conditions of the region (Benson and Clay 1998). Rathore

(2005) explained that the effects of drought can be both, direct and indirect (Fig 1.2). Direct impacts of drought include variation in agricultural production, paucity of water for domestic and agriculture purposes, severe stress on groundwater, adverserly effect on natural resources, biodiversity and pressure on government revenue, in turn and expenditure etc. Drought has a direct bearing on agriculture sectors, including fisheries and forestry due to their dependence on water availability. The indirect impacts of drought comprise unemployment, increase regional inequality, indebtedness, crimes, insecurity and migration, etc. Moreover, the purchasing capacity declines, rises unemployment, decline credit cost are forcing the vulnerable people to migrate, work at lower wages or live in near-starvation.

The micro-level (village or household level) drought impacts are also important. Drought can result in a substantial intensification of food security, water-related health risks and loss of agricultural production and livelihoods. The marginal and small farmers are more exposed to drought because there are mainly dependent on rainfed agriculture which results in relatively greater loss of crop production.

Drought affects all parts of our environment and communities. Drought impacts are often classified as “economic,” “environmental,” and “social” impacts by Nation Drought Mitigation Centre. Crop loss due to drought has been most quantitatively and widely identified impact. The consequences of production losses comprise rises in food prices, food scarcity (Sam et al. 2019; Ding et al. 2011), and decrease in food consumption, with effects on human health (increasing diseases, mortality, malnutrition etc.) (Epule et al. 2014; Yusa et al. 2015). Drought is responsible for depletion in water availability, fall employment in the agricultural sector, decline purchasing power and degradation of water quality, resulting in health problems. Drought has adversely effect on rangeland production and on the animals warer requirement hence, indirectly effects on livestock and milk production. Droughts are the results of social stress, tension, disruption of a social institution and increase social crime (Otto et al. 2017; Nath et al. 2017).

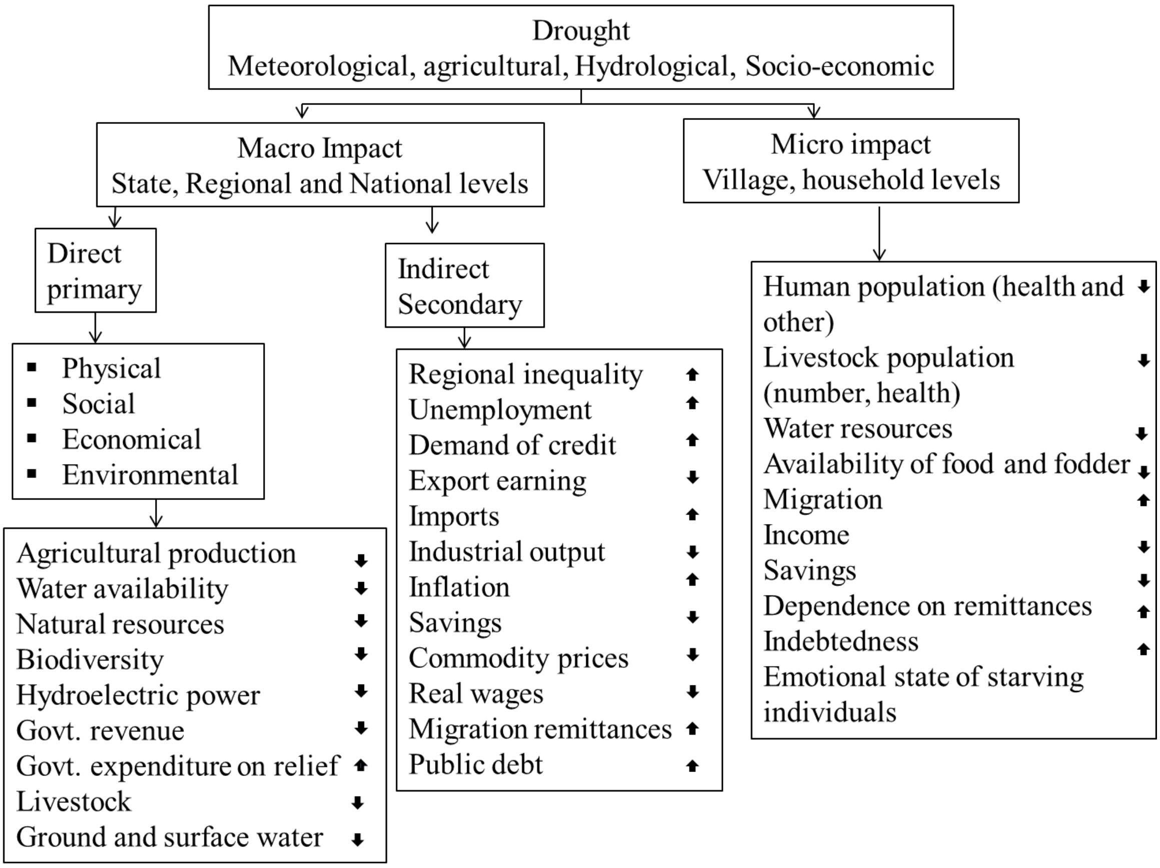

Fig. 1.2 Drought impacts

Drought is a widespread occurrence (Kogan 1997), and around half of the world’s lands are vulnerable to drought. More prominently, the major agricultural lands are found there (USDA 1994). The impact of droughts on different continents around the globe has been observed. In Europe, The yearly average economic damage of droughts has been €5.3 billion during the past two decades, with the higher economic loss of the 2003 amounting around €8.7 billion (European Communities 2007). In many parts of Asia, crop production (rice, maize and wheat) was decreased due to drought during the past few decades and about 60 million people in Asia were affected by continuing drought during 1999–2000 (IPCC 2014). In Australia, recent droughts decreased the national winter cereal production by 36% and cost around AUD 3.5 billion, leaving abundant farmers in a financial crisis (Wong et al. 2013). Africa has underwent a drought of unprecedented intensity in recorded history which had devastating effects (Zeng 2003). In the United States, drought events regarded 10 out of the total 58 weather-related disasters (Ross and Lott 2003) during 1980 to 2003 and the cost of the droughts was $144 billion (Ross and Lott 2003).

1.2 DROUGHTS AS NATURAL HAZARDS

Drought grades maximum among all natural hazards while quantified the number of people affected (Wilhite 2000b; Mishra and Singh 2010). Bryant (1991) assayed hazards based on their attributes (the degree of severity, spatial extent, suddenness, duration, and occurrence of associated hazards) and impacts (life loss, economic loss, social impact and long-term effect). In economic terms, drought is the costliest natural disaster to strike globally (Hewitt 1997; Cook et al. 2007). Drought happened by rainfall deficit is a deadly natural environmental hazard because it directly affects the basic requirements of life (i.e. water and food). Droughts, deriving from the accumulative influence of water paucity cause widespread failure in agricultural production and natural vegetation and therefore trigger famine and starvation to the people and animal of the area concerned. According to Wilhite (2000a) drought is different from other natural hazards in various aspects:- First, determination of the onset and the ending of a drought is challenging, the effects of drought increase gradually, often accumulate over a substantial period and may remain for years after cessation. Therefore, drought is characterized as a creeping occurrence. Second, drought has no universal definition. Third, impacts of drought are non-structural and have extensive spatial extension than damages that may result from other natural hazards. The precise quantification of the impact and the endowment for relief is further more complicated for droughts. Fourth, endeavors of human can directly prompt drought, distinct from other natural hazards, with intensifying reasons like excessive irrigation, deforestation, over farming and exploiting available water, erosion and unscientific use of the land to capture and hold water.

1.3 CLIMATE CHANGE IMPACT ON DROUGHT

Warming-induced drought has become a major focus and associated water and food scarcity are some of the difficulties being confronted in today’s world (Nadeem et al. 2019). Globally temperature is rising with considerable regional disparities in the present (20th) century and can be distinguished in two distinct periods, from 1910s to 1940s (0.35° C), and more intensely from 1970s to present (0.55 ° C) (IPCC, 2007). The rising rate of warming has been recorded over the last 25 years, and 11 of the last 12 years have been declared as warmest years. Generally, this warming adversely influenced the global hydrological cycle (Wang 2005).

Based on climatic model projections, IPCC reports (2012) suggested that the present and the future trends in droughts would increases and remain uncertain at regional scale. Numerous articles (Mishra and Singh 2010) emphasized that drought risk has been increased and the frequency and intensity of these recent droughts have enhanced by global climate changes since the 1990s. Drought has significantly increased in Africa, southern Europe, East and South Asia, and eastern Australia since the 1990s due to global warming (Dai 2011).

Intensifying drought frequency and a change in special extension of dryness over sub-humid regions, are perhaps one of the foremost concerning effects of recent warming (Berg and Sheffield 2018). As a result, in the developing countries, where livelihoods predomemtly depend on agriculture, drought can have devastating effects (Maharatna 2014). The increasing drought frequency and intensity can cause a 40 % loss in annual production in Southeast Asia (Pandey and Bhandari 2007; Chou et al. 2019), which converts to economic losses above 55 % (Pandey and Bhandari 2007; Hasegawa et al. 2011). The risk of warming-induced drought on rainfed agriculture is more severe in the sub-humid region of Southern Asia. About 23 million hectares of rainfed paddy cultivated area in Southern Asia is highly prone to drought (Pandey et al. 2007). Associated with global warming, the occurrence and duration of drought show an increasing tendency. Its impact is becoming more severe, particularly to the people of Southern Asia (Zhai et al. 2017). Southern Asia, which mainly includes China, India, Pakistan, and Bangladesh, is highly impacted by drought every year. The drought over this province is mainly associated to the inconsistent nature of the monsoon rainfall and rising temperature (Zhang and Zhou 2015). Therefore it necessary to understand the climate change impacts on drought to prepared mitigation strategies for relieving the damaging impacts and taking appropriate preparedness planning for boosting yield and sustainability (Li et al. 2015).

1.4 NEED FOR DROUGHT RESEARCH

Drought is one of the most unpredictable and frequent phenomenon (Anjum et al. 2017), that severely damage yield worldwide (Golldack et al. 2014; Hussain et al. 2018). Drought evaluation is immensely necessitated for water resources management planning. This provides fundamental knowledge about the spatiotemporal variation of historic droughts and its impacts in the region.

Conflicts occurred in various sub-humid regions (Ex. Brazil, Australia, India and China) during recent drought between meteorology and scientists and policymaker, for example, scientists and policymakers found that this region had experienced more droughts while meteorology had identified only fewer drought events (Wilhite and Glantz 1985). Rainfall records are summarized by year rather than growing season basis and rising temperature is not considered. Thus, rainfall records were misleading and did not detect emerging drought conditions in sub-humid regions during the recent period. Nature also reported that drought is relatively under-researched. When droughts are likely to strike, a forecast of their duration and impact are essential for drought mitigation and preparedness planning at various scales which can improve the coping capacity of the regions to manage drought.

The frequency of drought is increasing in recent decades severely affects global food production (Lesk et al. 2016). Considering climate change and anthropogenic influences, and overall enhanced drought risk for crop yield in humid regions is well recognized (Dai et al. 2013). In sub-humid regions of India, drought risk is higher due to erratic and deviated monsoon rainfall (Thomas and Prasannakumar 2016), increasing temperature, groundwater depletion, and increasing demand for food and water by large populations (Zhang et al. 2017).

Agriculture in India is predominately rain fed, occupied around 58% of cultivated area, 40% of food production and farmers (Venkateswarlu and Prasad 2012). Various recent studies concluded that droughts to become a danger to agricultural sector in near future, therefore it is necessary to assess the drought characteristics and potential impacts at various scales. This will facilitate adaptation to reduce the vulnerability of the farming sector and therefore secure the farmers livelihood. In India, 62% of people are dependent on agriculture and 16% of their contribution to the national gross domestic product is primarily affected by drought thus from the food security and societal need perspective drought assessment essential key aspect (Kulkarni et al. 2020).

1.5 BACKGROUND OF THE STUDY ON DROUGHT AND ITS SPATIOTEMPORAL VARIABILITY

Droughts appear in almost all climatic regions, such as low as well as high rainfall areas over the world (Mishra and Singh 2010). Drought is a recurring feature and most widespread phenomenon (Gupta et al. 2011) nearly all of the major agricultural lands are prone to droughts (USDA 1994).

Drought is projected to increase in severity and frequency during the recent and near-future period as a consequence of regional rainfall variation and raising evaporation driven by global warming (Dai, et al. 2011; Seneviratne et al. 2012). Of all the natural hazards of 20th century, drought has had the extreme detrimental impact (Bruce 1994; Mishra and Singh 2010). In recent years, exreme droughts have affected considerable areas in Africa, Australia, Asia, Europe, America (Spinoni et al. 2014; Van Loon et al. 2016) and excessive economic and social losses have led to developing awareness to droughts (Downing and Bakker 2000).

Drought management practices throughout the world are generally based on crisis management (Wilhite and Pulwarty 2005). Thus the national drought policies (WMO 2013) emphasize risk reduction and complemented through drought mitigation and preparedness planing at different levels of government (Wilhite et al. 2014). Risk management includes comprehensive monitoring, impact assessment and early warning, are promote the adoption of preventive measures and strategies that will alleviate the future drought impacts, and thereby reducing social and economic exposure (Mishra and Singh 2010). Water availably and food security is closely attached, the occurrence of drought puts this balance at risk. Improved understanding of drought characteristics would therefore be essential for drought planning and management.

1.5.1 World scenario

A global database of meteorological drought maintained by the Global Drought Observatory of the European Commission’s Joint Research Centre found several drought hotspots in the recent decades: Northern South America, Africa, North-east Asia, Mediterranean regions and southern Australia. The recent rising temperature, increasing outbalanced in rainfall causing frequent drought in North America, Central Europe, Southeast Asia and Australia (Spinoni et al. 2019). The recent droughts occurrence and their effect on different continents around the world are discussed.

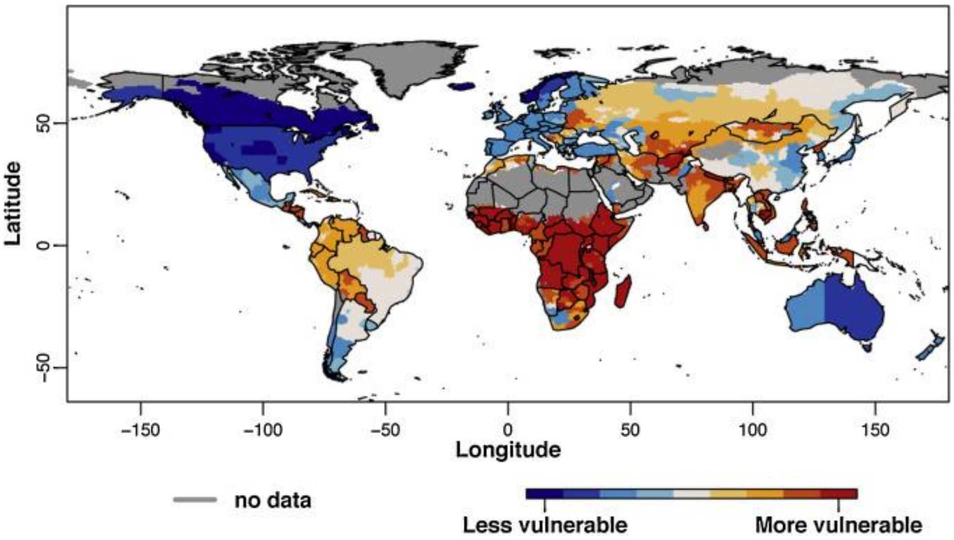

Fig. 1.3 Global map of drought vulnerability (source: Carrao et al. 2016)

1.5.2 America

Numerous studies (Wilhite and Hayes 1998; Changnon et al. 2000) revealed that drought frequency and intensity have significantly increased with an increased impact of droughts during the recent decades in the United States. The National Climatic Data Center, USA (2002) reported that around 10% of the total agricultural land of the United States suffered extreme to severe droughts during the last century. From 1980 to 2003, there were 10 droughts out of the 58 meteorological disasters in the United States (Ross and Lott, 2003). Sub-tropical regions of America are highly susceptible to severe drought in recent times due to worming (Miranda et al. 2020; Venegas-Gonzalez et al. 2018). Recent droughts in 2005, 2010and 2015 were exceeded the long-term return value in sub-tropical America with profound socioeconomic impacts (Erfanian et al. 2017). In the recent drought of 2000-2010, the aggregate level of the largest river basin and Great Lake dropped to their deepest point in more than 30 years (Martin et al. 2020).

1.5.3 Europe

It is observed that during the recent period rising evaporation may develop frequenct and prolong droughts in southern Europe (Spinoni et al. 2017; Hanel et al. 2018). Over the last 30 years, Europe has been affected by numerous severe droughts, most remarkably in 1992 (Western and Northern Europe), 2003 (nearly entire Europe), 2015 (large portion of Europe), and recently, the lengthened drought over entire Europe combined with the summer heatwave in 2018 (Hansel et al. 2019; Crocetti et al. 2020). The most serious drought in the Iberian Peninsula stricken in 2005 and 2015, reducing annual EU cereal yields around ten percent (United Nations Environment Programme, 2006). Since 1991, droughts in Europe caused an annual average economic loss of €5.3 billion (European Communities 2007). Northern and Eastern Europe experienced the highest crop failure in 2018 due to low rainfall and combination with high temperature between March to August of the year (Beillouin et al. 2020).

1.5.4 Asia

An increased risk of droughts has been observed in Asia since the late 1970s, as global warming increases which fabricates both higher temperature and dryness (Guo et al. 2019; Zou et al., 2005; Dai et al., 2011). Crop production (rice, wheat and maize) in the prior few decades was dropped in several countries of Asia due to intensifying drought frequency, temperature, El Nino and reduce the number of rainy days (Li et al. 2017; Xu et al. 2016;

Bates et al., 2008). Many areas of northern China have experienced frequent severe droughts since 1990 caused large economic and societal losses (Zhang and Zhou 2015). Under increasing temperature, growing population and capricious south Asian monsoon in recent periods, concerns about drought and its effects are on the rise in Southeast Asia (Zhang et al. 2020). In Central and Southwest Asia (Iran, Afghanistan, Western Pakistan, Tajikistan, Uzbekistan and Turkmenistan), above 60 million people suffered from prolong drought during 1999–2015, one of the vastest from a global viewpoint (Guo et al. 2019). In the context of monsoon variability, China, India and Bangladesh are highly influenced by meteorological droughts that develop agricultural drought (Zhang et al. 2020; Hossain et al. 2020’; Dar et al. 2020). In 2000, drought-affected agriculture areas in China were estimated to exceed 40 million hectares (Zhang and Zhou 2015).

1.5.5 Australia

Drought is a recurring phenomenon in Australia (Berbel et al. 2019; Bond et al. 2008). Southern and Eastern Australia has been affected by frequent severe drought and is considered as one of the nastiest in the area since 1990 (Kim and Rhee 2016; Murphy and Timbal 2007). The prolonged drought in Australia has lasted for almost a decade (Wright et al. 2019; Bond et al. 2008) with several rivers undergoing record down flows (nearly 40% below the earlier lowest records) during this period (Murray Darling Basin Commission 2007). Australia has been recently subjected to two worst droughts in the historical record such as 2000-2009 and 2017-2019 (Kauwe et al. 2020). The 2006 drought in Australia decreased cereal production almost 36% and cost around AUD 3.5 billion, triggering several farmers in economic crisis (Wong et al. 2010).

1.5.6 Africa

Drought is seen to be the more frequent, intense and longer duration in spring and summer in East Africa as the overall rainfall and water storage rapidly decline (Haile et al. 2019). The serious food security and humanitarian crises were caused by the recent two droughts in 2009, 2010 in East Africa (Mwangi et al. 2014). The spatial extent of drought in southern Africa has been increased since 1970 due to stronger ENSO, rainfall and temperature (Gizaw and Gan 2017; Rouault and Richard 2005). Equatorial rainy areas of Africa have experienced drought during the rainy season 2008-2011 resulting in acute food shortages and massive migration (Nicholson 2014, 2016). The occurrence and areal extent of drought have been increased during cropping season (Shiru et al. 2019). The more severe and frequent drought was prevailed in Africa during cropping season due to climate change (Shiru et al. 2019).

1.5.7 Indian Scenario

India is the most vulnerable to drought (Gupta et al. 2020). Droughts have been perceived at least once every three years in the past five decades. Since the mid-nineties, extended and extensive droughts have happened in successive years, similarly the intensity and frequency of droughts have grown in recent phases (Mishra and Singh 2010).

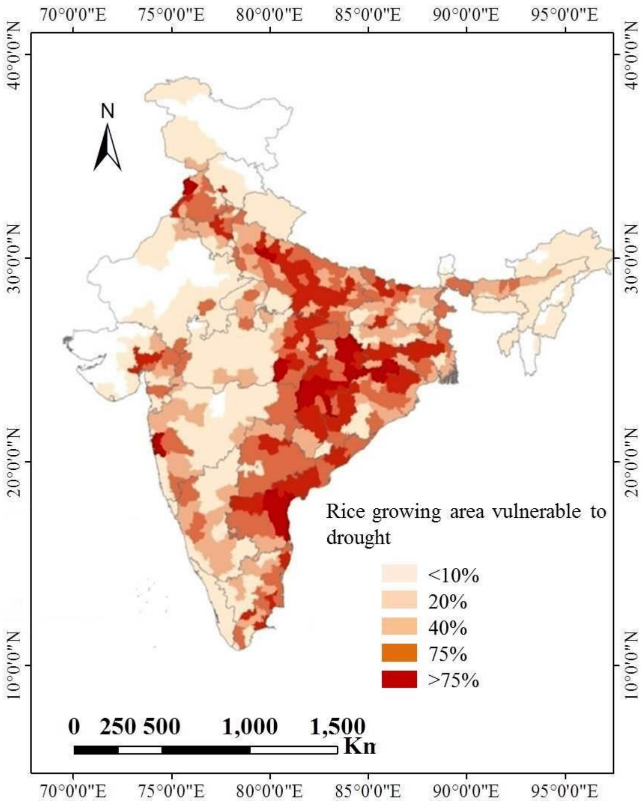

Fig. 1.4 Vulnerable to drought in Sub-humid area of India (Source: Kannan et al. 2017)

Numerous present studies (Udmale et al. 2020; Pai et al. 2017; Mallya et al. 2016; Kumar et al. 2013) analyzed the drought characterizes over the Indian monsoon region by rainfall based Standardized Precipitation Index (SPI) and evaporation based Standardized Precipitation-Evapotranspiration Index (SPEI). India faced a rise in intensity and areal extension by moderate drought in recent decades (Mujumdar et al. 2020). Mishra (2020) revealed that recent two droughts (2015 and 2018) affected crop production, livelihood and socio-economic condition of one-fourth Indian population associated with agriculture. Drought frequency substantially increased during the monsoon season (Mishra et al. 2018). Investigation of Indian monsoon drought variability using various indices indicated an increasing trend in drought frequency and intensity during recent decades due to rising temperature (Preethi et al. 2019). The monthly monsoon drought analysis using SPI found a 44% yield reduction in rice production (Subash and Mohan 2011). India experienced 21 all India drought years in the monsoon season during the last century (Tyalagadi et al. 2015). The enhancement in evapotranspiration is 2.9 mm/decade over India and low rainfall values in recent drought years such as 2002, 2010 were associated with higher evapotranspiration (Madhu et al. 2015). The rising temperature has been observed to be considerably associated with the variability of meteorological drought over India (Pai et al. 2017). Shah and Mishra (2020) detected Gangetic plane and peninsula India as major drought clusters which experienced drought in the monsoon season during recent times due to increasing temperature. In the perspective of the climate change scenario, improving the drought analysis is a great concern to enhance agricultural productivity in the rainfed farming system (Das et al. 2020). The frequency and s of drought have noticeably depended on temperature variation during the year at a local scale (Amrit et al. 2018). In the present decade, the frequency and intensity of drought have been elevated in India. Around 330 million people in India had affected by the recent drought in 2016 (Gumma et al. 2019). Since the 21st century, monsoon rainfall is deviating much from its prediction and excesses evapotranspiration due to rising temperature therefore sub-humid regions come under drought-prone regions (Gautam and Bana 2014; Rathore et al. 2014; Mishra and Liu 2014).

Frequent drought prevailed over Kerala during recent times due to climate change (Abhilash et al. 2019). Assessment of drought characterized by SPI in the Narmada basin revealed that the frequency and severity of drought have risen in present decades (Swain et al. 2020). Rajkumar (2020), Todmal (2019) also found a similar trend when drought event in Tamil Nadu, Maharashtra examined by SPI/SPEI respectively. Drought characteristics during the monsoon season in Madhya Pradesh were analyzed which indicated an increase in frequency and intensity of drought (Swain et al. 2020). Taggu and Shrivastava (2021) observed a maximum number of droughts that occurred during the monsoon season in humid Tripura. Mishra et al. (2018) found higher uncertainty for a localized drought over a significant portion of India during the crop growing monsoon season. Drought occurrence in Jhelum was examined using SPEI by Parvaze and Ahmad (2018), they concluded that the most frequent and intensive drought in the basin occurred since 1999. SPI was used to analyze drought on multiple timescales in the Godavari basin, finding revealed that the basin experienced short-term drought in recent decades (Masroor et al. 2020). Pathak and Dodamani (2020) observed a significant number of moderate to severe droughts over the Bundelkhand region on all time scale of SPI. Trend assessment of SPI for the monsoon months indicated a significant positive trend over central-north eastern India (Guhathakurta et al. 2017). SPEI was evaluated for Spatio-temporal drought assessment in the Krishna basin (Singh et al. 2019). Sub-humid district Odisha was repeatedly affected by drought in recent years (Arora et al. 2019). Continually Short-term drought has been observed in sub-humid red and laterite areas of India (Kerala, Telangana and Odisha) (Adarsh and Reddy 2019). The humid Gangetic plain region has become increasing drought-prone in the recent decade with a decline in rice and cereal production since 2000 (Nath et al. 2017). In 2015 severe drought was found in sub-humid red and laterite regions (Sahana et al. 2020). Warming induces droughts that are becoming more frequent in sub-humid regions of India that make the marginal agrarian population more vulnerable (Kishore et al. 2019).

Around one-third of the rice cultivation area in India has been affected by frequent drought in recent years which is a principal constraint to the sustainable improvement of agricultural productivity in the rainfed farming system (Birthal et al. 2019). As agriculture in India profoundly depends on monsoon rainfall, meteorological drought propagated to agricultural drought (Todmal 2019). Remote sensing data played an important role in agricultural drought assessment in India (Kulkarni et al. 2020; Liu et al. 2016; Murthy et al. 2007). VCI, TCI, SCI derived from multi-sensor remote sensing data were applied for agricultural drought assessment in Maharashtra (Singh et al. 2020). Agricultural drought has been assessed using remote sensing derive indices in Rajasthan (Dutta et al. 2015, 2013), Maharashtra (Mahajan and Dodamani 2015), Tamil Nadu (Vaani and Porchelvan 2018), Aravalli (Bhuiyan et al. 2006), Gujarat (Bhuiyan et al. 2017), Karnataka (Pathak and Dodamani 2018; Sruthi and Aslam 2015), Chhattisgarh (Sarkar et al. 2020), Madhya Pradesh and Haryana (Sahoo et al. 2015), Bundelkhand (Padhee et al. 2017; Patel and Yadav 2015). Indian farming system is mostly supported by monsoon rainfall, a slight variation in it affects the crop production and increasing temperature decline the soil moisture which makes the sub-humid RLZ region of India more vulnerable to drought (Bhavani et al. 2017; Sruthi and Aslam 2015).

1.6 MAJOR OBSERVATIONS

Trend analysis of drought indicates that drought frequency and severity are increasing during the recent decades (Preethi et al. 2019; Bisht et al. 2019; Mishra et al. 2018; Pai et al. 2017; Kumar et al. 2013). Drought is becoming more regional and reallocates to the agricultural important Indo-Gangetic plains, coastal south India and central Maharashtra resulting in high food insecurity and socio-economic susceptibility (Mallya et al. 2016). Sharma and Mujumdar (2017) also found a significant trend of recent drought occurrences in sub-humid central northeast India. In recent decades, sub-humid regions of India experienced more droughts during the monsoon which are a short-term but have devastating impact on agriculture (around 10-15% Kharif crop failure) (Mahto and Mishra 2020).

Higher temperature may produce excessive evaporation, thereby, increase the drought affected areas in recent years (Nath et al. 2017). Drought has the most significant impacts at the local level (Amarasinghe et al. 2020). Short-term droughts have a major impact on rainfed agriculture in India (Singh et al. 2020) and these droughts are more prone to fluctuations due to monthly variations in meteorology (Singh et al. 2019). Severe to extreme drought is mostly observed in monsoon months (July, August and September) (Meshram et al. 2018).

The average annual rainfall of sub-humid RLZ of India is pretty good and a slight departure from the normal is very significant in affecting agricultural production of the regions. Thus an intensive study of drought in sub-humid RLZ is very essential (Mishra and Desai 2005). Drought assessment in Sub-humid regions of India is important for planning and management of water resources in coping with climate change at a local scale (Malik and Kumar 2020). Rice is the most significant food grain, occupying 36% of the gross cropped area and 42% of food-grain production in India where the major rice-growing area accounting for about half of the total rice production in India. Much of this production is predominantly rainfed. The significant reduction in rice production in recent drought years in the Sub-humid RLZ region revealed that frequent drought is a major constrains in these regions (Bhandari et al. 2007).

1.7 THE IMPORTANCE OF CONSIDERING THE PRESENT STUDY AREA

Drought in Indian meteorology has been equated with annual rainfall deficits and the generalization of the analysis may have been misleading or did not detect emerging drought conditions especially in sub-humid regions during the recent period. Despite Purulia receives quite a good amount of annual rainfall but it remain as one of the most chronic drought-prone area in the red and laterite area of West Bengal (Palchaudhuri and Biswas 2013). Drought induced water shortage, undulating topography, laterite soil and lack of irrigation affecting rainfed agricultural and socioeconomic conditions in the district (Palchaudhuri and Biswas 2020; Pant and Verma 2010). Pandey et al. (2012) observed that crop yield in Purulia reduced during recent drought year around 69% relative to a normal year.

The district is underdeveloped and faces drought induce water stress due to climatic, geological and socioeconomic factors. Recurrent drought has reduced agricultural production and generated wasteland which also drives regional poverty and migration (Kar et al. 2020).

In the context of drought, a considerable number of out-migration has been illustrated in Purulia. Agriculture is the main source of income affected by drought and forces people to search for alternative livelihood options in districts or states (Raha and Gayen 2020).

The district faced severe droughts in the years 2002, 2010 and 2015 (Palchaudhuri and Biswas 2020). Since 1990 the district experienced frequent short-term droughts (Mishra and Desai 2005). Purulia experienced a maximum number of severe droughts in monsoon months (Asutosh 2019). From the perspective of climate change, drought frequency and intensity have been increased in the recent decade (Patra 2020). The people in the region are very poor (two-thirds of the population has been officially classified to be ‘below poverty line) and they mostly depend on agriculture (Samal et al. 2005). Around 60% of the cultivators are marginal and 30% are small farmers (Chandramouli 2011). The incident of crop failure in Purulia has been frequent and increased in recent times (Jana and Ghosh 2018) affecting 2.93 million populations, 18.5% of which are ‘deprived’ tribal populations (census 2011). Therefore it is incredibly essential to evaluate the drought in the Purulia district assess it’s spatial vulnerability and suggest some measures for drought risk reduction. For these reasons, the present study area is considered to be important.

1.8 PREVIOUS WORKS CONDUCTED IN THE PRESENT STUDY AREA

Although the Purulia district of West Bengal receives a considerable amount of rainfall (average annual rainfall 1300 mm) drought is a recurrent phenomenon (Goswami 2019). Few studies were conducted in the Purulia district of West Bengal, but comparatively more emphasis have been given on the long-term time scale such as Annual or seasonal. The drought assessments carried out in the Purulia were mainly using the rainfall-based index SPI. Assessment of the changing character of short-term (monthly) drought from the evaporation-based index is yet to be reported from this sub-humid RLZ region which is essential to understand the impact of growing global heat stress with climate change (IPCC 2022).

Bhunia et al. (2020) was conducted a seasonal drought assessment in Purulia using SPI and observed an increasing trend in drought frequency. Agricultural drought assessment in Purulia using VCI revealed that the region experienced severe drought and reduction of crop production recent decade (2000, 2001 and 2010). Thus drought in sub-humid RLZ has severe consequences on agricultural productivity due to climate variability (Dey et al. 2021). Goswami (2019), Palchaudhuri and Biswas (2020), Das et al. (2017) found that central and southern parts of the Purulia pose the highest risk to drought. Banik et al. (2002) concluded that drought-proneness has been extending in this area. Ghosh (2019) found that the Purulia district experienced frequently severe drought in the monsoon season. Kharif rice production was severely affected by frequent drought especially in mid-season or late-maturing cultivars (Goswami 2019). High evaporation due to rising temperature cause drought in this area (Mandal 2013). Agriculture is the main livelihood but drought forces people to search for alternative livelihood options in their neighboring state. Thus drought induces migration in Purulia is high (Raha and Gayen 2020). Spatiotemporal drought occurrences in Purulia were investigated using SPI by Mishra and Desai (2005). Mishra et al. (2009), Ghosh (2019), Patra (2020) assessment drought occurrences using SPI and found that RLZ of West Bengal is more sensitive to severe to extreme drought. During the recent year, 2015 agricultural drought in Purulia indicated that around 35% and 76 % of the study area faced drought for Kharif and rabi season respectively (Palchaudhuri and Biswas 2020). The drought forecast indicated multiple severe to extreme droughts of appreciable duration during the near future in sub-humid RLZ (Shrestha et al. 2020). Thus high resolution spatial and temporal drought assessment plays a significant role for assessment of drought risk.

1.9 SCOPE OF THE STUDY

Drought being a regional occurrence has a serious effect on agriculture as well as the socio-economic condition of the region. A regional shift in drought occurrences from west to sub-humid southeast-central India has been observed with an increase in warming (Gupta and Jain 2018). In the past decade, drought has occurred in considerable frequency and intensity in RLZ of West Bengal (Nath et al. 2017). Short-term droughts are prevalent in this region during the monsoon season (Thomas et al. 2015). Around 70% of the total area of RLZ of West Bengal is under severe drought (Palchaudhuri and Biswas 2020). Sub-humid RLZ of India was more vulnerable to drought as this region is dominated by rainfed agriculture (Jha and Srivastava 2018). Around one-third of the rice area in sub-humid has been affected by drought which has increased in recent years (Birthal et al. 2015). Climate change poses major challenges to agriculture in the drought-prone region of RLZ of West Bengal with high poverty, lack of irrigation facility, undulating topography, low water holding capacity of soil and low productivity (Panda 2016).

Previous studies in Purulia have been applied rainfall-based single index (SPI) to assess meteorological drought and mainly focus on the long-term (annual and seasonal) behavior of drought. Meteorological drought is caused by a combination of rainfall deficit and temperature in the mode of evapotranspiration (Pathak and Dodamani 2020). A significant increase in evapotranspiration due to rising temperature would cause frequent drought in sub-humid RLZ during the last century (Gupta et al. 2020). The appropriate indicators for drought assessment can provide adequate preparedness to reduce drought risk. But preliminary studies would not focus on the evapotranspiration-based index for analyzing the effects of climate change on drought occurrence in sub-humid RLZ. The high resolution spatial and temporal drought assessment for long period is not emphasized to a great extent in the earlier researches undertaken. Vulnerability and Risk assessment in spatial scale, following the IPCC framework emerges as a necessity in this region prior to framing any drought adaptation strategy. Moreover, the changing characteristic (frequency, intensity and duration) of short-term drought and its impact at the micro-level in sub-humid RLZ is not yet reported and lastly, appropriate drought risk reduction measures remain to be explored and implemented.

All these above-mentioned causes have motivated me to undertake the present research in the sub-humid red and laterite zone of West Bengal. For the first time, three types of drought, comprising meteorological, agricultural and hydrological were studied at the same time using frequency, intensity, duration, and spatial-temporal evolution from 1901 to 2019. Specific interest was proposed to the monthly agricultural drought analysis during the crop growing (June to September) monsoon season and its impact on crop production and socio-economic conditions. The particular objective of this analysis is to accumulate the knowledge of net water deficit and the relative vulnerability of different blocks of the Purulia district from a systemic and finer aspect therefore enhancing the efficiency of adaptation strategies to reduce drought stress and increase crop yield at a local scale.

1.10 HYPOTHESIS IN THE STUDY

Based on the above understanding, the hypothesis of the present research has been formulated as follows:

High resolution spatio-temporal assessment of drought incidences in the sub humid red and laterite zones using geospatial technology and field investigations of agriculture and water use practices can aid in drought risk reduction through appropriate micro level adaptation to climate change.

1.11 RESEARCH QUESTIONS

The present research is mainly designed and developed to find answers to the following questions:

What changes in drought characteristics from the historical past are observed in the sub-humid RLZ of Purulia in the perspective of climate change?

What would be the most appropriate indices for assessment of droughts under climate change context?

What are the impacts of drought on crop production at the block level?

What is the relative vulnerability and risk of different blocks of the Purulia district to drought?

Will the present surface water resource, be able to meet the agricultural water requirement? If not, what are the appropriate spatial planning and adaptation options that may be undertaken for drought risk reduction?

1.12 OBJECTIVES OF THE STUDY

- To exemplify the changing characterizes of meteorological drought in terms of its duration, intensity, frequency and spatial-temporal evolution using SPI and SPEI during 1930- 2019.
- To assess the drought frequency , severity and extent in the RLZ of Purulia with rising temperature and changing rainfall pattern
- To identify monsoon season monthly agricultural drought in sub-humid RLZ (Purulia) at a sub-district level using MODIS derive multi drought indices (NDVI anomaly, VCI, TCI, TVDI and Z_{PET}) during 2005-2016 and SAR data (2015-2020).
- To analysis the impact of drought on crop production and socio-economic condition in the study area.
- To assess the net water availability/deficit (water demand vs availability).
- To assess the block-level vulnerability and risk to drought.
- To identify appropriate area-specific adaptation for drought risk reduction.

1.13 IMPORTANCE OF THE STUDY

Improve perception of spatiotemporal variability and trend of drought under current climate change scenario are necessary for selecting appropriate adaptation approaches. Rising temperature and changing rainfall even at a short distance are likely to intensify the regional drought occurrence. Therefore appropriate adaptation is required to reduce the drought risk at community level. Regional drought assessment is essential for area-specific adaptation and disaster prevention (Zhou and Liu 2016; Xu et al. 2015).

In sub-humid Purulia, drought is a recurrent phenomenon during the monsoon season (Asutosh 2019). The drought proneness of this region is increasing under climate change scenarios (Mishra and Desai 2005). The variations in drought characteristics under warming climatic condition are also significant for agricultural modification and water resource management. With the rising influence of climate change, droughts incidences in the RLZ region are observed with greater frequency and smaller duration (Bhunia et al. 2020). Agricultural drought is related to moisture deficit that harms the crops under cultivation – even without rainfall for 15days can harm several crops during certain times of the growing period. The present study identified short-term (monthly) spatiotemporal variability of drought in the RLZ of Purulia over the recent decade to deliver valuable suggestions to drought management and risk reduction. Even some of the adaptation measures have been implemented at community level with the help of a reputed NGO in the region to validate their efficacies for food security and water availability. The drought assessment in RLZ of Purulia will provide a tool for water managers under climate change scenarios and drought management plan well in advance to combat the drought risk. For the invention of preparedness for drought and water use plan at local level, information regarding spatiotemporal drought variability is appreciated. The high-resolution spatiotemporal drought assessment in RLZ of West Bengal can also assist decision-makers to design the drought risk reduction strategies on a sub-district level. Results of the study are expected to act as a guide in preparing people for sustainable natural resource utilization under drought situations.

1.15 THESIS OUTLINE

Chapter I deals with the general introduction, central queries, hypothesis along with the aims and objectives of the present research work. **Chapter II** elaborates the methodology, sampling strategy and research protocol adapted in the present research work. **Chapter III** describes the physiographic features as well as the socioeconomic condition of the present study area. **Chapter IV** assesses the changing characteristics of meteorological drought and portrays the high resolution spatiotemporal agricultural and hydrological drought variability in the perspective of changing temperature and rainfall pattern in the region. **Chapter V** details the impact of drought in sub-humid RLZ of Purulia at the sub-district level. **Chapter VI** illustrates water requirements for agriculture and water availability from various sources of irrigation vis a vis rainfall in sub-humid red and laterite zone of Purulia. **Chapter VII** Addresses the micro-level drought vulnerability and risk assessment following IPCC AR 4 and 5 frame work .**Chapter VIII** contains the feasible adaptation strategies for drought risk reduction .**Chapter IX** comprises the overall general discussion and conclusion drawn from all the outcomes of the present study.

CHAPTER II

RESEARCH METHODOLOGY

[This chapter represents the materials and methods exercised for the present study. The number of indices to assess the three types of drought i.e. meteorological, agricultural and hydrological and their impact on crop production and socioeconomic condition are discussed. Methods for the assessment of water resources in Purulia, block-level drought vulnerability and identifying the various area-specific drought mitigation strategies have been discussed. The procedures followed and formulae used to derive the parameters are detailed herein in this chapter. The collection of primary data and secondary data and processing is assimilated with the statistical analysis and using GIS and Remote Sensing data along with the statistical analyses conducted upon the data are also presented in the present chapter]

2.1 INTRODUCTION

Research methodology is fundamental for any research that contains research design, collection of data, analysis and interpretation of results. The conclusions of research depend on the methods used which are seleted on the type of data required to resolve the research queries. This chapter defines the research strategy, organization and steps to be followed for present research. The methodology applied in the data collection, processing and analysis utilized in the research are described in this chapter.

2.2 THE RESEARCH STRATEGY

Research plan provides a logical manual to guide a researcher in data collection, analysis and interpretation. Research strategy helps a researcher to collect appropriate data and analyze them in a proper way to address the principal research questions. Various methods for assembling data like observations, interviews, focus group discussion, participatory rural appraisal or secondary data surveys, quantitative and qualitative approaches have been applied in the present study.

2.3 FIELD RECONNAISSANCE

Before drawing the research strategy, a field survey has been done. The reconnaissance has also been conducted to make observations of the current physgraphic, socio-economic and drought condition in the study area.

2.4 DATA COLLECTED

The data functioned in this present study includes both spatial and non-spatial data. The data required for assessing drought has been arranged into three groups viz., meteorological, agricultural and hydrological. The data collected from different sources are described below.

2.4.1 Topographic Maps

Purulia district is covered by 9 topographic maps of Survey of India viz., 73E/15, 73E/16, 73I/2, 73I/3, 73I/4, 73I/6, 73I/7, 73I/8, 73I/10, 73I/11, 73I/12, 73J/5, 73J/9, 73I/14 and 73I/15 at 1:50,000 scale. From these maps, information such as the location, topography, water bodies, vegetation etc., was extracted and utilized as input to create database. These maps have also been employed as a base map of the remote sensing data.

2.4.2 Meteorological Data

The Indian Meteorological Department (IMD) generated gridded daily rainfall (0.25° latitude × 0.25° longitude) (Pai et al 2014) and daily temperature data (1º latitude × 1º longitude) (Srivastava et al. 2009) from 1901 to 2019 (120 years) were used as the input data in this study. Temperature data were re-gridded to the scale of rainfall using bilinear interpolation. The details of bilinear interpolation by the National Centre for Atmospheric Research (NCAR) are available at https://climatedataguide.ucar.edu/climate-data-tools-and-analysis/regridding-overview. The monthly rainfall and temperature data was used to analyze the monthly rainfall and temperature pattern and trend of monthly rainfall and temperature. Monthly rainfall and mean temperature were used to examine monthly and seasonal drought intensity, duration, frequency, and spatial extent in Purulia during the years 1901–2019 by calculating the SPI and SPEI.

2.4.3 Remote Sensing Data

LANDSAT (Landsat 4-5 TM C1 Level-1, Landsat 7 ETM+ C1 Level-1 and Landsat 8 OLI/TIRS C1 Level-1) data at 30m resolution and Sentinel-2 data at 10 m resolution (Band 2, 3, 4 and 8) have been used for produce the land use /land cover map at the district level and LISS IV (5.8m resolution) has been used for prepare block-level (village level) land use /land cover map. The LANDSAT and Sentinel-2 products are freely accessible from the USGS Earth Explorer *(https://earthexplorer.usgs.gov)* or USGS Global Visualization Viewer *(http://glovis.usgs.gov).* Satellite images were downloaded for the year March 2000, 2005, 2010, 2015 and 2020. The elevation map was developed from ALOS PALSAR DEM (Digital Elevation Model) at 12.5 m spatial resolution which was downloaded from Alaska Satellite Facility (https://search.asf.alaska.edu/) for November 2009.

Sentinal-1C SAR data were downloaded from The Copernicus Open Access Hub (https://scihub.copernicus.eu) which delivers open access to Sentinel-1 data in the years 2015 to 2020 for monthly agricultural drought monitoring.

MODIS (Moderate Resolution Imaging Spectrometer) data were used for assessing vegetation condition/health index (MOD13A3 Version 6) temperature condition (MOD11A2 Version 6) evaporation (MOD16A2 ET/PET) and soil moisture regarding agricultural drought analysis. MOD13Q1 data products of MODIS (Moderate Resolution Imaging Spectroradiometer- Terra) with 250 m 16 days composite, MOD11A2 8 days composite data products at 1 km resolution, and MOD16A2 8 days composite data products at 500 m resolution for 15 years (2005 to 2019) were downloaded (https://lpdaac.usgs.gov) to develop monthly indices for agricultural drought estimation.

2.4.4 Groundwater Level Data

Central Ground Water Board, Kolkata monitors groundwater in the State. Seasonal (Pre-Monsoon, Monsoon, Post-Monsoon Kharif and Rabi) groundwater level data for 1256 observation wells were accrued from Central Ground Water Board, Kolkata for the period from 1996 to 2019.

2.4.5 Agricultural Data

Agricultural data have been retrieved from the Bureau of Applied Economics & Statistics, Department of Statistics & Programme Implementation, Government of West Bengal and the data included the area is sown, production, and yield for each block in the district during the years 2000-2015. Details information related to irrigation such as different sources of irrigation and area irrigated by different sources of irrigation for each block in the district in the year 2000-2015 were accrued from the Bureau of Applied Economics & Statistics, Department of Statistics & Programme Implementation, Government of West Bengal.

2.4.6 Census Data and Block Development Works

Census data of 1991, 2001 and 2011 has been collected from the Office of the Registrar General & Census Commissioner, Ministry of Home Affairs, Government of India (http://www.censusindia.gov.in). The information associated with amenities like educational, elecricity, transport, housing condition, banks, etc., and the data regarding population and agriculture dependents (cultivators/agricultural laborers) were considered to group the blocks into spacific classes.

2.4.7 Ancillary Data

The secondary data including physiography, geology, soil and other necessary data were obtained from the different departments of the Government such as the Geological Survey of India, National Bourn of soil survey and Land use planning, Survey of India, etc. These maps have been used as a base map for the environment-related analyses of drought adaptation. Also, the researcher considered several reports, manuals and memoranda from various sources to get the details needed to justify the objectives of the study.

2.5 METHODOLOGY

The methodology section illuminates the detailed procedures to be followed for the present research.

2.5.1 Statistical Technique (Mann-Kendal Test) For Rainfall and Temperature Trend Assessment

The daily rainfall data have been analyzed to identify the rainfall patterns and trend for the monthly, seasonal and annual time scale across the Purulia. Monthly average maximum and minimum temperature data have been used for trend analysis of temperature for identification of the worming effect.

The rank-based Mann–Kendall (M–K) trend test, a nonparametric statistical test, is used frequently to evaluate significance in a monotonic increasing or decreasing trend in hydro-meteorological time-series (Sicard et al., 2010; Kumar et al., 2009) including a series of drought indices (Damberg and AghaKouchak, 2014). The M–K test had high computational efficiency and was not sensitive to measurement error, missing values, and outlier data. Therefore, in this study, M–K test has been used to detect the significant trends in rainfall, temperature and drought (SPI and SPEI time series). The formula is as follows (Liu et al. 2021):

$$\beta = mean\left(\frac{xj - xi}{j - i}\right), j > i$$

Where, xj and xi represent time series data, β > 0 implies the time series presents an upward trend, while β < 0 suggests the time series presents a downward trend.

The M–K trend test does not need to follow a normal distribution and. its statistical method is calculated as follows (Li et al. 2012):

$$z = \begin{cases} \dfrac{S}{\sqrt{Var\ (S)}} (S > 0) \\ 0\ (S = 0) \\ \dfrac{S + 1}{\sqrt{Var(S)}} (S < 0) \end{cases}$$

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(xj - xi)$$

$$sibn(\theta) = \begin{cases} +1, & if\ \theta > 0 \\ 0, & if\ \theta = 0 \\ -1, & if\ \theta < 0 \end{cases}$$

$$Var(S) = \frac{n(n-1)(2n+5)}{18}$$

Where, xj and xi represent time series data, when n ≥ 10, the test statistic S is approximately normally distributed. A positive Z value reveals an upward trend, while a negative Z value reveals a downward trend. |z| value greater than 1.65, 1.96, and 2.58 implies that the test has a significant trend with a reliability of 90%, 95%, and 99%, respectively. In this study, the M–K trend test at significance level 0.05 was used to determine the drought characteristic trend on different time scales (1 month, 3 months, and 12 months).

2.5.2 Slope

The slope map of Purulia has been composed using the digital elevation model (DEM) with 1m contour interval through the IDW interpolation method in Arc GIS 10.3v and verified by Toposheet map.

2.5.3 Soil texture and Geology

The maps of soil texture and geological were obtained from the National Bureau of Soil Survey and Land Use Planning, Kolkata and Geological Survey of India. Acquired maps have been scanned, rectified and digitized in Arc GIS software (10.5v).

2.5.4 Lineament

Lineaments were extracted from a high-resolution remote sensing data (Sentinel 2B). In the first stage “Principal Component Analysis” was performed for image enhancement using ERDAS 14 platform and “automatic line extraction” tool was operated than transform it to vector format by PCI Geometica 9.1.The final map was verified by geological map.

2.5.5 Watershed Delineation

Micro Watershed has been outlined from DEM by running flow direction using the “watershed” tool in ArcGIS 10.5v. Flow accumulation threshold has been used to delineate watershed, the pore point represents the junction of the stream network obtained from flow accumulation. Thereby a flow accumulation raster will be identified the minimum number of cells that contain a stream.

2.5.6 Land Use/Land Cover (LULC)

Land use /Land cover (LULC) maps of 2000, 2010 and 2020 have been prepared for the Purulia. Landsat TM (2000 and 2010) and high resolution (10 m) Sentinel 2A remote sensing data have been classified using supervised in ERDAS 14 software and field verification by GPS survey.

2.5.6a Supervised classification

ERDAS IMAGINE 14 software has been used for image processing of Landsat and Sentinel images. Training samples were chosen for each of the determined LULC by demarcating polygons in representative locations. The supervised maximum likelihood method has been used as a classification method. Three initial LULC maps were produced.

2.5.6b Classification accuracy assessment

Perform the accuracy assessment for specific classification is necessary if the resultant records are applied in change detection analysis (Usman et al. 2015). In the present study 385, ground truth data were considered as reference data collected by GPS survey. The reference and classification data were compared and statistically scrutinized by error matrices (Stehman 2012). Error matrix has been prepared using cross-tabulation of classified data against reference data (Rana and Suryanarayana 2020). The accuracy measures viz., Producer’s accuracy (quantify omission error), User’s accuracy (assess commission error) and Kappa statistics (overall and conditional) have been computed. Kappa coefficient was analyzed to measure agreement or accuracy (Rwanga and Ndambuki 2017). Kappa coefficient equal to 1 denotes perfect agreement where as a value close to 0 refers to the agreement is not good.

2.5.6c Detection of LULC changes

The post-classified rectified LU/LC maps were utilized for change detection for 2000–2020**.** The Post-classification comparison (PCC) method is the most accurate change detection technique (Thakkar et al., 2017). Land cover changes have been detected by comparing individually generated groupings of images from different years (Lu et al., 2004; Lu et al., 2012). The PCC reduces the difficulties related to multi-temporal images captured under varied atmospheric and environmental conditions (Coppin et al. 2004; Warner and Campagna 2009; Abd El-Kawy et al. 2011; Butt et al. 2015; Prasad and Ramesh 2019). The PCC method has located change with the additional advantage of indicating the nature of change

(Rawat and Kumar 2015; Mishra et al. 2020). In the present study, PCC was employed to compare and indentify differences among each category of LULC maps (i.e., 2000–2010 and 2010-2020).

2.5.6d Predicted Land Use /Land Cover

Markov model is combaind with cellular automata model which has been performed to predict land use/cover conversion at various scales (Weng 2002; Ye and Bai 2007; Guan et al. 2011). The CA-Markov approach is considered as a spatial change model in the current analysis (Mishra and Rai 2016). It can predict two-way conversions between the available LULC classes, while othe techniques such as Geomod only calculates one-way decrease/increase from one class to another (Pontius and Malanson 2005). Kumar et al. (2014) noticed that integrate CA-Markov model functioned better than regression-based models and provided more accurately results in predicting land-use transition.

2.5.6e Markov chain-cellular automata model

The conversion probabilities have been performed for the period 2010–2020 with the 2010 LULC base map to model LULC in 2020 using the integrated CA-Markov technique. The accuracy of the predicted 2020 LULC map was measured by the kappa statistic to estimate the coherence with the referenced LULC map of 2020. To accepte the layout in the spatial pattern in calculating the validity of the model the agreement and disagreement influences among the two maps were computed according to Halmy et al. (2015). Following the similar procedure, the CA-Markov approached was utilized to project LULC in the Purulia by 2030 and 2040. The LULC base map of 2020 was used in transition probability model for the period 2030–2040 and. The assessment was conducted by the IDRISI Selva$^{\copyright}$1987–2012 (Eastman 2012) platform.

The principal elements of CA-Markov model are as follows: (a) cells, (b) cell neighborhoods and (c) conversion rules. the cell is the essential component of the automation approach, i.e. the cell are regulated in a matrix. The conversion rule defines the status of each cell for the upcoming time depends on the recent status of that cell and its contiguous neighborhood cells. Thereafter, a land use\cover change suitability map is required and the dynamics should be defined in the system. The basic expression of the CA model can be expressed as:

$\mathcal{S}(t,t+1)=f(\mathcal{S}(t),N)$S(t,t+1)=f(S(t),N) where S refers states of definite cellular, t and $t+1$ denote the time instant and the coming time instant respectively, N indicates cellular field and f represents conversion rule of cellular states in local space.

2.5.7 Drainage

The drainage of the study area was delineated from DEM using flow direction and flow accumulation raster, and then the "Stream to Feature" tool was operated to convert it to line features (vector format). Drive drainage was validated by topographic sheets.

2.5.8 Depth of Ground Water Table

Depths of ground water level for observational wells (1256 points) in the study region were obtained from the Central Ground Water Board (CGWB) and were exported to point features in ArcMap10.5v. The spatial-temporal variability over the study area was generated using the "IDW" interpolation technique of the spatial analysis tool.

2.6 METHODOLOGY FOR ASSESSMENT OF METEOROLOGICAL DROUGHT

Meteorological drought is mainly related to the deficit precipitation from long-term average over an extended period of time. Generally meteorological drought precedes agricultural and hydrological droughst.

2.6.1 Standardized Precipitation Index (SPI)

Numerous meteorological drought indices have been formulated based on various parameters (Gupta et al. 2018; Guhathakurta et al. 2017). A detailed description of the drought indices has been obtained in Heim (2002), Mishra and Singh (2010) and Sivakumar et al. (2011). The Standardized Precipitation Index (SPI, Mckee et al. 1993) is one of the most extensively used among various drought indices. Tom Mckee, Nolan Doesken and John Kleist of the Colorado Climate Centre formulated the SPI in 1993. The SPI was invented to quantify the deficiency of precipitation for various time scales. These time scales reveal the impact of drought on the accessibility of the different water resources. The SPI is calcutated based on the long-term precipitation that is suited to a probability distribution, then converted to a normal distribution so that the mean SPI is zero for desired period (Edwards and McKee 1997). Negative SPI values signify less than long-term average precipitation while positive SPI values denote greater than average precipitation. Thereby, a drought begins when SPI is negative and extends the magnitude of -0.99 or less. The consequence terminates when the SPI value becomes positive. The drought duration has delineated by its onset and end. The minimum time scale of the SPI is one month. SPI is calculated from rainfall data in different time scales (1, 2, 3, 6, 9, 12, 24… months) to quantify drought intensity, duration, severity and frequency (Bhunia et al. 2020). The SPI has simple calculation and is decisively performed in space-independently compared with other indices (Bhunia et al. 2020). Thereby, SPI has already been considerably applied to detect drought conditions in numerous countries all over the world, such as Turkey (Dabanli et al. 2017), Iran (Awchi and Kalyana 2017), China (Li et al. 2020; Zhang et al. 2019; Xia et al. 2018; Zhang et al. 2017), Bangladesh (Rahman and Lateh 2016), Italy (Marini et al. 2019) and Ethiopia (Belayneh et al. 2016).

2.6.1a Computation of SPI

The SPI (McKee et al., 1993) calculation for a specific time scale and location requires a long-term monthly rainfall series. The first step is to find the probability density function that best describes the distribution of the rainfall data for a selected time scale. Here, the rainfall data (1930-2019) was fitted to a Gamma distribution function (Liu et al. 2021):

$$g(x) = \frac{1}{\beta\alpha\Gamma(a)} x^{a-1} e^{-\frac{x}{\beta}}, x > 0$$

Where α is the shape parameter, β is the scale parameter, x is rainfall, and the gamma function $\Gamma(a)$ is presented as (Zarch et al. 2015):

$$\Gamma(a) = \int_0^\infty x^{a-1} e^{-x} dx$$

The values of α and β were computed by the maximum likelihood method using the approximation of Thom (1958), as follows:

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right)$$

$$\beta = \frac{\bar{x}}{\hat{\alpha}}$$

$$A = ln(\bar{x}) - \frac{\ln(x)}{n}$$

Where n is the number of rainfall observations.

The cumulative probability for a given month was calculated by the following equation:

$$G(x) = \int_0^\infty g(x)dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^\infty x^{a-1} e^{-\frac{x}{\beta}} dx$$

SPI is an index that was developed to quantify rainfall deficit at different time scales, and thus it enables the assessment of drought severity. It was computed using the monthly rainfall data as defined by (Abramowitz and Stegun 1965; Zarch et al. 2015):

$$SPI = S \frac{t - (c2t + c10) + c0}{[(d3t + d2)t + d1]t + 1.0}$$

$$t = \sqrt{ln \frac{1}{G(x)^2}}$$

Where x is rainfall and G(x) is Γ function related rainfall probability distribution, S is the positive and negative coefficient of cumulative probability distribution, when G(x) > 0.5, S = 1 and when G(x) ≤ 0.5, S = -1. c0 = 2.5155, c1 = 0.8028, c2 = 0.0103, d1 = 1.4327, d2 = 0.1892, d3 = 0.0013. Positive SPI values signify greater than average rainfall (wet condition), and negative values imply less than average rainfall (dry condition). The present study calculates SPI at1, 3 and 12-month time scales represent monthly, seasonal and annual droughts respectively. Table 1 shows the different categories of drought intensity according to the SPI values as given by Mckee et al. 1993.

Table 2.1 Classification of drought category

SPI/ SPEI values	**Drought category**
0 to -0.99	Mild drought
-1 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
< -2	Extreme drought

Source: McKee et al.(1993)

2.6.2 Standardized Precipitation Evapotranspiration Index (SPEI)

The main shortcoming of SPI is that it exercises only rainfall data and does not investigate other significant variables, like temperature. Although rainfall is the obvious fundamental factor for drought in sub-humid regions, but recent studies have demonstrated the significance of temperature in illuminating recent trends in water resources of this region (Gupta et al. 2020; Nath et al. 2017, 2018). The proximal drought index must conside the variations in moisture demand affected by raised surface temperature (Pathak and Dodamani 2019). The drought index, standardized precipitation–evapotranspiration index (SPEI) has been popular (Begueria et al., 2010; Vicente-Serrano et al., 2010a, 2010b) to measure the drought condition in the context of increasing surface warming in recent time (Monish and Rehana 2020; Gupta et al. 2018). The SPEI considers both temperature and precipitation, thus, assumed to be a superior approach for investigating the influences of climate change on drought occurrence (Shaik et al. 2020).

2.6.2a Computation of SPEI

SPEI takes into account both rainfall and temperature components and presents the influence of evaporation variations, which is more responsive to the drought occurrences caused by rising temperature (Liu et al. 2021). Under the warming condition, SPEI can better exhibit the dry and wet conditions owing to its combination of rainfall and temperature (Zhao et al., 2017). The Log-logistic distribution provided a better fit for SPEI (Hernandez and Uddameri, 2014). The SPEI is obtained by normalizing the water balance into the Log-logistic probability distribution. The Log-logistic probability distribution function can be conveyed as (Liu et al. 2021):

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-\gamma}{\alpha}\right)\left[1+\left(\frac{x-\gamma}{\alpha}\right)\right]^{2}$$

Where α, β, and γ denote scale, shape, and origin, respectively. The following equation represents the probability density function:

$$F(x) = \left[1+\left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1}$$

In the present study procedure for calculation of SPEI has been adopted in Vicente-Serrano et al. (2010a). The SPEI can be expressed as:

$$SPEI = W - \frac{C0 + C1W + C2W^{2}}{1 + d1W + d2W^{2} + d3W^{3}}$$

When $P \leq 0.5$, $= \sqrt{-2\ln(P)}$, and when P > 0.5, $W = \sqrt{-2\ln(1-P)}$, C0 = 2.5155,C1 = 0.8028, C2 = 0.0203, d1 = 1.4327, d2 = 0.1892, d3 = 0.0013. The measures of the drought intensity classifications according to SPEI are the same as the SPI value (Table 2.1).

2.6.3 Analysis of Drought Characteristics

Drought characteristics that include drought intensity, frequency, and duration, have been defined using the runs theory proposed by Yevjevich (1967). The drought intensity was calculated by the following formula:

$$S = \frac{\sum_{n=1}^{T}\left[S_{SPI/SPEI} - K\right]}{T}$$

where S refers to drought intensity, $S_{\mathrm{SPI/SPEI}}$ is SPI or SPEI value below the threshold, K is a drought threshold value, set to be less than or equal to -0.99 in the present study, means the drought level is moderate drought, T refers the duration of the drought. The drought frequency calculation formula is as follows (Liu et al. 2021):

$$P = \frac{n}{N} * 100\%$$

Where N denotes the time and n signifies the number of droughts during the time.

2.7 METHODOLOGY FOR IDENTIFICATION OF AGRICULTURAL DROUGHT

Advances in satellite derive data of different resolutions are reliable, and can also be used for agricultural drought assessment (Sanchez et al. 2018; Dutta et al. 2015). High-resolution Spatio-temporal remote sensing data have provided new directions in agricultural drought monitoring (Yoon et al. 2020; Zhang et al. 2017). MOIDS data has been widely used to derive indices that represent agricultural drought intensity with spatiotemporal variation (Faisol et al. 2020; Kukunuri et al. 2020; Reddy et al. 2020).

Numerous drought indexes have been formulated using MODIS data such as Normalized Difference Vegetation Index (NDVI), NDVI anomaly, Vegetation Condition Index (VCI), Temperature Condition Index (TCI), TVDI and Z_{PET} have been acknowledged globally for characterizing agricultural drought in sub-humid regions with variable ecological conditions (Surendran et al. 2019; Junxia et al. 2018; Zhang et al. 2017).

NDVIanomaly and VCI generally give information on biophysical responses to droughts (Kogan, 1995; Javed et al. 2020). Soil moisture is believed to be one of the significant indicators of agricultural drought (Mao et al. 2017). Temperature and associate evapotranspiration have been proved to be a major cause for the occurrence of agricultural drought in various studies (Han et al. 2020; Hu et al. 2019). Mandal and Chakrabarty (2013) concluded that temperature and evapotranspiration are highly variable in Purulia. Z_{PET} index can provide valuable information on the spatial extension of drought conditions and evapotranspiration (Anderson et al. 2008; Hao et al. 2015). The widely used satellite-derived drought indices like TCI and TVDI responsive to the temperature and soil moisture (Seiler et al. 1998; Chen et al. 2015; Zhang and Jia 2013; Hao et al. 2015) were applied successfully to assess monthly drought conditions. Many studies (Jaio et al. 2019; Zhang et al. 2017) indicated the usefulness of multi drought indices over any single or integrated index for short-term agricultural drought assessment in the warm wet regions (Rhee et al. 2010). Thus, in the present study MODIS derive indices like NDVIanomaly, VCI, TCI, TVDI and Z_{PET} have been used for monthly drought assessment in the monsoon season.

2.7.1 Normalized Difference Vegetation Index

NDVI reflects the vegetation conditions like health, density etc and is determined from red and near-infrared spectral radiance of the satellite image using the formula:

NDVI= (NIR-R) / (NIR+R)

Where, NIRand R denote near infrared and Red band respectively. NDVI is a nonlinear function that ranges varies between -1 and +1. Furthermore, NDVI is effective for estimating net primary production of vegetation, crop growth conditions and crop yields, thereby widely used for agricultural drought monitoring, detecting weather impacts on agriculture (Ramesh et al. 2003).

2.7.2 NDVI Anomaly

Agricultural drought can be analysed to assess vegetation conditions through the NDVI anomaly (Meroni et al. 2019). NDVI anomaly is the easiest and universally utilized NDVI-based approach for detecting and classifying agricultural drought (Nanzad et al. 2019). NDVI anomaly was calculated based on NDVI values. Maximum NDVI and long-term mean maximum NDVI at a given time were computed to derive NDVI anomaly (Nanzad et al. 2019). NDVI anomaly was then acquired by the following equation for each grid cell in the study area for the period 2005 to 2019 (Kogan 1990):

$$\text{NDVI anomaly} = \frac{NDVI_{max} - Mean\ NDVI_{max}}{Mean\ NDVI_{max}} * 100$$

Where, NDVI max is Maximum NDVI of the month and Mean NDVI max is long-term mean maximum NDVI of the month of the total range of the year. The deriving NDVI anomaly was reclassified into five drought intensity classes based on Table 2.2

Table 2.2 NDVI Anomaly Based Drought intensity Class

Drought Categories	NDVI anomaly
Extreme Drought	Above -80
Severe Drought	-60 to -80
Moderate Drought	-40 to -60
Mild Drought	0 to -40
No Drought	Above 0

2.7.3 Vegetative Condition indices

Vegetative Condition Index is suitable for detecting drought conditions with superior spatial details during the monsoon season (Dutta et al. 2015). VCI is derived from long-term minimum and maximum NDVI (Kogan 1990) and expression as:

$$VCI = \frac{NDVI_j - NDVI_{min}}{NDVI_{max} - NDVI_{min}} * 100$$

Where NDVImax and NDVImin exemplify maximum and minimum NDVI of each pixel computed for each month and j symbolizes the observed month. VCI range varies from 0 to 100 which reflect the agricultural drought condition from extreme to normal (Kogan 1995; Kogan et al. 2002). After calculating the VCI, The resulted image of VCI were classified into five classes based on drought intensity classification Table 2.3

Table 2.3 VCI Based Drought intensity Class

Drought Categories	VCI
Extreme Drought	Below 10
Severe Drought	10 to 20
Moderate Drought	20 to 30
Mild Drought	30 to 40
No Drought	Above 40

2.7.4 Temperature Condition Index

Temperature Condition Index has been proposed by Kogan (1997) to detect vegetation response to temperature i.e. higher the temperature more extreme the drought. Relative changes in vegetation condition due to thermal stress can be investigated by the TCI (Kogan, 1995, 2000, 2002). The TCI is estimated as:

$$TCI = \frac{LST_{max} - LST_{i,j}}{LST_{max} - LST_{min}} * 100$$

Where, $LST_{i,j}$ is the value of month i and year j, LSTmax and LSTmin are the multi-year average maximum and minimum value of monthly LST over the period 2005-2015. The TCI value of 50% indicates the normal condition or no drought and different intensities of drought are denoted by TCI values under 40% (Table 2.4).

Table 2.4 TCI Based Drought intensity Class

Drought Categories	TCI
Extreme Drought	Below 10
Severe Drought	10 to 20
Moderate Drought	20 to 30
Mild Drought	30 to 40
No Drought	Above 40

2.7.5 Temperature Vegetation Dryness Index

Agricultural drought has been efficiently detected using Temperature Vegetation Dryness Index (TVDI) (Patel et al. 2019). Numerous researchers have been applied TVDI for quantification and real-time monitoring of spatial extent and intensity of drought in the monsoon season. TVDI is determined from NDVI-LST triangle space. The scatter plot of NDVI-LST often displays a negative correlation and the outcomes of NDVI-LST triangle space provide information on soil moisture condition (Son et al. 2012). The cells situated within the NDVI-LST triangle space signify a varying intensity of agricultural drought.

$$\mathrm{TVDI} = \frac{\mathrm{LST}_{i,j} - \mathrm{LST}_{NDVI\mathrm{Min}_{i,j}}}{\mathrm{LST}_{\mathrm{NDVIMax}_{i,j}} - \mathrm{LST}_{\mathrm{NDVIMin}_{i,j}}}$$

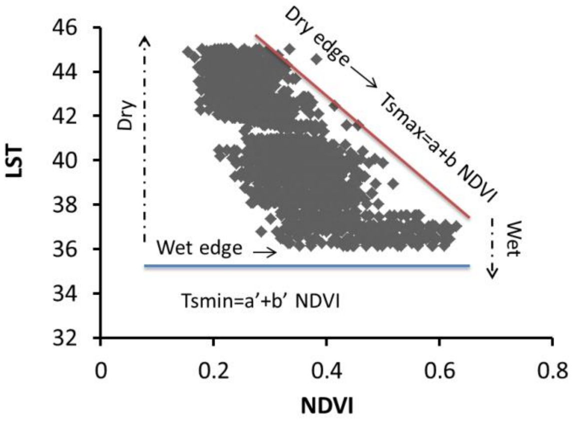

Fig 2.1 NDVI-LST triangle space.

Where $LST_{NDVIMax}$ and $LST_{NDVIMin}$ are maximum and minimum surface temperatures in NDVI-LST triangle describing the wet and dry edge at the same NDVI interval of the month i and year j. LST is the observed surface temperature of the month i and year j. The scatter plot of NDVI and LST was composed using ENVI image processing software. The wet and dry edges were obtained from this scatter plot by assorting both maximum and minimum temperature for each interval of NDVI. The LST_{Max} will be calculated (the upper straight line in the NDVI-LST triangle space shown in Fig. 2.1) from linear regression of the dry edge ($LST_{Max} = a + b \times NDVI$) based on maximum LST for the same NDVI. Considering the results of Patel et al., (2009) on the NDVI–LST trapezoid, the wet edge is also linearly regressed in this study ($LST_{Min} = a' + b' \times NDVI$). In the linear regression, a, a' are the intercept and b, b' are the slope of the wet and dry edges. TVDI ranges from 0 at the wet edge indicating maximum evapotranspiration resulting in higher intensity of drought and 1 at the dry edge indicating limited less water stress.

2.7.6 Standardized Potential Evapotranspiration (Z_{PET})

Potential Evapotranspiration (PET) can indicate the degree of water deficit and has been widely used for agricultural drought assessment (Anderson et al., 2008, 2011). Agricultural drought has been efficiently detected in a timely way by Z_{PET} (Zhang et al., 2019). PET was standardized with the fllowing equation (Zhang et al., 2019):

$$Z_{PET} = ({}_{PET} - \bar{y}_{PET}) / \delta_{PET}$$

Where Z represents the standardized PET, PET denotes the ET/PET for the month of A. ȳ and δ denotes the mean and standard deviation of ET/PET of the month A during 2000–2015 respectively.

Table 2.5 Drought intensity-based categories by Z_{PET}

Drought Categories	Z_{PET}
Extreme Drought	Above -2.0
Severe Drought	-1.5 to -1.99
Moderate Drought	-1 to -1.49
Mild Drought	0 to -0.9
No Drought	Below 0

2.7.7 SAR

The Sentinel-1A data have been processed using the Sentinel Application Platform (SNAP) Sentinel-1 Toolbox software developed by ESA. By image-processing techniques, the radiometric calibration was applied to convert the pixel data to backscattering values of sigma naught (dB). The Range-Doppler terrain correction process adjusted the geometric distortion and projected range to the WGS84 earth ellipsoid model. Then the refined Lee filter was performed to remove speckle noise in SAR data (Chang et al. 2021).

The variation of rice plants at different growth stages is reflected in the SAR backscatter value (Verma et al. 2019; Son et al. 2021). Numerous studies (Bazzi et al. 2019; Mansaray et al. 2017; Nguyen et al. 2016) concluded that the characteristics of backscatter (dB) of the growth period are also an important feature to detect rice growth trend. The rice growth detection accuracy of VH polarization is much better than that of VV polarization (Chang et al. 2021). Compared with VV, VH is more representative of the actual rice growth structure and can provide more information in paddy distinguishing (Verma et al. 2019; Bazzi et al. 2019; Mansaray et al. 2017). Therefore, VH polarization was considered in the present study, and rice growth curves were produced based on the monthly SAR backscatter values of the rice growth period (June to September) from 2015 to 2020. The backscatter variation curves were produced by using 300 rice fields randomly selected from the ground truth data. In addition, Average Normalized Backscatter (ANB) was also performed to identify agricultural drought from the constructed rice growth trend.

2.7.7a Average Normalized Backscatter (ANB)

The trend of rice growth developed by the value of average normalized backscatter is coherent with the rice growth cycle from sowing, heading to maturity. The ANB was computed by (Chang et al. 2021):

$$ANB = \frac{1}{T_{end} - T_{min}} \int_{T_{min}}^{T_{end}} \frac{\sigma(t)}{\sigma_{min}} dt$$

Where, Tmin and Tend represent the corresponding dates of the minimum backscatter point and endpoint in the rice-growing season, respectively. The average normalized backscatter (ANB) is the ratio of the integrated area of the normalized growth curve to the growth period.

2.8 METHODOLOGY FOR IDENTIFICATION OF HYDROLOGICAL DROUGHT

Standardized Water-Level Index (SWI)

Standard Water-Level Index was intended to monitor anomalies in ground-water level as a correspondent of aquifer-stress (Bhuiyan 2004). SWI can measure decline and recharge of water-table, thus it is used an indicator of hydrological drought. The SWI is interpreted by long-tern seasonal ground-water level. For standardization, an incomplete gamma function has been operated same as SPI. SWI is expressed by the following formula:

$$SWI = \frac{W_{ij} - W_{im}}{\sigma}$$

Where, W_{ij} refers seasonal water level for the wells, W_{im} is the seasonal mean ground water level during the period 1996-2019, and σ indicates its standard deviation. As the water level is measured from the surface to downstairs in observation wells, thus positive anomalies represent the drought condition (water stress) and negative anomalies are normal condition (Table 2.6). Point values of SWI corresponding to the wells have been interpolated to produce the spatial variations of hydrological drought.

Table 2.6: Drought intensity-based categories by SWI

SWI values	Drought category
0 to 0.99	Mild drought
1 to 1.49	Moderate drought
1.5 to 1.99	Severe drought
< 2	Extreme drought

Source: Bhuiyan (2004)

2.9 ESTIMATION OF CROP FAILURE

The present study also used the Crop Failure Index of Simelton et al., (2009), denoted by

Crop failure index= Ā / A

Where Ā denotes average production for 16 years (2000-2015) and A refers to the observed production of a particular year. A score >1 for the above index indicates below-normal production or crop failure in a particular year.

2.10 FARMERS' PERCEPTION OF DROUGHT IN PURULIA: A FIELD EXPERIMENT

In The present study, qualitative research using key informant semi-structured interviews and focus group discussions were carried out to study the perception of drought and its impact on community livelihood at 12 villages of Kashipur block in Purulia district where the villagers are primarily engaged in rainfed mono-crop farming.

2.10.1 Field Survey

Field studies and household survey has an important role in research on the impact of climate especially at the micro level (Bryan et al. 2013; Raymond and Robinson 2013). These studies provided consistent local information (Raymond et al. 2010; Lei et al. 2014) and first-hand knowledge for decision-makers by illuminating peoples' actual problems and needs. For the present study, chose 12 villages of drought-prone Kashipur block to execute a detailed investigation. The field surveys were conducted from 2015 to 2019 to collect primary data through in-depth interviews or questionnaire surveys on villagers, farmer households, and farm-level land use investigations.

2.10.2 In-Depth Interviews with the Village Managers and Project Managers and Volunteers of NGO

This study firstly organized face-to-face interviews and group discussions with the village leaders, project managers and volunteers of DRCSC (NGO) and villagers to acquire an general knowledge of the village conditions. Second, the older villagers were preferred as important informants for delivering historical knowledge about drought. The open-ended questions for village managers and farmers focused largely to examine: a) what are the changes in climatic variables (rainfall and temperature) and drought have noticed by villagers' during the recent periods? b) how the changing climate and recurring droughts may influence local agriculture and c) how the government, NGOs and farmers are tending to deal with droughts.

2.10.3 Household Survey

Semi-structured questionnaires were accomplished with farmer households during September 2018 to determine farmers' perceptions of drought and explore the effects of warming and drought on local agriculture. A total of 550 marginal farmer householders of Kashipur were selected for interview using a random sampling approach that comprises different genders, age groups, and economic levels. The open-ended questions for the farmers were related to a) What does the word “drought” mean to you? b) How did you recognize drought? c) What do you think about the causes of drought? d) Have you experienced any droughts in the last 10 years? What years? Did your crops get damaged during drought years? Which year most affects your farming practice? e) Do you think droughts will occur more or less frequently in the future in your locality? f) Suppose you had a drought this year. What would expect next year? Based on designed questionnaires, we recorded farmers' think about drought and the frequency, duration, intensity, probability and impact of the recent drought years.

2.11 ESTIMATION OF WATER DEMAND FOR AGRICULTURAL USE

2.11.1 Description of CROPWAT (v8.0)

CROPWAT is a decision-support platform which includes several processes, developed by the FAO (Food and Agriculture Organization, Land and Water sector. http://www.fao.org/landwater/databases-and-software/cropwat/en/) to compute reference evapotranspiration (ET0, crop water requirement), and irrigation water requirement (IR), using climatic, soil and crop data (Munoz and Grieser 2006).

Climatic parameters (rainfall, maximum and minimum temperature, humidity, wind speed, sunshine and evapotranspiration) for 30 years (1970–2000) were obtained from the CLIMWAT 2.0 which offers observed climatic data for range of climatological stations worldwide and to be used in combination with the CROPWAT software for calculate the crop and irrigation water requirement for various crops (Clarke et al. 2001). The information related to crops including crop coefficient, rooting depth, critical depletion, yield response factor, and length of plant growth stages for rice, wheat, maize, pulses, oilseed and potato were taken from the FAO Manual 56 and which is also contained to the CROPWAT model (Clarke et al. 2001). Planting dates were taken from the Agricultural department (Agriculture Contingency Plane, 2011). The soil data acquired from the FAO CROPWAT 8.0 model comprise detailed information on the soil near the climatic station. The United States Department of Agriculture (USDA) soil conservation (S.C.) approach was used in the study.

2.11.2 Reference Evapotranspiration (ET0)

The crop water requirement defines as the amount of water is lost from a cropped field by the evapotranspiration (ET). The CROPWAT model uses the FAO Penman-Monteith method for the computation of the ET (Smith et al. 2002). Evapotranspiration is the result of a combination of both transpiration (water lost from the plant surface) and evaporation (water lost from the soil surface), that happen at the same time (Feng et al. 2007).

Evapotranspiration is conveyed by the rate of ET in mm/day. Crop water requirement is estimated from crop evapotranspiration (ETc) which has been computed by the following equation (Pereira et al. 2015):

$$CWR_i = ET_i = \sum_{t=0}^{m} (ET_{0t} * K_{ct})$$

Where, CWR is crop water requirement for crop i for the entire growing season. m is total effective crop growth period in days, t is the time interval in days, ET0t is the reference crop evapotranspiration and Kct is the crop coefficient.The ET_0, represents an integration of the effects of four essential qualities that differentiate the crop from reference grass, and it reflectance of the crop–soil surface, crop height, canopy resistance, and evaporation from the soil. the Kc for the crop will vary over the developing period which can be divided into four distinct stages of crop development: initial, mid, and late-season (Allen et al. 1998).

2.11.3 Irrigation Water Requirement (IR)

Irrigation water requirement refers as the amount of water needed for efficacious crop growth. For rice, the irrigation necessities start immediately after transplanting (or a week after direct seeding) and continue till the terminal drainage starts which is generally represented as the normal irrigation period. For other crops, irrigation beginnings as soon as planting start and continue as long as water is required by the crop (Valiantzas 2013). Irrigation water requirement (IR) is expressed by the formula:

$$IWR_{nc} = \sum [(K_c * ET_O) + P - (R_e + GW_c)]$$

Where IWRnc denote the irrigation water requirement for normal growth period (from sowing/transplanting to last watering) (mm), P, Re and GWc are deep percolation loss, effective rainfall and groundwater contribution during the growing period respectively.

2.12 ESTIMATION OF WATER AVAILABILITY FROM DIFFERENT SOURCES OF IRRIGATION

Irrigation water availability from tanks has been evaluated by subtracting the minimum water requirement for evaporation loss, survival of fish and domestic use (45%) from the water holding capacity in tanks. The water holding capacity of tanks has been calculated based on the number of tanks for irrigation (District statistical handbook, 2015), average surface area (block-wise average tank area has been delineated from LISS-IV image) and average depth (by field survey). Water availability from the Open dug well (1.6 m^3/h/day) and RLI (15 m^3/h/day) (SWID) have been estimated using their number, water yield capacity and time of operation (180 days). Water availability from farm ponds have been measured by their number, area ($3*3m^2$) and depth (2 m).

2.12.1 Estimation of Surface Runoff

Micro Watershed was delineated from DEM using hydrology tools in Arc GIS software (10.5 version). Land use land cover map of Purulia district in 2020 was composed of sentinel 2 data by supervised classification method using ERDAS 14 software. The area under different land categories has been calculated and verified by GPS survey. The scanned soli map of Purulia was rectified and digitized in Arc GIS 10.5v.

The assessment of direct runoff from rainfall followed the Natural Resources Conservation Service Curve Number (NRCS-CN) (SCS, 1985) protocol. The curve number (CN) is a consistent and conceptual technique for evaluating surface runoff (Zhan and Huang 2004; D'Asaro and Grillone 2012). The GIS-based runoff modeling involved analyzing the soil maps and land use\land cover maps, and the rainfall data. The equation for estimating runoff using CN is:

$$Q = \frac{(P-\lambda S)^2}{P+(1-\lambda)S} \qquad \text{for } P > \lambda S$$

where Q is direct surface runoff, P is rainfall (mm), and S is potential maximum retention after runoff begins, and λ is the initial abstraction coefficient (surface depression storage) which is a constant value of 0.2. *S* is obtained from a mapping expression conveyed in terms of *CN* as:

$$S = \left(\frac{25400}{CN}\right) \quad -254$$

The *CN* is determined from a table, based on land use/land cover, Hydrological Soil Groups (HSGs), and AMCs (Satheeshkumar et al. 2017). The lower CN (which ranges from 0 to 100) represents a lesser proportion of surface runoff (Kumar and Jhariya 216). Satheeshkumar et al. (2017) suggested that depending on the infiltration rate, HSG can be of four types (A, B, C, and D) (Table 2.7).

Table 2.7 Hydrological Soil classification (USDA 1974)

Hydrological Soil	Soil texture	Runoff Potential	Water transmission	Infiltration
Group A	Deep, well drainage, sand and gravels	Low	High	>7.5
Group B	Moderately deep, well drainage	Moderate	Moderate	3.8 -7.5
Group C	Shallow sandy loam, moderate texture	Moderate	Moderate	1.3 - 3.8
Group D	clay soil	High	Low	<1.3

The categorization of AMC involves three levels (I, II, and III), rendering to the precipitation limits for inactive and cropping seasons. AMC II is referred to as average moisture condition and AMC I and III are denoted as dry and wet conditions, respectively. To adjust CN for dry, wet, and average moisture conditions, the AMC condition has been categorized based on the sum of rainfall in a 5-day duration (Singhai et al. 2019) (Table 2.8).

Table 2.8 Antecedent soil moisture classes (AMC)

AMC Group	Soil characteristics	5 days antecedent rainfall (mm)	
		Dry season	Wet season
I	Dry	<13	<36
II	Average	13 - 28	36 - 53
III	Wet	>28	>53

Equivalent CN of AMC I and III have been computed by the following expressions (Satheeshkumar et al. 2017):

$$CN(I) = \frac{CN(II)}{2.281 - 0.0128\, CN(II)}$$

$$CN(III) = \frac{CN(II)}{0.427 + 0.00573\, CN(II)}$$

2.12.2 Regression Analysis

A linear regression analysis was performed using the annual rainfall as an independent variable and the annual recharge as a dependent variable. Statistical analysis was carried out to assess the validity of the NRCS runoff model (Santhanam and Abraham 2018; Abraham and Mathew 2018; Karunanidhi et al. 2020).

2.12.3 Significant Test

The significant difference between regression estimated runoff and runoff estimated by the NRCS model was tested by t-test (Abraham and Mathew 2018).

2.13 DROUGHT VULNERABILITY AND RISK ASSESSMENT

2.13.1 Data Sources

Secondary data on different climate variables, crops, irrigation, land use and socio-economic condition for the 20 blocks of Purulia were chosen based on the obtainability of data and comprehensive literature review (Saha et al. 2021; Balaganesh et al. 2020; Singh et al. 2019; Sendhil et al., 2018; Piya et al., 2016; Rao et al., 2016; Maiti et al., 2015; Varadan and Kumar, 2015). Meteorological data such as gridded monthly rainfall and temperature data were collected from the IMD for a period of 120 years (1901 to 2019). Block-level crop production and irrigation data such as area and yield across Purulia, and socio-economic-related data were collected from District statistical Handbook (2000-2015).

2.13.2 Methods

In the present study, vulnerability and risk indices have been composed at the sub-district (block) level using the dimension reduction approach – ‘Non-Linear Principal Components Analysis’ (NLPCA) by the Statistical Package for the Social Sciences (SPSS) software version 22. PCA is the multivariate statistical process used to identify the fewer and more rational set of uncorrelated factors from an extensive number of variables (Uddin et al. 2019; Das et al. 2020; Ghose et al. 2021; Yu et al. 2021). The assessment of vulnerability and risk involved a large number of data with varied scales of measurement, NLPCA is applied to deal with the maxed scaling of the components (Rajes et al. 2018).

2.13.3 Selection of Components

Based on an extensive appraisal of the literature and obtainable secondary data, 33 hypothetically imperative and policy-relevant biophysical and socioeconomic factors have been chosen under nine major sections: climate variability, hazards, demographic profile, livelihood activity, basic facilities, agricultural livelihood strategies, socio-economic status, water resource and land use (Tables 2.9). The first two climatic elements are associated with the external component which is considered as ‘exposure’ and ‘hazard’ in the AR4 and AR5 respectively. Climatic variability was quantified by the mean standard deviation of the monthly rainfall, maximum and minimum mean temperatures over the past 120 years (Sendhil et al. 2016; Sendhil et al. 2018). Frequent drought and associated crop failure are the major environmental stressors in Purulia therefore drought frequency, affected area and crop failure have been used to determine the second major component (Maiti et al. 2015; Rai et al. 2017; Balaganesh et al. 2020). Drought characteristics have been evaluated using SPEI. Details on the SPEI and crop failure index are given in Beguería et al. (2010) and Simelton et al. (2009).

Table 2.9 A complete description of the preferred components (33 components) for drought vulnerability and risk analysis in Purulia

Variables	Explanation of variables	IPCC contributing factors		References
Average annual rainfall	Standard deviation of the average monthly rainfall for 120 year	E1		Sendhil et al. (2018)
Annual maximum temperature	Standard deviation of the monthly average maximum temperature of 120 year	E2		Sendhil et al. (2016)
Annual minimum temperature	Standard deviation of the monthly average minimum temperature of 120 year	E3		Sendhil et al. (2015)
Evapotranspiration	Standard deviation of the average monthly evapotranspiration for 120 year	E4		Balaganesh et al. (2020)
Drought frequency	No of extreme drought occurrences over 90 years	E5	H1	Rai and Singh (2017)
Drought effected	Percentage of agricultural area	E6	EX1	Rai and Singh

area	affected by extreme drought			(2017)
Crop failure	Percentage of crop production failure by extreme drought	E7	EX2	Kamali et al. 2018
Population density	Number of people per square kilometre	S1	EX3	Rao et al. (2016)
Female population	Percentage of female population to total population	S2	EX4	Das et al. 2020
Child mortality rate (above age group 5)	No of child death above age group 5	S3	S1	Sharafi et al. 2020
Scheduled tribes	Percentage of scheduled caste and scheduled tribe population to total population	S4	S2	Rajesh et al. 2018
Scheduled caste	Percentage of scheduled caste and scheduled caste population to total population	S5	S3	Rajesh et al. 2018
Literacy rate	Percentage of literates to the total population age 7 years and above	AC1	AC1	Mohmmed et al. (2018)
Livestock population	Percentage of population have livestock	AC2	AC2	Balaganesh et al. (2020)
Fisheries	Percentage of population engaged in fisheries to total population	AC3	AC3	Mohmmed et al. (2018)
Marginal workers	Percentage of marginal workers to total working population	S6	S4	Balaganesh et al. (2020)
Non-workers	Percentage of non-workers to total population	S7	S5	Das et al. 2020
Small and Marginal farmer	Percentage of small and marginal farmers to total cultivators	S8	S6	Balaganesh et al. (2020)
Cultivator and Agricultural labour	Percentage of cultivators and agricultural labours (dependent on agriculture) to total working	S9	S7	Hoque et al. (2020)

Main workers	Percentage of main-workers to total population	AC4	AC4	Balaganesh et al. (2020)
Percentage of households with access to safe drinking water	No. of mouzas having drinking water facilities	AC5	AC5	Fahad and Wang (2018)
Electricity	Percentage of mouzas have electricity connection	AC6	AC6	Fahad and Wang (2018)
Ration shop	Number of ration shop	AC7	AC7	Rajesh et al. 2018
Fertiliser	No. of fertilizer depots	AC8	AC8	Mohmmed et al. (2018)
Irrigated area	Percentage of net cropped area under irrigation	AC9	AC9	Balaganesh et al. (2020)
Crop diversity (number of crops)	number of crops cultivated in a year	AC10	AC10	Mohmmed et al. (2018) Palanisami et al. (2010),
Seed store	Number of seed store	AC11	AC11	Sharafi et al. 2020
Crop water stress	Water deficit from total crop water requirement	S10	S8	Zhao et al. 2020
Ground water level fluctuation	Deviation of seasonal ground water level from long term average	S11	S9	Balaganesh et al. (2020)
Water body	Percentage of water body to the total geographical area	AC12	AC12	Zhao et al. 2020
Fallow Land	Percentage of fallow land to the total geographical area	S12	S10	Sharafi et al. 2020
Upland	Percentage of upland to the total geographical area	S13	S11	Kamali et al. 2018
Forest	Percentage of forest to the total geographical area	AC13	AC13	Fahad and Wang (2018)

The other seven major components have sub-factor that includes sensitivity and adaptive capacity in AR4 and AR5. Tribal populations are more susceptible due to low incomes and larger dependence on natural resources (Maiti et al. 2017). Farming population whose livelihood mainly dependent on agriculture are severely effected by drought (Ghimire et al. 2010; Jaganatha et al. 2021). In the socio-economic aspect, Marginal and small cultivators, illiterates and females are economically underprivileged people usually considered to be the greatest susceptible to climate change impacts (Yu et al. 2021). On the other hand, literate people and main workers can acquire early warning information and can plan for drought preparedness (Kim et al. 2021). Access to safe drinking water, irrigation, electricity, fertilizer, seed and ratio shop determine the ability of the system to reduce the intensity of drought effects (Rajesh et al. 2018). The demographic and livelihood components such as percentage of major crops and unirrigated area to the total cropped area; percentage of tribal population, percentage of child death, population density (Singh 2020; Maiti et al. 2017; Kumar et al. 2016; Varadan and Kumar 2015), percentage of small and marginal farmers and agricultural labour to total farmers have positively correlate with the sensitivity, hence, drought vulnerability increases. Whereas, indicators like percent of the population engaged in Fisheries and other livelihoods, livestock population, the yield of major crops (Singh et al. 2019); having drinking and irrigation facility; fertilizer and seed consumption and average farm size (Sendhil et al. 2018; Varadan and Kumar 2015) show a positive relationship with adaptive capacity. If they increase, adaptive capacity increases hence, vulnerability decreases.

2.13.4 Calculation of Principal Component Analysis

NLPCA has been utilized to analyze mixed-scale data set. The principal components approach was used to identify the majority of the variation in the data set and object scores were calculated for individual observation for each indicator (Ghimire et al. 2010).

The foundation testing for data analysis was decided before processing the PCA. The level of significance for components was chosen 0.35, and indicators having eigenvalues greater than one were taken in the analysis suggested by Kaiser (1996). In the present analysis, the number of sample is 20 community blocks of Purulia. The IPCC approach denoted different subjects-to-variables (STV) ratio for the different influencing components, the minimum value is 3 (3:1 ratio) (Kim et al. 2021). Histogram, Scree plot and descriptive statistics were applied to detect the contributing factors in SPSS software. Additionally, the

Kaiser-Meyer-Olkin test and Bartlett's test of sphericity were performed to assess the sampling adequacy (MSA), selecting 0.7 as the minimum threshold. The Kaiser- Meyer-Olkin (KMO) test (Kaiser 1970; Abson et al. 2012) also measured multi-collinearity in the dataset. The Bartlett's Test of Sphericity (Bartlett 1954: Yu et al. 2021) has been performed to assess the intensity of the relationship among variables (Kim et al. 2021). Consequences of all assays recommend that principal component analysis is a suitable method to integrate the data.

In the next step, component score coefficients have been estimated to compute a composite index. The value of contributing factors has been estimated using the expression (Gupta et al. 2019; Das et al. 2020):

$$CF = \sum \frac{Fi}{TV} * FSi$$

Where, CF refers contributing factors (exposure, hazard, sensitivity and adaptive capacity), Fi denotes the percentage of variance for each component, TV represents the total variance and FSi signifies the component score coefficients.

The CF value can have both positive and negative, which creating difficult to apply for further calculation and interpretation. For easy comparison, measurement on different scales for each indicator have been normalized to ensure that all variables are comparable (Varadan and Kumar, 2015; Rajesh et al. 2018; Zarafshani et al. 2020). The following equation has been used for normalization:

$$\text{Normalization} = \frac{\text{Maximum value} - \text{Actual value}}{\text{Maximum value} - \text{Minimum value}}$$

The normalization process calibrates the CF values on a 0–1 scale (Antony and Rao 2007; Balaganesh et al. 2020) that simplifies interpretation and comparison.

2.13.5 Calculation of Drought Vulnerability and Risk

Vulnerability refers to the propensity to have harmful effects, due to the nature, intensity and rate of exposure and sensitivity with absence of adaptive capacity (IPCC 2014). Exposure is the character and magnitude of climatic extreme events. Sensitivity denotes the measure of negatively affected by climate-related stress. Adaptive capacity is the production system's capability to better adjust to extreme events (IPCC, 2007). Exposure, sensitivity and adaptive capacity were determined individually by their respective components. Based on IPCC method, composite drought vulnerability has been evaluated by the following Eq:

$Vulnerability = (Exposure + Sensitivity) - Adaptive\ Capacity$

Vulnerability is the degree of potential impact over the adaptive capacity of the area by controlling exposure and sensitivity (Sendhil et al. 2018). Therefore, Vulnerability can be redrafted as:

$Vulnerability = Potential\ Impact - Adaptive\ Capacity$

Where,

$Potential\ Impact = Exposure + Sensitivity$

The Fifth Assessment Report (AR5) of the IPCC describes the risk assessment procedure, which is a modifier version of vulnerability. Risk is acknowledged as the potential adverse impacts, is not determined only by natural hazards (cyclone, drought, flood, etc), but combined consequences of hazards and vulnerability (IPCC 2012, 2014). According to the framework proposed by IPCC (2014) AR5 'potential impact' (PI) is determined by the combination of hazard, exposure and sensitivity, while adaptive capacity is the ability to cope with these impacts (Satta et al. 2017; Malakar et al. 2021). Risk has also been calculated by the following formula:

$Risk = (Hazard + Exposure + Sensitivity) - Adaptive\ Capacity$

The computed value for drought vulnerability and risk indices ranges from 0 to 1, with higher values represent a higher extent of vulnerability and risk. Finally, Block level drought vulnerability and risk maps have been composed in ArcGIS platform (10.5v) and were categorized into five groups as very high, high, moderate, low and very low.

2.14 DROUGHT ADAPTATION AND MITIGATION THROUGH WATER AND AGRICULTURE MANAGEMENT

2.14.1 Agricultural Land Classification

Based on their influences on agriculture, several criteria like land use, slope, soil moisture, geology, soil properties, distance from drainage, and depth of groundwater (Das et al. 2017; Kahsay et al. 2018b; Geng et al. 2019; Teshome and Halefom 2020) were widely used as critical factors for land suitability assessment in the drought-prone lateritic area. Soil moisture plays a determinant role in agricultural land suitability, particularly in drought-prone regions (Yalew et al. 2016a, b). Hydrogeological factors (drainage, soil moisture, geology, and depth of groundwater table) also significantly influence agriculture in drought-affected areas (Vasu et al. 2018; Paul et al. 2020; Cornwell et al. 2020). Thus, in the present study, ten criteria (land use/cover, slope, soil moisture, soil depth, texture, erosion, pH, drainage, geology, and depth of groundwater level) were selected for agricultural land suitability assessment through weighted overlay modelling based on AHP method.

All thematic maps (soil depth, texture, erosion and pH, slope, land use/land cover, drainage density, soil moisture, geology, and depth of groundwater level) were prepared based on different remote sensing and GIS methods. Weights for the criteria used for land suitability assessment were calculated using AHP (Feizizadeh and Ghorbanzadeh 2017; Tashayo et al. 2020), and weighted overlay model (Kamau et al. 2015; Yalew et al. 2016a; Ennaji et al. 2018) was adopted to combine thematic layers and construct the suitability map utilizing the "spatial analysis tool" in ArcGIS 10.5 program Fig. 2 illustrate the methodology followed in the present study.

2.14.1a Construction of Input Criterion maps

Land use and Land cover (LULC)

The land use/land cover map of Purulia was prepared for the year 2019. Supervised classification on high-resolution (5.8 m) LISS IV remote-sensing data was performed using the maximum likelihood algorithm in ERDAS 14 software. The accuracy of land use/land cover classification was analyzed based on rigorous ground survey data through an error matrix (Rwanga and Ndambuki 2017). The columns of the error matrix comprise observed classes, while the rows exemplify the result of the classification LULC map (Gumma et al. 2017). The total 485 ground survey points (245 in Kashipur and 240 in Chhatna) were collected randomly by GPS. Field samples for the different classes were collected: 235 points for agricultural land and 50 points each for vegetation, settlement, fallow land, upland, and water body. The supervised classification achieved an accuracy of around 81.5% (kappa coefficient 0.79). Delineated agricultural land was extracted and used for further analysis.

Slope, Geology and Soil

The slope map represents the rate of change of elevation. It was prepared from ALOS PALSAR DEM data applying the "surface" tool under spatial analysis in ArcGIS 10.5v (Yalew et al. 2016a). The geological map of the Purulia obtained from the Geological Survey of India was geo-referenced and digitized in ArcGIS 10.5 software. The maps of soil depth, texture, erosion, and acidity/alkalinity (pH) were procured from the National Bureau of Soil

Survey and Land Use Planning, Kolkata. Acquired maps have been scanned, rectified, and digitized in the Arc GIS software (10.5v).

Soil moisture

Soil moisture was calculated using the Land Surface Temperature (LST) – Vegetation Index Triangle method based on the scatterplot between Normalized Difference Vegetation Index (NDVI) and LST (Sandholt et al. 2002; Chen et al. 2011). The temperature vegetation dryness index (TVDI) enables us to estimate water content in the soil available for crops at the local scale (Przezdziecki and Zawadzki 2020). TVDI was calculated to estimate soil moisture using Landsat-8 satellite data (Pandey et al. 2020). The TVDI is a dryness index, values of 1 indicate low moisture condition (dry edge) and 0 imply adequate moisture contain (wet edge). The TVDI was computed according to Patel et al. (2009):

$$TVDI = \frac{T_S - T_{S-min}}{T_{S-max} - T_{S-min}}$$

where T_S denotes observed LST in a given pixel, Ts-max is the maximum surface temperature, defining dry edge, and Ts-min is the minimum surface temperature in the triangle indicating the wet edge. Ts-min and Ts-max are linear functions of NDVI computed as follows:

$$T_{S-min} = a_{min} + b_{min} * NDVI$$

$$T_{S-max} = a_{max} + b_{max} * NDVI$$

where a_{min} and a_{max} are the intercepts for the dry and wet edges; b_{min} and b_{max} are the slopes for the dry and wet edges (least squares).

NDVI was processed using the red and near-infrared bands (Band 4 and 5) of Landsat-8 according to the following equation (Pandey et al. 2020):

$$NDVI = \frac{NIR - R}{NIR + R}$$

where NIR refers the near-infrared and R refers the red band of Landsat-8.

LST was computed from the thermal bands (Band 10 and Band 11) of Landsat-8 according to Govil et al. (2019) :

$$LST = \frac{K_2}{1 + \left(\frac{\lambda\sigma T_B}{hc}\right) ln\varepsilon}$$

where K_2 is a calibration constant ($K_2 = 1321.08$ for Landsat-8), λ is the effective wavelength (11.335 µm for band 10 in Landsat-8 OLI data), σ is Boltzmann constant (1.38×10^{23} J/K), h is Plank's constant (6.626×10^{34} J), c is the velocity of light (2.998×10^{8} m/s), ε is emissivity, and T_B is the brightness temperature in Kelvin (K), which is calculated according to Govil et al. (2019):

$$T_B = \frac{K_2}{ln((K_1/L_\lambda) + 1)}$$

where, L_λ is the spectral radiance in $Wm^{-2}sr^{-1}mm^{-1}$; K_1 is a calibration constant ($K_1 = 774.89$ for Landsat-8).

The spectral radiance (L_λ) was determined by the equation (Pandey et al. 2020):

$$L_\lambda = M_L * Q_{cal} + A_L$$

where M_L is band-specific multiplicative rescaling factor (3.3420E-04), Q_{cal} band image and A_L is band-specific additive rescaling factor (0.10000).

Emissivity (ε) was assessed based on the NDVI threshold method according to Kumar et al. (2020).

$$\varepsilon = \begin{cases} a + b\rho_{red} & \text{NDVI} < \text{NDVI}_S \\ \varepsilon_V P_V + \varepsilon_S(1 - P_V) + C_\lambda & \text{NDVI}_S < \text{NDVI} < \text{NDVI}_V \\ \varepsilon_V P_V + C_\lambda & \text{NDVI} > \text{NDVI}_V \end{cases}$$

where a and b are regression coefficients retrieved from the metadata of a particular Landsat-8 image, ρ is the reflectivity of the red band, C_λ represents surface roughness ($C_\lambda = 0$ for a plane surface), ε_V and ε_S are emissivities of vegetation and soil, respectively, and P_V is partial vegetation.

The partial vegetation of each pixel was computed according to Kumar et al. (2020).

$$P_V = \left(\frac{NDVI - NDVI_S}{NDVI_V - NDVI_S}\right)^2$$

Where $NDVI_v$ and $NDVI_s$ are the threshold NDVI for healthy vegetation and a dry soil pixel, respectively, evaluated from the NDVI histogram.

For validation, the TVDI map is compared with in-situ soil moisture measurements using root-mean-squared error (RMSE) correlation coefficient (r) (Kumar et al. 2020). Soil moisture measurements in randomly selected 140 surveyed sites in the paddy field were conducted during pre-monsoon season by soil moisture meter (PMS-714, LUTRON, Taiwan, analytical resolution 0.1%). The r^2 (0.57) and RMSE (0.36) value was found to be significant ($p < 0.05$).

Drainage

Drainage of the study area was delineated from DEM using flow direction ad flow accumulation raster, and later the “Stream to Feature” tool was performd to transmute it to vector form (Mahmood et al. 2020). Drive drainage was validated by topographic sheets. Spatial proximities to drainage were subtracted using the spatial overlay of the GIS layer. The distance of a particular from the adjacent drainage characteristics was calculated using multiple buffer areas from the rivers (km) in ArcGIS10.5 software (Pramanik 2016).

Depth of groundwater table

Depths of groundwater level for observational wells (21 points) in the study area were obtained from the Central Ground Water Board (CGWB) and were exported to ArcMap10.5v. The spatial variability maps were prepared using the inverse distance weighted “IDW” interpolation (the appointed values to unknown points are computed with a weighted average of the values available at the known point) method of the spatial analysis tool.

2.14.1b Computation of weights of the criteria by Analytic Hierarchy Process (AHP)

AHP approach of the MCDM method is extensively used for the assessment of agricultural land suitability due to its high precision and flexibility (Yalew et al. 2016 a; Bozdag et al. 2016; Owusu et al. 2017; Gashaw et al. 2018; Sisay et al. 2020). In the present study, the AHP approach was used to find out the agricultural land suitability in the following steps, i.e. (1) resolve ranks, (2) pair-wise comparison matrix, (3) computation of weights. The field surveys, experts’ outlooks, and literature reviews (Bandyopadhyay et al. 2009; Akinci et al. 2013; Zolekar and Bhagat 2015; Pramanik 2016; Yalew et al. 2016a, b; Ennaji et al. 2018; Zolekar 2018; Roy and Saha 2018; Akpoti et al. 2019) were utilized in choosing the ranks of influencing parameters and the sub-classes.

AHP is an efficient approach to compare a list of objects or alternatives. The pair-wise comparison matrix is produced using Saaty's scale (Harker and Vargas 1987; Bana e Costa et al. 2008) where the number in the row and column presents the relative significance of an individual parameter (Li et al. 2017; Saatsaz et al. 2018). The sum of each column, and then, the division of each column by the corresponding sum is computed to obtain the normalized weights. Table 2.10 shows the obtained weights of all criteria using a pair-wise comparison matrix based on AHP. Consistency ratio (CR) was computed to measure the consistency of comparison of the criteria (Kahsay et al. 2018a). The CR of the matrix is referred to as:

$CR = (CI/RI) = (0.0637/1.45) = 0.05$

Where, $CI = (\lambda_{max}-n)/(n-1)= (9.51 - 9) /8 = 0.0637$, and λ_{max} is the highest Eigenvalue and n is the number of components used in the assessment. Since $CR < 0.1$, the conclusion is acceptable (Li et al. 2017; Kahsay et al. 2018a).

Table 2.10 Normalized Pairwise comparison matrix (9 layers) developed for Computation of Weights using AHP method

	Slope	**Soil moisture**	**Drainage**	**Soil depth**	**Soil texture**	**Soil erosion**	**Depth of ground water level**	**Soil pH**	**Geology**	**Priority vector/weight**
Slope	1.00	2.00	2.00	2.00	3.03	3.03	3.03	4.00	4.00	0.251
Soil moisture	0.50	1.00	1.00	1.00	1.52	1.52	1.52	2.00	2.00	0.125
Drainage	0.50	1.00	1.00	1.00	1.52	1.52	1.52	2.00	2.00	0.125
Soil depth	0.50	1.00	1.00	1.00	1.52	1.52	1.52	2.00	2.00	0.125
Soil texture	0.33	0.66	0.66	0.66	1.00	1.00	1.00	1.32	1.32	0.083
Soil erosion	0.33	0.66	0.66	0.66	1.00	1.00	1.00	1.32	1.32	0.083
Depth of ground water level	0.33	0.66	0.66	0.66	1.00	1.00	1.00	1.32	1.32	0.083
Soil pH	0.25	0.50	0.50	0.50	0.76	0.76	0.76	1.00	1.00	0.063
Geology	0.25	0.50	0.50	0.50	0.76	0.76	0.76	1.00	1.00	0.063

2.14.1c Standardization of input thematic layers

To perform a weighted overlay model, all criteria are required to be of standardized value (Pramanik 2016; Das et al. 2017; Teshome and Halefom 2020). The standardization method converts the measurements of all criteria to a uniform unit (Mishra et al. 2015; Singh et al. 2019; Halder et al. 2020). To compose a uniform unit, the vector layers were transformed into a raster layer with equal cell size, following which all raster layers were reclassified in the spatial analyst toolbox of Arc-GIS 10.5 software. Standardized values of sub-criteria denoted the comparative significance. For identification of agricultural land suitability, all thematic layers were reclassified into four different categories according to FAO (1996), Yalew et al. (2016a), and Roy and Saha (2018). The scores for sub-criterion representing internal differences within the criteria assigned the uniform rank of 1 to 4, where 1 signifies unsuitable, and 4 denotes high land suitability. Table 2.11 displays the rank, and area of sub-layers of different criteria.

Table 2.11 Weights and rankings assigned to criteria and sub-classes for agricultural land suitability

Variables	**Class**	**Weight**	**Influence (%)**	**Rank**	**Area (sq km)**
slope	0 – 1.5°	0.25	25	4	121
	1.5 - 3°			3	250
	3 – 4.5°			2	145
	4.5 - 6°			2	65
	6 -8°			1	22
	> 8°			1	4
Soil moisture	0-0.2	0.13	13	4	65
	0.2-0.4			3	139
	0.4-0.6			2	293
	0.6-0.8			1	99
	0.8-1.0			1	12
soil depth	<25 cm	0.13	13	1	85
	25 – 50 cm			2	125
	50 – 75 cm			2	135
	75 -100 cm			3	90
	100 -150 cm			4	75

Distance from Drainage	0.15 km	0.13	13	4	76
	0.35 km			3	96
	0.65km			2	109
	0.80 km			1	53
	1.0 km			1	65
	1.5 km			1	114
soil texture	sandy loam to loam	0.08	8	2	168
	sandy loam to sandy clay loam			3	82
	sandy clay loam to clay loam			4	45
	sandy loam to clay loam			4	85
	loamy sand to sandy loam			1	120
soil erosion	5 -10t/ha/yr	0.08	8	4	150
	10 -20 t/ha/yr			3	203
	20 -40 t/ha/yr			1	157
Depth of ground water	2.5-3.5 mbgl	0.08	8	4	64.2
	3.5-4.2			3	115
	4.2-4.5			2	155
	4.5-5.0			2	135
	5.0-6.0			1	33
soil pH	5 - 7.3	0.06	6	4	210
	7.3 - 8			2	195
	> 8			1	108
Geology	Granite Gneiss	0.06	6	2	193
	Sijua Formation			2	1.6
	Metabasic Rock			2	2.5
	Mica Schiest			2	22.4
	Granite			2	0.7
	Pyroxenite/granulite			1	2.8
	Pinkgranite/biotitegranite gneiss			2	281.0

2.14.1d Modelling of agricultural land suitability based on Weighted Overlay

The weighted overlay analysis plays a significant role in resolving spatial complexity in suitability analysis and site selection (Kamau et al. 2015; Pramanik 2016; Maddahi et al. 2017; Kazemi and Akinci 2018; Negi et al. 2020). The agricultural land suitability was appraised by integrating all the spatial parameters using the weighted overlay method based on AHP and MCDM process. The agricultural land suitability model was created in the model builder of ArcGIS 10.5v (spatial analysis tool). Cell values of the standardized layer were multiplied with their criteria weights (Kahsay et al. 2018a; Zolekar and Bhagat 2018; Zolekar 2018). Land suitability map for agriculture has been produced based on the following equation:

$$ALS = \sum_{i=1}^{n} WiXi$$

Where ALS denotes the total agricultural land suitability score, Wi means the weight of ith factor, Xi refers to the normalized criterion score of agricultural land suitability factor *i*, and n denotes the total number of land suitability criteria (Yalew et al. 2016a; Halder et al. 2020).

2.14.2 Groundwater Potential Zone

The Six most influenced criteria (Lithology, Slope, Land Use/Land Cover, Lineament Density, Drainage Density and FIS) on groundwater availability (Mukherjee et al. 2012; Agarwal et al. 2013) have been prepared. The GWPZs map was developed by integrating all the thematic layers in the weighted overlay method (Waikar and Nilawar 2014) using the spatial analysis tool in ArcGIS 10.5v platform.

2.14.2a Generation and classification of the criteria

Collected lithological map of the Purulia was scanned, rectified and digitized in ArcGIS 10.5v. The slope map was prepared from the digital elevation model (DEM) using the spatial analysis tool in ArcGIS10.5 software. Lineaments were extracted from a high-resolution satellite image (Sentinel-2B) by automatic line extraction in PCI Geometica 9.1. Drainage was derived using the DEM and toposheets. By using ArcGIS10.5 software the drainage and lineament density map was produced taking into account the length of drainage/ lineanent per sq km area. Land use /Land cover map for the year 2019 was created from sentinel-2A data at spatial resolution 10 m using knowledge-based classification technique in the ERDAS Imagine (14). Satellite-derived NDVI data (from Sentinel-2B image) was utilized to estimate fractional vegetation cover (FVC) (Kaspersen et al. 2015). The relation between the fractional vegetation cover (FVC) and fractional impervious surface area (FIS) has been derived by the following expressions (Ridd 1995; Owen et al. (1998):

$$FIS= 1 – FVC \text{ ------- } (1)$$

$$FVC= (NDVI_S)^2 \text{------}(2)$$

$$NDVI_S = NDVI- NDVI_{low}/NDVI_{high} - NDVI_{low} \text{ ------- } (3)$$

where, $NDVI_{high}$ and $NDVI_{low}$ values were derived from dense vegetation and bare soil, as suggested by Carlson and Ripley (1997).

2.14.2b Assigning rank and weight

The groundwater potential zones were assessed by superimposed all the thematic layers using a weighted overlay approach. Before the overlying process, each spatial layers were reclassified to a uniform order of 1 to 4, where 1 signifies poor groundwater potential and 4 denotes excellent groundwater potential. Weights have been consigned through a pairwise comparisons matrix based on AHP (Table 2.12).

Table 2.12 Normalized Pairwise comparison matrix produced for AHP based groundwater potential zoning.

Parameters	**Lithology**	**Slope**	**Lineament**	**Drainage**	**Land use/ land cover**	**FIS**	**Weight**
Lithology	6	5	4	3	2	1	0.41
Slope	6/2	5/2	4/2	3/2	2/2	1/2	0.2
Lineament	6/3	5/3	4/3	3/3	2/3	1/3	0.14
Drainage	6/4	5/4	4/4	3/4	2/4	1/4	0.1
Land use/ land cover	6/5	5/5	4/5	3/5	2/5	1/5	0.08
FIS	6/6	5/6	4/6	3/6	2/6	1/6	0.07

The ranks were offered to the respective components considering the field survey, stakeholder consultation, and specialist outlook as well as review the existing literature (Krishnamurthty et al. 1996; Saraf and Chowdhary 1998; Waikar and Nilawar 2014). Lithology was determined the highest weight, whereas slope, lineament and drainage density were spacified moderate weight and land use /land cover and FIS were allotted low weight (Table 2.13). After giving weights to the respective factors, individual scores were specified for sub-variables (Butler et al. 2002, Asadi et al. 2007, Yammani 2007). The maximum value was used to depict the highest groundwater potentiality and vice-versa.

Table 2.13 Weights allocated for different ground water control variables.

Parameter	Classes	Weight	Influence (%)	Rank	Area(sq km)
Lithology	Conglomerate	0.41	41	4	20
	Granite Gneiss			1	4266
	Granite Gneiss with Quartz and pegmatic vein			2	573
	Granite, Pegmatite and Quarzite			3	719
	Muscovite and Biotite Schiest			4	536
	Sandstone			4	137
Slope(Degree)	0 - 2˚	0.2	20	4	965
	2 - 4˚			3	1883
	4 - 6˚			2	1579
	6 - 8˚			1	970
	8 -10˚			1	461
	> 10˚			1	523
Lineament density(Km/Km^2)	0.02-0.08 km/km2	0.14	14	1	2719
	0.09-0.12			2	2240
	0.13-0.16			3	877
	0.17-0.2			3	234
	0.2-0.3			4	183
Drainage density(Km/Km^2)	0.03-0.15 km/km2	0.1	10	4	779
	0.16-0.22			3	1517
	0.23-0.27			2	2098
	0.28-0.33			2	1460
	0.33-0.53			1	397
Land use/ land cover	Vegetation	0.8	8	3	986
	Water Body			3	252
	Pediment			1	910
	Fallow Land			2	1133
	Agricultural Land			4	2898
	Settlement			1	84
FIS	0.03-0.41	0.7	7	4	658
	0.41-0.50			3	952
	0.51-0.60			2	1721
	0.61-0.70			1	2446
	0.71-1.00			1	482

2.14.3 Identifying Potential Rainwater Harvesting Structure Site

Integrating all the essential parameters is necessary to delineate the suitable sites for RWHS because it is a complex procedure where inter-related multiple criteria influence each other (Singh et al. 2017; 2020). LULC, topographic aptness, surface-runoff potential, permeability, drainage, soil, geology, and groundwater infiltration zone are the core layers that play a crucial role in selecting rainwater harvesting sites (Singhai et al. 2019). Surface runoff is a crucial parameter to identify possible RWH sites in sub-humid undulating terrains (Bhagwat et al. 2018). LULC, soil texture, slope, and antecedent moisture conditions (AMCs) affect the surface runoff (Mahmood et al. 2020). The characterization of RWHSsuitable sites needs a ground-level understanding of the runoff coefficient, detailed evaluation of surface topography, permeability, soil properties (like permeability and texture), drainage, geology, and land use in drought-prone regions (Adham et al. 2018). Lineaments and the proximity of a particular location from the surface and groundwater sources are also critical factors (Kumar et al. 2008; Kumar and Jhariya 2017; Matomela et al. 2020). Therefore, in this study, the evaluation of optimum sites for RWHS involved all the thematic layers, namely runoff coefficient, land cover/land use, slope, soil, lineament, drainage density, stream order, geology, and groundwater level (Ramakrishnan et al. 2009; Kumar and Jhariya 2017; Singhai et al. 2019).

2.14.3a Preparation of thematic layers

Integrating all the essential parameters is necessary to delineate the suitable sites for RWHS because it is a complex procedure where inter-related multiple criteria influence each other (Singh et al. 2017, 2020). Land use/land cover, topographic aptness, surface-runoff potential, permeability, drainage, soil, geology, and groundwater infiltration zone are the core layers that play a crucial role in selecting rainwater harvesting sites (Singhai et al. 2019). Surface runoff is a crucial parameter to identify possible RWH sites in sub-humid undulating terrains (Bhagwat et al. 2018). Land use/land cover, soil texture, slope, and antecedent moisture conditions (AMCs) affect the surface runoff (Mahmood et al. 2020). The characterization of RWHS suitable sites needs a ground-level understanding of the runoff coefficient, detailed evaluation of surface topography, permeability, soil properties (like permeability and texture), drainage, geology, and land use in drought-prone regions (Adham et al. 2018). Lineaments and the proximity of a particular location from the surface and groundwater sources are also critical factors (Kumar et al. 2008; Kumar and Jhariya 2017; Matomela et al.

2020). Therefore, in this study, the evaluation of optimum sites for RWHS involved all the thematic layers, namely runoff coefficient, land cover/land use, slope, soil, lineament, drainage density, stream order, geology, and groundwater level (Ramakrishnan et al. 2009; Kumar and Jhariya 2017; Singhai et al. 2019).

Land use/land cover

Analysis of Sentinel–2B Level 1C data developed the land use/land cover map of Purulia for the year 2019. This study implemented the maximum likelihood algorithm of the supervised classification method to classify six land use and land cover classes, namely vegetation and forest, waterbody, agricultural land, upland (pediment), fallow land, and settlement, by using ERDAS 14. Pre-classification steps included image-processing techniques like layer stacking and image extraction by clipping the study area using ERDAS 14. The Google Earth, toposheets, and field observations from the RLZs helped us selecting the training data and signatures representing various land use classes.

The analysis of the classified result comparative to the validated data set using an error matrix led to the accuracy assessment. Accordingly, the computation of overall, producer’s and user’s accuracies, and Kappa coefficient followed. The accuracy assessment involved 300 ground truth points acquired by GPS surveys. This study followed the methodology of Rana and Suryanarayana (2020) for formulating the error matrix. The vegetation and cultivated lands account for enhanced infiltration and interception rates, while settlement and upland promote high runoff (Mahmood et al. 2020). Thus, the ranks for vegetation and agricultural land were high and low for land use classes like settlement, upland, and fallow land. Fallow land is usually suggested for rainwater storage structures (Rana and Suryanarayana 2020), hence moderate rank has been given.

Slope

The analysis of ALOS PALSAR DEM (12.5 m) data implementing the spatial analysis tool in ArcGIS 10.5 enabled us to prepare the topographic slope layer. A steeper slope eases enhanced runoff by reducing the rainwater residence time. On the contrary, a gentle slope reduces the surface runoff, and enhances the rainwater percolation time, leading to more penetration. According to Bhagwat et al. (2018), the ranks for gentle slopes are high and vice-versa.

Soil texture

The soil map of Purulia went through geo-referencing and digitization exercises to prepare the soil texture map using ArcGIS v10.5. Kumar and Jhariya (2017) extracted the hydrological soil groups (HSGs) based on soil texture. This study followed the same protocol. Adham et al. (2018) specified that medium-textured and fine soils were highly suitable for RWH due to increased water-holding capacities. Sites with sand and silt have higher permeability and are usually not capable of storing the harvested rainwater (Mbilinyi et al. 2007). The assignment of ranks followed accordingly.

Lineament

The analysis of Sentinel 2B data following the principal component analysis (for image enhancement) led to the development of the lineament map using ERDAS14. An automatic line extraction tool in PCI Geometica 9.1 helped us interpret the lineaments and convert them into a vector format. Field observations coupled with information derived from the geological map enabled us to verify the final lineament map. Using hydrological tools like flow-direction raster and stream-link raster led to the delineation of watersheds. The spatial join tool in ArcGIS v10.5 enabled us to combine the information of the watershed area and lengths of the lineaments under respective watersheds for calculating the lineament density per watershed. Increased lineament density ensures higher percolation potential (Ramakrishnan et al. 2009). Therefore, in the present study, higher lineament density had a low rank and vice-versa.

Drainage

The flow direction and stream raster layers and the Stream to Feature tool enabled us to characterize the drainage network from the DEM data and convert it to a vector format. Toposheets of the 1:50000 scale helped us validate the drainage maps. Hydrological tools in ArcGIS v10.5 enabled us to delineate the stream orders. A buffer of 100 m on both flanks of the streams was considered while preparing the stream-order buffer map. The length of drainage per sq km enabled us to generate the drainage density map. Rais and Javed (2014) and Kumar and Jhariya (2017) concluded that high drainage density is more favourable and vice-versa for harvesting rainwater. Thus, in this study, high drainage density had a high rank for RWH. The obtainability of the total amount of surface water is proportionate to the stream order (Rana and Suryanarayana 2020). Therefore, a relatively high stream order area had a high rank.

Geology

Scanning, rectification, and digitization exercises on the amassed geological map using ArcGIS v10.5 helped us generate the geological information thematic layer. Granite Gneiss Phyllite and Mica schist having medium to low permeability (Ghosh et al. 2020) are considered as favourable zones for RWHS (was assigned a higher rank). Weathered residuum (Quarzite and Metabasic Rock) and fractures of granite are highly permeable (Bhunia et al. 2020) (low rank). Gondwana Rocks are arenaceous and form good aquifer. Sijua formation and Calc Granulites have a moderate water-bearing capacity (Chowdhury et al. 2010). Thus, Gondwana rocks and Sijua formation had a medium rank for RWHS.

Depth of Ground Water Level

The data on mean post-monsoon groundwater levels (from the observational wells) from 1990 to 2019 enabled us to prepare the groundwater-level map. The inverse distance weighted (IDW) interpolation method of the spatial analysis tool (ArcGIS v10.5) helped us characterize the spatial variability of groundwater level. A lower groundwater depth implies a higher potential for perennially (Singh et al. 2017). Therefore, in the present study, lower groundwater depth had a high rank and vice-versa.

Runoff Coefficient

Runoff coefficient is the ratio of total runoff depth to rainfall, expressed as a runoff percentage of total precipitation (Ramakrishnan et al. 2009). The dividend of annual runoff with annual rainfall for the ‘normal rainfall year’ enabled us to compute the runoff coefficient (Kumar and Jhariya 2017). The micro watershed was generated from the hydrology tool of ArcGIS. The focal statistics tool of ArcGIS enabled the estimation of runoff coefficient per pixel (Matomela et al. 2020). The runoff coefficient signifies the portion of precipitation that adds to direct runoff (Singh et al. 2017). Therefore, a higher runoff coefficient area had a higher rank and vice-versa.

2.14.3b Determining weights of multi-criteria using AHP

Saaty (1987) developed AHP for the first time. It has been a widely employed MCDM technique to resolve decision-making issues associated with water resources (Rana and Suryanarayana 2020). The method deals with a complex decision and converts it into a simple hierarchy system (Singh et al. 2020). This approach simultaneously evaluates two criteria by constructing a pair-wise comparison matrix. It assesses each of them by placing all probable pairing in a proportion scale to define the relative significance by mathematical magnitudes (Matomela et al. 2020).

In this study, the rank of the selected thematic layers was adopted and modified from literature reviews, experts' opinion, local farmers outlook, and field surveys (Ramakrishnan et al. 2009; Ammar et al. 2016; Kumar and Jhariya 2017; Wu et al. 2018; Matomela et al. 2020; Rana and Suryanarayana 2020; Singh et al. 2020, 2017). The estimated weights of all criteria (runoff coefficient, land cover/land use, slope, soil, lineament, drainage density, stream order, geology, and groundwater level) were developed using the pair-wise comparison matrix method (Table 2.14) for potential runoff storage zones are shown in Table 2.15. The obtained eigenvalue of each criterion, representing its relative importance (Saaty 1987), is satisfactory if the consistency ratio (CR) < 10%. Hence, to ensure the acceptability of weights provided to various themes, the CR, as suggested by Saaty (1987), was computed using the following comparison:

$$CR = \frac{\frac{(\lambda_{max} - n)}{(n-1)}}{RI}$$

Where λ_{max} is the principal eigenvalue, n denotes layer numbers, and RI denotes the random index that is subject to the number of criteria (Saaty 1987). The CR in the present pair-wise matrix is 7.5% (i.e., < 10%). Hence, the judgments made and assembled in the pair-wise matrix of Table 2 are satisfactory.

Table 2.14 Normalized Pairwise comparison matrix (9 layers) developed for Computation of Weights using AHP method

	Runoff	**Slope**	**Soil**	**Land use**	**Drainage**	**steam order**	**Geology**	**Lineament**	**Ground Water table**	**Priority vector/ weight**
Runoff	1.00	1.13	1.13	1.13	1.29	1.29	1.50	1.50	1.50	0.14
Slope	0.89	1.00	1.00	1.00	1.14	1.14	1.33	1.33	1.33	0.12
Soil	0.89	1.00	1.00	1.00	1.14	1.14	1.33	1.33	1.33	0.12
Land use	0.89	1.00	1.00	1.00	1.14	1.14	1.33	1.33	1.33	0.12
Drainage	0.78	0.88	0.88	0.88	1.00	1.00	1.17	1.17	1.17	0.11
Steam order	0.78	0.88	0.88	0.88	1.00	1.00	1.17	1.17	1.17	0.11
Geology	0.67	0.75	0.75	0.75	0.86	0.86	1.00	1.00	1.00	0.09
Lineament	0.67	0.75	0.75	0.75	0.86	0.86	1.00	1.00	1.00	0.09
Ground Water level	0.67	0.75	0.75	0.75	0.86	0.86	1.00	1.00	1.00	0.09

Sub-criteria in the layers varied from 1 (unsuitable) to 5 (highly suitable) in terms of suitability scale. The stacking of thematic layers over one another involved the weighted overlay tool in ArcGIS v10.5. Malczewski (2006) multiplied each thematic layer with its weight and summed the outcomes based on the following expression:

$$A_j = \sum_{i=1}^{m} W_i X_{ij}$$

Here Aj denotes the final suitability score in each cell, Xij stands for the suitability of the ith cell for the jth layer, and Wi represents normalized weight of I layer. A re-classification of the resultant suitability map into five categories as (a) Unsuitable, (b) Very Low Suitable, (c) Low Suitable, (d) Moderately Suitable, and (e) Highly Suitable followed this exercise.

Table 2.15 Weights and scores consigned to elements and sub-classes for RWH potential zone

Variables	Class	Weight	Influence (%)	Rank	Area (sq km)
Runoff Coefficient	0.1-15%	0.14	14	1	461
	16-25%			2	1129
	26-35%			3	2486
	36-45%			4	670
	45-64%			5	411
slope	0 - 2˚	0.12	12	5	965
	2 - 4˚			4	1883
	4 - 6˚			3	1579
	6 - 8˚			2	970
	8 -10˚			1	461
	> 10˚			1	523
Land use /Land cover	Vegetation and forest	0.12	12	5	986
	water body			0	252
	Agricultural land			4	2898
	Fallow land			3	1133
	Up land			2	910
	settlement			0	84
soil texture	sandy loam to loam	0.12	12	3	1911
	Gravally loam to loam			5	1779
	Gravally Loam			4	537
	Coarse Loamy			1	759
	loamy sand to sandy loam			2	1232

Drainage Density	0.03-0.15 km/km2	0.11	11	1	779
	0.16-0.22			2	1517
	0.23-0.27			3	2098
	0.28-0.33			4	1460
	0.33-0.53			5	397
Stream Order	1	0.11	11	2	1785
	2			3	799
	3			4	333
	4			5	250
Geology	Granite Gneiss	0.09	9	5	3862
	Gondwana Rocks			3	137
	Mica Schiest			4	536
	Quarzite & Pegmatite			2	36
	Granite			1	683
	Metabasic Rock			1	331
	Sijua Formation			3	20
	Calc Granulites			2	38
	Meta Volcanics			1	34
	Phyllite & Mica schiest			4	573
Lineament Density	0.02-0.08 km/km2	0.09	9	5	2719
	0.09-0.12			4	2240
	0.13-0.16			3	877
	0.17-0.2			2	234
	0.2-0.3			1	183
Depth of ground water	2.5-3.5 mbgl	0.09	9	5	332
	3.5-4.2			4	1379
	4.2-4.5			3	1451
	4.5-5.0			2	1795
	5.0-7.0			1	1295

2.14.3c Characterization of appropriate sites for rainwater harvesting structures

After the delineation of RWH potential zones, a GIS-based Boolean logic protocol enabled us to identify the suitable sites for RWHS like farm pond, nala bunds, check dams, sub-surface dyke, and percolation tanks. The combined weighted overlay and Boolean overlay methods enabled us to rule out the sites that do not have any RWH potential. The Boolean approach categorizes layers into two classes as 0 and 1, where 0 denotes unsuitable and 1 signifies promising sites. In the present study, suitable sites for RWHS were found based on characteristics of each criterion and RWH potential zones as suggested by Ramakrishnan et al. (2009), Jha et al. (2014) and Singh et al. (2017) are summarized in Table 2.16.

Table 2.16 Site selection criteria of Boolean method for water harvesting structures.

Structure	Slope (degree)	Permeability	Stream order	Runoff coefficient	Depth of ground water level	watershed area
Farm ponds	0–5	low	1	high to moderate	2-2.5	1-2
Nala Bund	1-3	moderate to high	1-2	high to moderate	2-3	1-2
Check Dam	<15	low	1-3	high to moderate	4-5	25
Percolation ponds	<10	high	1-4	low	5-7	25-40
Subsurface dykes	0–3	high	4	moderate to low		>50

2.14.4 Rural Land Use Management

2.14.4a Field studies

Numerous researches (Bryan et al. 2013; Raymond and Robinson 2013) concluded that field surveys and household interviews are principal approaches in area-specific drought adaptation measures at the local level. This approach provides coherent local information and first-hand knowledge on decision-makers, the adaptation measures used by farmers and its proficiency (Raymond et al. 2010). The field survey was conducted in December 2019 in villages to examine the efficiency of drought adaptation measures which had taken by Govt. and NGO.

2.14.4b In-depth interviews with the villagers

The study conducted face-to-face conversations with the village managers and project managers and volunteers of DRCSC (NGO) to acquire a general perception about the village conditions. The open-ended questions for villages and NGO volunteers mainly concentrated on the overall drought adaptation situation in the study villages. The open-ended questions for the informants were related to (1) what are the measures commonly taken by the villagers to mitigate the drought impact? (2) what are the significant changes in agricultural and rural land use including alterations in land use modes, crop varieties, and changing farming practices. Personal interviews were also organized with the farmers who have taken adaptation measures in the Villages. Informations related to agricultural have been recorded including production, profits, cropping pattern, and the drought-tolerant crops cultivation in pre and post-adaptation drought years.

2.14.4c Household surveys

The primary information's on farmers' agricultural production and the effectiveness of adaptation activities to drought were collected through a semi-structured questionnaires approach with marginal farmer households and nutrition garden households. A total of 500 householders were interviewed using a stratified random sampling approach that contains different age groups, economic levels and genders. Questions were asked concerning the detailed information on substantial changes in the farmer's livelihood activities, financial condition and food security due to adaptation measures. In particular, based on designed questionnaires, we recorded detailed information on a variety of drought-tolerant crops and local vegetables, agricultural production, incomes and food availability in recent drought years.

2.14.4d Survey and assessment of micro-level land-use change

The present study also surveyed the land-use change at the farm level for observing farmers' adaptive processes. The high resolution satellite images LISS-IV (5.8 m) use to detect micro-level land-use patterns. Since satellite images and GPS were generally used to categorize agricultural fields and with the help of villagers and household heads, the changes in land use and crop varieties of major farmland were recorded.

2.14.4e Assessing the Effectiveness of Adaptation Activities

The area-specific adaptation to drought emphasis not only on mitigating the drought effect but also on socio-economic well-being of farmers' livelihood. Positive changes in crop yield, cropping intensity, income, and food supply are influential factors for farmers to engross in agricultural (Malik et al., 2014; Lei et al. 2014, 2016; Deora and Nanore 2019). Impacts on land-use changes have been established through a comparison of changes in drought tolerance crop production and cropping intensity across the two drought years- before (2015) and after (2019) adaptation. The study also establishes the impacts of cost-effective drip irrigation used for nutrition gardening by analyzed duration and percentage of food supply from nutrition garden during drought year (Suri 2020; Rammohan et al. 2019). Analysis of the qualitative data collected through focus group discussions information on social and ecological impacts of the reforestation. All the data were collected from field surveys, and the average value of all of the respondents has been used to avoid individual errors.

2.15 CONCLUSIONS

The chapter has described the methodology executed in this study in all its rationale and relevance, towards understanding the spatiotemporal drought and impact on agriculture. Now the principal themes of the study are being emphasized, which are the assessment of different types of drought and its impacts on agriculture and farmers livelihood, drought vulnerability and risk, water resource assessment and appropriate adaptation strategies for drought resilience.

CHAPTER III

OVERVIEW OF THE STUDY AREA

[In the chapter, an effort has been made to provide detailed information in the study area of the sub-humid RLZ zone of West Bengal. A geographical study of the Purulia district has been done for understanding the relevant features of geology, topography, climatic conditions and variability, soils, drainage, lineament, micro watershed, land use, and land cover patterns, change, predicted land use/land cover, groundwater level, demographic and socio-economic condition of the geographical entity.]

3.1 INTRODUCTION

A drought disaster is caused by the combination of both a climate hazard (the occurrence of rainfall deficits) and a societal vulnerability (the economic, social, and political characteristics). The severity of the drought is determined by the quantity of moisture deficiency, extent period, and affected area. Several components can be considered essential in the presentation of a comprehensive picture of droughts in a given region. Thus, the geographical study of the region has been essential for knowledge about the attributes of topography, climatic conditions, geology, soils, drainage system and land use and land cover patterns of the area. The geographical study of an area is composed of listings and descriptions of principal resources such as agricultural land, groundwater resources, vegetation and other related things in the region. This database provides the impact of the drought and helps factual basis for drought management land planning decisions. This study will also help quantify the vulnerable area which use as a baseline for assessing the impact of future growth. The geographical study provides information that will support sustabable land use planning, land and water resource conservation (Stone 2001). Hence, Geographical analysis acts as the beginning of the present study. Based on the literature review, rainfall, temperature, slope, soil, lineament, drainage condition, surface water storage, land-use change, agriculture profile, seasonal groundwater level and socioeconomic condition has been studied for drought analysis in Purulia. The obtained results have been discussed in this chapter.

3.2 LOCATION

The Purulia district is situated between 22˚42' 35"N to 23˚42'00" N and 85˚49'25"E to 86˚54' 37" E. The total spatial extent of the Purulia district is 6259 sq. km (Census 2001), out of which the rural and urban areas consist of 6179.63 sq. km (98.73 %) and 79.37 sq. km (1.27%) respectively. In the Western part of the district of West Bengal, Purulia is surrounded on its three sides by the State of Jharkhand. On the North, South and West flanks of the Purulia covered by Hazaribagh and Dhanbad, Singbhum and Ranchi respectively. On the Eastern side, the districts of West Bengal viz. Burdwan, Bankura and Medinipur cover the edge.

Administrative Setup: The District headquarter is located in Purulia town having three administrative subdivisions: Sadar-East, Sadar-West and Raghunathpur. There are 20 community development blocks, 3 municipalities, 170-gram panchayet, 2683 Mouzas, 2468 inhabited villages and 20 police stations.

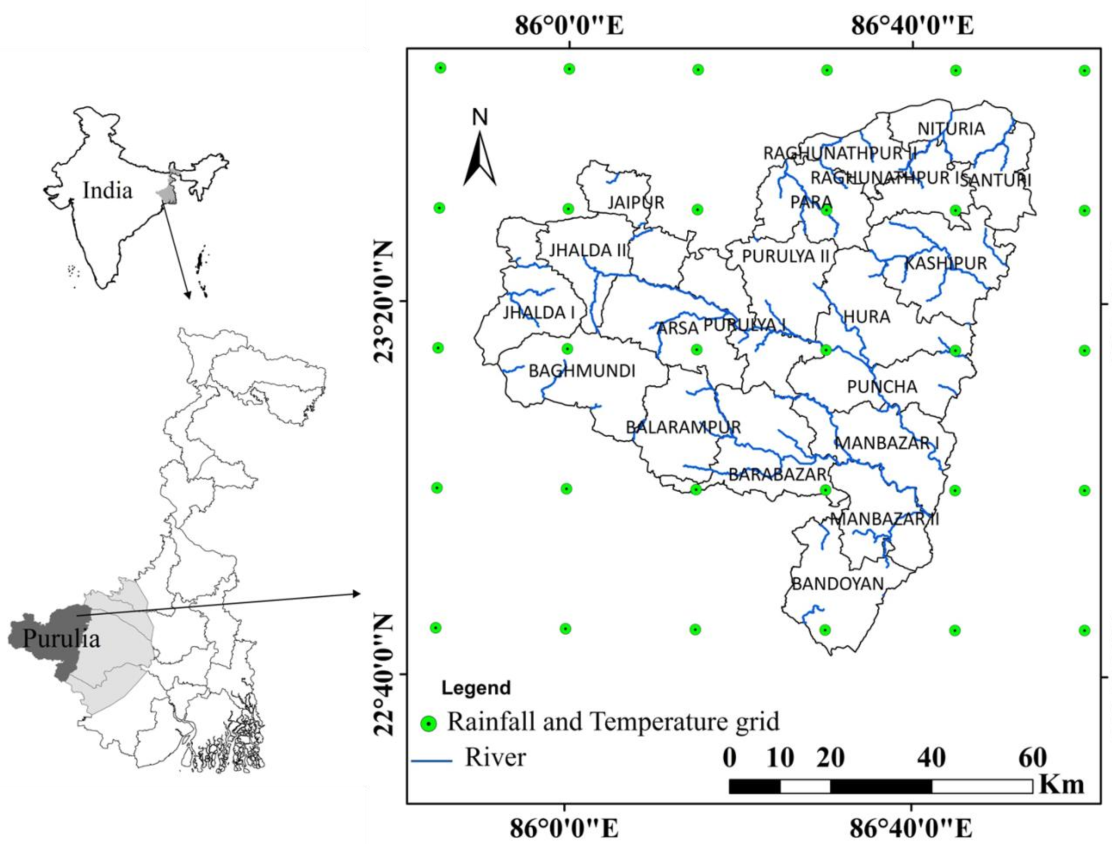

Fig. 3.1 Location map of the study area

3.3 CLIMATE AND CLIMATIC VARIABILITY

Rainfall and temperature are controlling the formation and persistence of drought (Lloyd-Hughes and Saunders 2002). Drought is occurred due to precipitation deficit (Li et al., 2019), high temperature, and high evapotranspiration (Yang et al. 2017). Drought is the most frequent natural disaster in the world and it greatly affects crop production and livelihoods (Wang, 2005). Hence, Rainfall and temperature are the most important types of data used for drought analysis.

The monthly rainfall and temperature data for 1901-2019 years were analyzed to understand the pattern of climate in Purulia. The district experiences a humid subtropical climate and is known for its extreme climate. South-west monsoon (80% rainfall) is the main source of rainfall in the Purulia. Analysis of rainfall data in Purulia for the period 1901–2019 showed that the hot and dry summer usually starts from March and continues till June and May is the hottest month. The winter season varies from being pleasant to cold, beginning from the middle of November and lasting till the middle of February. The month of June marks the arrival of the monsoon and continues till mid-September. The average temperature ranges between the maximum 43°C-47°C (summer) and minimum 7°C-12°C (winter) respectively. The annual rainfall (1200-1400 mm) is distributed throughout the year as 100-150 mm during the pre-monsoon season, 900-1100 mm during the monsoon season and 80-110 mm during the post-monsoon season. Monsoon rainfall is uncertain and uneven, therefore monsoon starts early resulting in flood and delay onset resulting in drought. The early and late retreat of monsoon rainfall also results in drought.

3.3.1 *Rainfall and Temperature Trend*

The annual report of the IMD (annual report, 2010, IMD) indicates that in the southern regions of West Bengal, the post and pre-monsoon rainfall has reduced by -14.5 mm and -6.7 mm respectively between 1901and 2003. In the monsoon season, an increase in rainfall of about 57 mm is observed. According to the IPCC report, the 20th has observed the rise of global surface temperatures by 0.74°C. The global temperature has been predicted to rise by 1.8°C under the RCP4.5 scenario (compared with that of 1986–2005) (IPCC 2007, 2013). An increasing trend of annual rainfall, temperature and shifting pattern was observed in the western part of West Bengal (Mukharjee and Bennerjee 2009).

With the increasing effect of climate change, the frequency and intensity of drought are enhancing clearly, which have devastating impacts on the environment and human society (Dai and Zhao 2017; Mallya et al. 2016). In the perspective of climate change, Purulia has perceived higher frequency droughts in recent years, it has been revealed that a moderate drought arises once every 3 years and severe drought happens once in every 10 years in the district (Palchaudhuri and Biswas 2013). Therefore, trend analysis of rainfall and temperature is necessary for analyzing the influences of climate change on drought events.

The present study attempted to determine the trend in monthly rainfall and temperature in Purulia for the period 1901–2019. Sen’s sloper has been performed to estimate the magnitude of trend, whose statistical significance was evaluated by the Mann–Kendall test. The monthly rainfall trend analysis indicated that August showed a significant reducing trend and the month of May has an increasing trend at a 95% confidence level. Trend analysis of rainfall data of 120 years (1901– 2019) indicated no significant trend for annual and seasonal rainfall in Purulia.

Table 3.1 M–K test for rainfall trend during years 1901–2019 in Purulia

Rainfall	May	August
S	1150	-809
VAR(S)	99813.34	99812.34
Z	3.64	-2.56
SEN Slope	0.504	-0.952
Trend	POSITIVE	NEGATIVE
p	95%	95%

Regarding trends in monthly temperature, the mean maximum temperature showed a rising trend at most of the months (February, July, August, October, November and December) and showed the falling trend in May only. The mean maximum temperature was found to be increasing during Monsoon, Post-monsoon and annual.

Table 3.2 M–K test for Maximum temperature trend during years 1901–2019 in Purulia

Maximum temp	Feb	May	Jul	Aug	Oct	Nov	Dec	monsoon	post	annual
S	655	-802	768	656	921	948	872	572	770	752
VAR(S)	79624.34	82298.66	79618	79616.66	79622.34	79620.66	79625.34	79625.34	79625	79625.34
Z	2.32	-2.79	2.72	2.32	3.26	3.36	3.09	2.02	2.73	2.66
SEN Slope	0.017	-0.015	0.012	0.014	0.018	0.028	0.21	0.006	0.017	0.01
Trend	Positive	Negative	Positive	Positive	Positive	Positive	Positive	Positive	Positive	Positive
p	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%

The mean minimum temperature showed a rising trend in February, March, October, November and December. Pre-monsoon, Post-monsoon and annual mean minimum temperature were also found a rising trend. The rate of increasing maximum temperature is much higher than the rate of increasing minimum temperature.

Table 3.3 M–K test for Minimum temperature trend during years 1901–2019 in Purulia

Minimum tem	**Feb**	**Mar**	**Oct**	**Nov**	**Dec**	**Pre**	**post**	**annual**
S	876	608	747	790	798	603	794	604
VAR(S)	79625.34	82290	79621.66	79625.34	79625.34	79624.34	79625.34	79625.34
Z	3.1	2.12	2.64	2.8	2.82	2.13	2.81	2.14
SEN Slope	0.018	0.01	0.015	0.03	0.02	0.005	0.019	0.007
Trend	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE
p	95%	95%	95%	95%	95%	95%	95%	95%

3.4 SLOPE

Slope plays an important role in impacting land use, soil formation, structure, organic content, infiltration rate, erosion and hydraulic connectivity within an undulating terrine area (Zhang et al. 2018). The slope makes important contributions to sediment production, transport, and delivery to rivers (Fiener et al. 2011). It is necessary to understand the slope for rational planning of land use, particularly in undulating terrine areas.

The general elevation of the district ranges between 50 to 600 m above MSL (Mean Sea Level) and the two highest peaks recorded are Gorgaburu (677 m) and Karma hill (663 m) situated on the Bagmundi scarps. The Purulia district is illustrated by undulating topography with rocky hilly terrain in the western and southern portions. The average elevation of land surface ranges between 150 to 300 m, the master slope towards the east and south-east. The alluvial soil is found in very narrow strips along the rivers. The valleys are steep along the rivers. Alluvial fans are found in the fringe areas of Ajodhya hills. The gentle slope (< 3˚) occupies about 25% of the total area and the steep slope (> 10˚) is 30% of the total area. The slope was grouped into five classes that vary from < 3˚, 3 to 6˚, 6˚ to 10˚, 10˚ to 20˚ and greater than 20˚. The slope map of the study area based on this classification is shown in Figure3.2

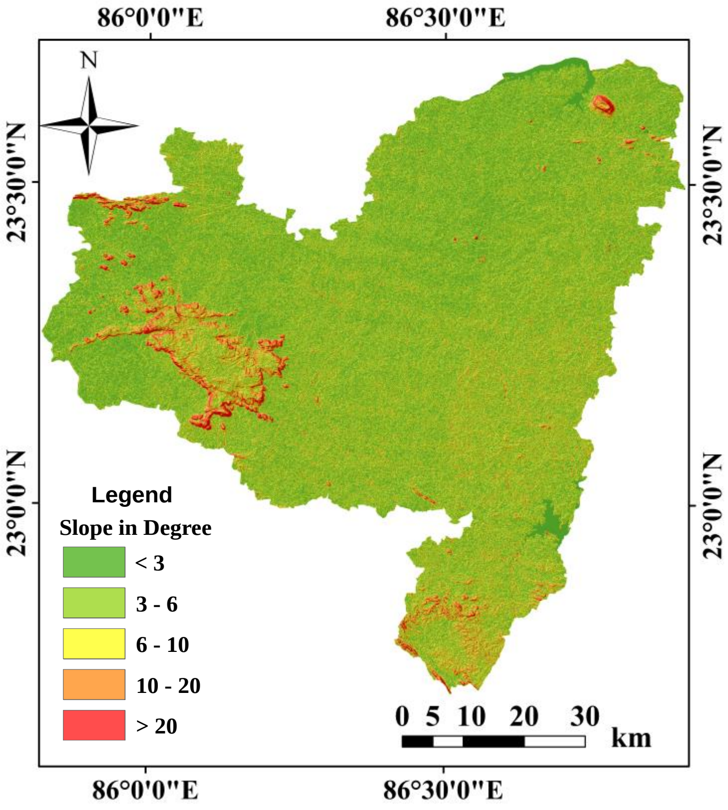

Fig 3.2 Slope map of the Purulia district.

3.5 SOIL

Soil is the foundation of basic ecosystem function that plays a significant role in watershed management, natural resource inventory, and environmental sciences. Soil filters water provides essential nutrients to vegetation and crops.

Red and Lateritic soils are characterized by low water holding capacity, prone to erosion, shallow soil depth and gravels (Murmu et al. 2019). Three types of soils have been observed in the Purulia district viz., residual soil originated from weathering of granites, gneisses and schist, Lateritic soil in the upland areas and Clay loam to clay in the valleys. Soil is mainly acidic, pH varying between 5.5 and 7.2. The nitrogen concentration varies between 0.87 % to 0.036 %. The organic matter contain is very low thereby soil is less fertility. Shallow soil and deep soil occupy 29.5 % and 23.2% of the district. The soils of the district are dominantly loamy sand to loam in texture (32.9%) followed by sand loam to loam (29.5%) and sandy loam to sandy clay loam (23.6%). About 31.1% area of the Purulia is under moderate erosion followed by slight to moderate erosion (21.3%).

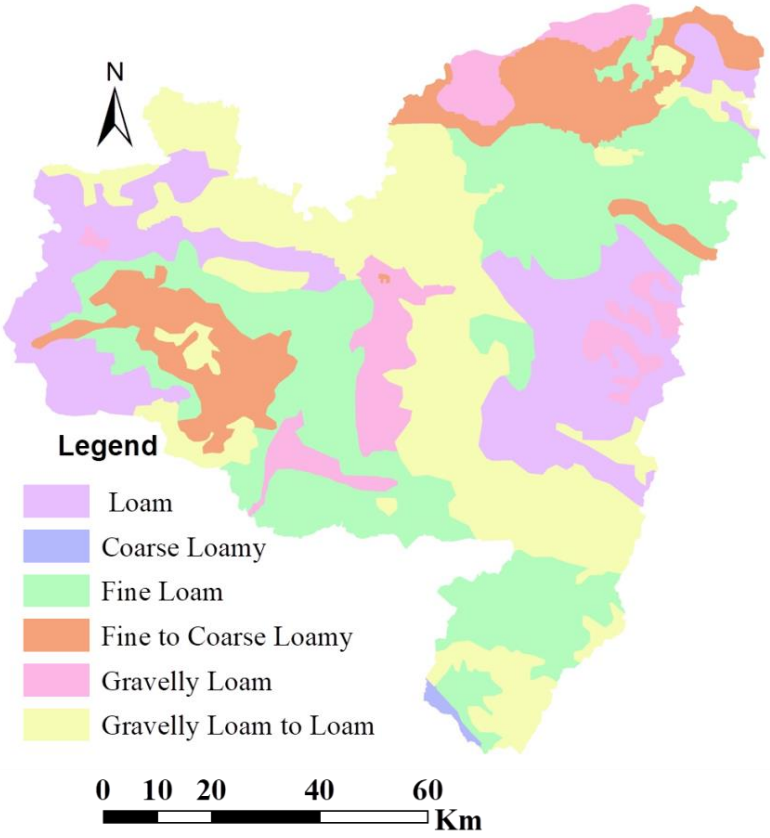

Fig. 3.3 Soil texture map of Purulia district

3.6 GEOLOGY

The Purulia district mainly displayed two geological features viz., a) Granite-gneiss (b) Gondwana landform (NBSS & LUP, Kolkata). The oldest and most extensive rock formation of the district is Granite-gneiss. They comprise granitic rocks, calc-granulites, meta-sedimentaries and metabasics. The former schistose ricks contain phyllite, quartzschist, and quartzite. The granitic rocks comprise gray banded biotite-granite, porphyritic granite gneiss pink granite, and basic rocks that have been intruded by pegmatites and quartz veins. The common Granite-gneiss rock of the district is gneiss. Gondwana sediments are deposited along a narrow belt to the north of the district. A few insignificant patches of laterite have been shown in the easternmost part of the Purulia district.

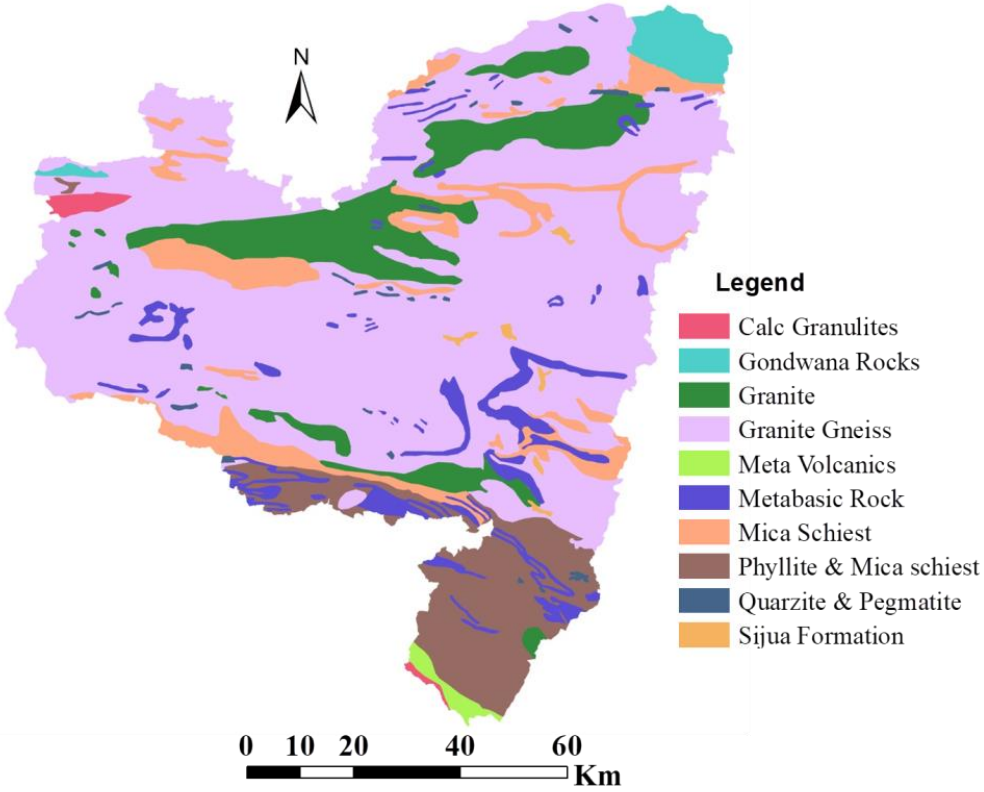

Fig. 3.4 Geological map of Purulia

3.7 LINEAMENT

Lineaments are surface manifestations of structurally controlled features, such as joints, fractures, folds, faults, straight courses of streams and vegetation alignment (Preeja et al. 2010). Earlier studies have shown a positive correlation between lineaments and groundwater recharge and yield (Chandra et al. 2006; Acharya et al. 2012; Das et al. 2018). Lineaments are caused by weathering and enhanced permeability and porosity (Suzen and Toprak 1998). Lineament map was also utilized with other maps such as a drainage map, a correlation can be drawn which will depict a very good result of hydrogeologic information of an area (Dasho et al. 2017). Lineament map is an important tool that may reveal locations of groundwater recharge and flow especially, in undulating hilly areas (Kim et al. 2004).

Lineament map has been prepared by analyzing remote sensing data and was verified using a field survey. Mainly NE–SW and NW–SE, N–S trending lineaments were found in the Purulia (Fig. 3.5). The NW-SE orienting joints act as conduits and facilitate the flow while NE-SW orienting lineaments act as an obstruction of the flow. The lineament density of Purulia ranges from 0.02 to 0.3km/km^2. The entire area is categorized into five groups according to lineament density. Areas (5%) with very high lineament density (0.2–0.3

km/km^2) is observed in the northern and central part of the district whereas, the areas (27%) with very low lineament density (0–0.08 km/km^2) in estern part.

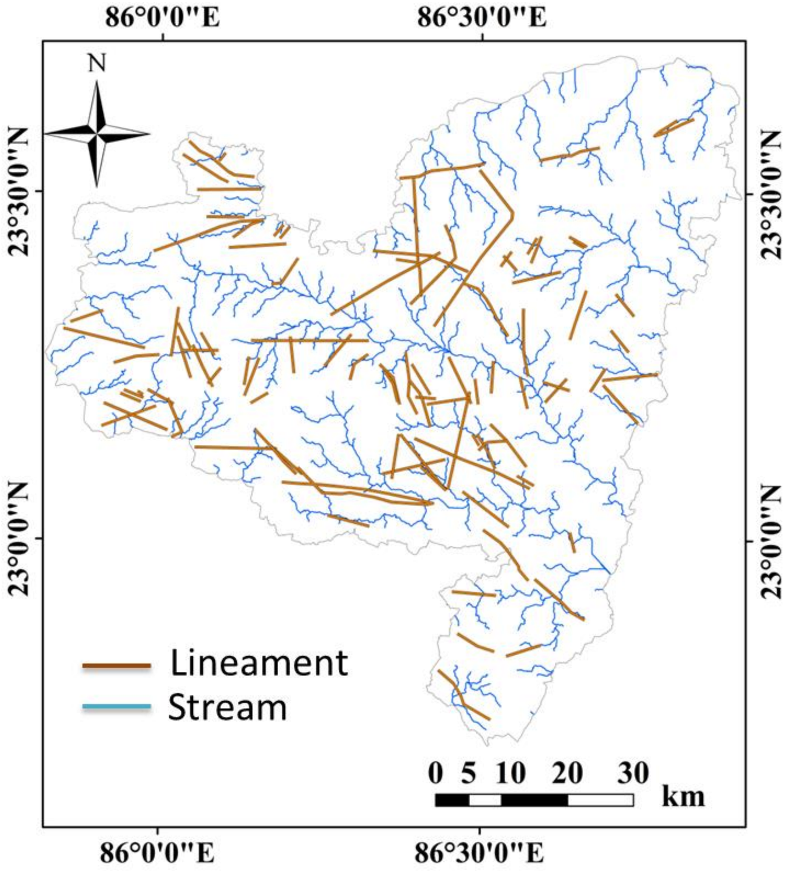

Fig. 3.5 Lineament map of Purulia district.

3.8 WATERSHED DELINEATION

Watershed management refers to describe the process of implementing land-use and water management practices to save and improve the quality of the water and other natural resources within a watershed by managing the use of those land and water resources comprehensively (Martz and Garbrecht, 1992). The micro watersheds of suitable sizes can be delineated by recoding the flow accumulation raster DEM as per the required threshold and overlaying with flow path raster and is suited in the undulating area (Liang and Mackay 2000). Watershed development focuses on ridge area treatment, drainage line treatment, soil and moisture conservation, water harvesting structure, livelihood support activities and other watershed work in rainfed/degraded areas (Tsakiris 2017). Watershed delineation is helpful in decision-making on the action plans towards drought mitigation.

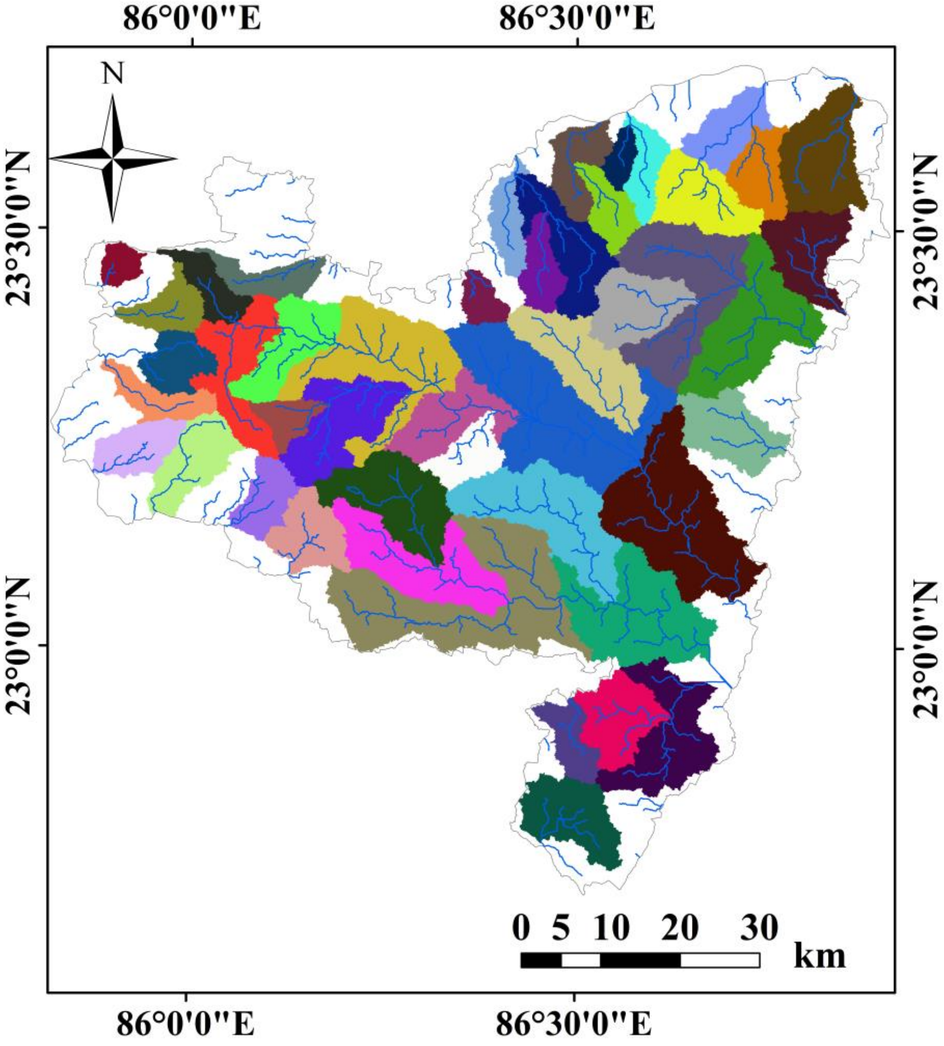

Fig. 3.6 Micro Watershed of the Purulia.

3.9 LAND USE AND LAND COVER ANALYSIS

The land is used for agricultural, industrial, recreational, residential and other purposes. The Land use/Land cover pattern of a region depicts the natural and socio-economic conditions. The land is becoming scant due to enormous agricultural activities and demographic pressure. Land cover denotes the natural vegetative cover and give the basic idea of the local climate and landforms, which may be transformed by human action (Sherbinin 2002). Therefore, information on Land Use and Land Cover (LULC) and potentials for their optimum use are fundamental for the planning and implementation of various schemes to achieve the increasing requires for human basic needs and welfare. This knowledge also helps to monitor the dynamics of land use due to the changing needs of the growing population (Zubair et al. 2006). Land use involves both the method of manipulating the biophysical properties of land are and the underlying intent of manipulating the purpose for which the land is used (Lambin et al. 2001).

Townshend et al. (1991), Amler (1999), Manandhar et al. (2009) and Singh et al. (2020), have proposed a study on, LULC classification using remote sensor data. This study recommended that LULC analysis helps a sustainable use of land in rural areas and the introduction of the appropriate measures for application and monitoring of the land resources.

Land use land cover change detection using remote sensing help in understanding landscape dynamics (Rawat and Kumar 2015). The present study exemplifies the spatio-temporal dynamics of land use and land cover of Purulia district. Satellite imageries (Landsat and Sentinel 1B) of three different years, 2000, 2010 and 2020 were acquired by the earth explorer site and quantified the changes in land use over 20 years (from 2000 to 2020). Supervised classification with adequate field validation has been employed. The classified images of the study area were classified into six different categories namely vegetation, agricultural land, fallow land, upland (pediment), settlement and water body.

Fig. 3.7(a,b and c) depicts spatial distribution of land use/cover of the Purulia for the year 2000, 2010 and 2020 respectively. These data reveal that in 2000, about 16.04% (1005 km^2) area of Purulia was under vegetation, 50% (3136.50 km^2) under agriculture land, 8.5% (517.71 km^2) under fallow land, 0.7% (42.35 km^2) under settlement, 21.22% (1328.72 km^2) under upland (pediment) and 3.5% (218.13 km^2) under water body. In 2010 the area under these land classes was obtained about 12.05% (754.70 km^2) under vegetation, 49.97% (3129.56 km^2) under agriculture land, 13.43% (841.28 km^2) under fallow land, 20.84% (1305.82 km^2) under upland, 1.06% (66.32 km^2) under settlement and 2.64% (165.73 km^2) under water body. In 2020, the area under these land groups was acquired about 15.80% (989.65 km^2) under vegetation, 46.36% (2903.98 km^2) under agriculture land, 17.88% (1119.81 km^2) under fallow land, 14.60% (914.24 km^2) under upland, 1.34% (83.78 km^2) under settlement and 4.02% (251.96 km^2) under water body.

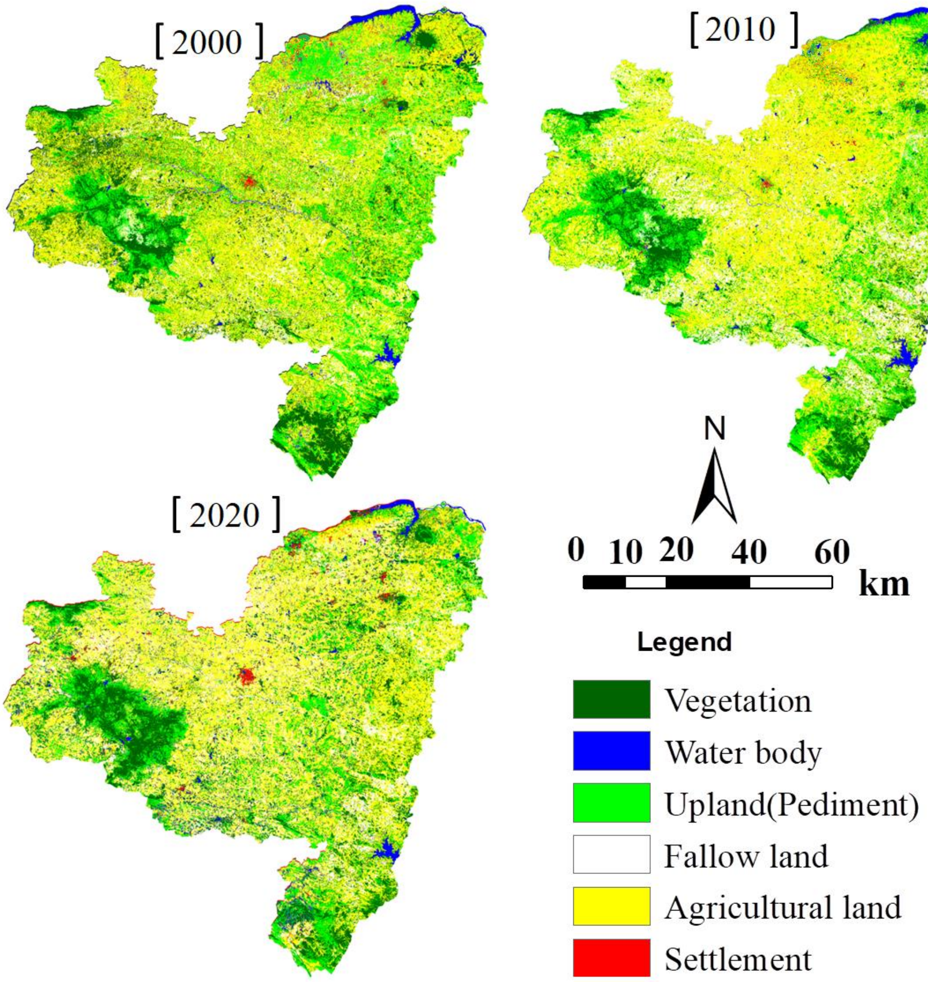

Fig. 3.7 Land Use Land Cover map of Purulia in [a] 2000, [b] 2010 and [c] 2020

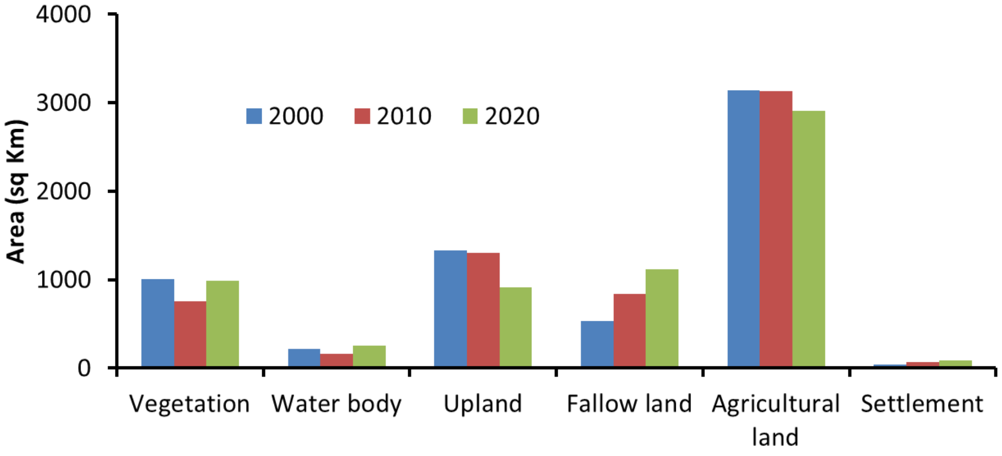

Fig. 3.8 Area in different land use/cover categories in Purulia from 2000 to 2020.

3.9.1 Land use/Land Cover Conversion

Land use is the result of interaction between man and environment in a process of permanent adjustment between contrasting land properties and socio-economic factors (Thakkar et al. 2017). The change in Land use pattern over space and time are thus in response to physical, economic, social and environmental factors (MohanRajan et al. 2020). Land-use conversions have been widely studied owing to their important role in environmental properties, services and influences to regional climate change (Gogoi et al. 2019). Land use present a significant relation between human activities and the natural environment. The increasing demand for food, fodder, fiber and bioenergy is likely to necessitate intensification in productivity or transformation of other land to agricultural use (Pandey et al. 2018). Land use/cover is the purpose of establishing land by human beings (e.g., forestry for plantations, timber products, crop cultivation or human settlements). Humans are the major force of changeing land to provide food, water, shelter, and products for use (De Sherbinin 2008). Land-use change in a course of time leads to the formation of food demand at local, national and international levels as well as in developed countries, developing countries and underdeveloped countries. Land use / Land cover (LULC) alteration is a major problem of global environment change (Prakasam 2010). Monitoring the adverse sequences of LULC change while sustaining the production of fundamental resources have thus become a main importance of policymakers and researchers in globally (Mishra et al. 2020). At global scale, population growth is often utilized as a proxy for land-use transformation, but at regoinal scale, a set of complex drivers is significant (Patel et al. 2019). Rural land use is highly shaped for satisfying the demands of global food consumption by stimulating agricultural production.

The comparative study of maps for three years (2000, 2010 and 2020) revealed the spatial distribution and transforming nature of different land use/land cover classes in the study area, which has been summarized below:

- ♣ The area under vegetation has decreased from 1005 km^2 in 2000 to 754.70 km^2 in 2010 then increase to 989.65 km^2 in 2020.
- ♣ In Purulia, the upland (pediment) has decreased from 1328.72 km^2 in 2000 to 914.24 km^2 in 2020.
- ♣ It has been seen that agricultural land has slightly reduced from 3136.49 km^2 in 2000 to 3129.56 km^2 in 2010, also marginally decreased 2903.98 km^2 in 2020. Waterbody

has also decreased from 218.13 km^2 in 2000 to 165.72 km^2 in 2010 then increased 251.96 km^2 in 2020.

♣ During this period (2000 – 2020) fallow land and settlement have gradually increased by 532.71 km^2 in 2000 to 1119.81 km^2 in 2020 and 42.35 km^2 in 2000 to 83.78 km^2 in 2020 respectively.

3.9.2 The tendency of Land Use/Land Cover Change

The change among different land use/land cover classes is shown in Table 3.4 for the period 2010 to 2020. The changes in the areal extent of a particular class are associated with the changes in the areal extent of one or more classes in the study area.

Table 3.4 Land use/Land cover conversion matrix

Land Use /Cover Change (2010-2020)	Area(km^2)	%
No Change	2887.75	42.55
Agriculture-Fallow	832.43	12.27
Upland-Agriculture	572.13	8.43
Upland-Vegetation	556.18	8.20
Fallow-Agriculture	547.17	8.06
Agriculture-Vegetation	270.16	3.98
Vegetation-Upland	195.69	2.88
Vegetation-Agriculture	192.25	2.83
Upland-Fallow	147.83	2.18
Agriculture-Water	132.49	1.95
Upland-Water	92.65	1.37
Fallow-Vegetation	52.71	0.78
Agriculture-Settlement	47.14	0.69
Fallow-Water	42.25	0.62
Water-Vegetation	39.10	0.58
Vegetation-Water	39.06	0.58
Water-Fallow	37.82	0.56
Vegetation-Fallow	32.05	0.47
Upland-Settlement	26.10	0.38
Settlement-Vegetation	20.95	0.31

The matrix shows that agricultural land has been converted to fallow (12.28%) due to very high summer temperature, low water retention capacity of the soil, insufficient water resources and variability of monsoon rains in recent years and settlement (0.69%) due to population growth. Similarly, the upland has been converted to agricultural land (8.43%), vegetation (8.20%) and settlement due to the demand for agriculture, social forestry and the increasing demand for land for settlement. In some areas, fallow land has been converted to agricultural land (8.06%) and agricultural land has been converted to vegetation (3.98%) and water body (1.95%) due to soil and water conservation. Due to deforestation, vegetation area has been converted to upland (2.88%) and agricultural land (2.83%). However, about 43% of the area that is about 2887.75 km^2 has remained unchanged for over 10 years.

3.9.3 Predicted land use/land cover

Land use/cover conversion models generally seek to detect where the conversion happened or will potentially appear (Veldkamp and Lambin 2001). By knowing the components contributing to the change, the models provide a probabilistic projection of where the change may appear (Halmy et al. 2015). Land use/cover models are performed to evaluate the cumulative accumulative of land-use change and acquire future scenarios, which assist and reinforce land use planning and decision making (Veldkamp and Lambin 2001; Guan et al. 2011; Halmy et al. 2015).

Predicting LULC have been applied in various applications (Pijanowski et al., 2002) such as rural development (Theobald et al 2005), choosing conservation primacy areas and placing alternative conservation actions (Halmy et al. 2015), and simulating land dynamics under various climate change scenarios (Rahaman et al. 2017).

Markov chain assessment is a simple stochastic modelling technique that has been widely used to investigate the dynamics of land-use conversion at various scales (Halmy et al., 2015; Al-sharif and Pradhan, 2014). It can predict multi-directional land-use conversions among all land-use groups (Pontius and Malanson 2005).

Many studies (Guan et al. 2011; Al-sharif and Pradhan, 2014; Mishra and Rai, 2016; Singh et al. 2020) have applied Markov model to predict and simulate land-use transformation over various types of landscapes. Markov approch can be assimilated with cellular automata model which have been employed to project land-use conversion at various scales (Guan et al. 2011; Halmy et al. 2015). The present study used the CA-Markov approach which is a functioned as spatial transition method and it combines Markov techniques with the cellular automata method (Mishra and Rai 2016).

LULC in Purulia has been simulated and predicted using the CA-Markov model for understanding the dynamics of land cover change in Purulia to act as a reference for further planning. Land use maps in 2010 and 2020 were defined as input data to simulate 2030 and 2040 land-use scenarios. Since 2000, due to a slow pace of development, the LULC of Purulia has changed marginally.

According to the prediction results shown in Table 3.5, the vegetation area would increase, mostly at the expense of pediment and fallow land. The increase in the settlement would result in the loss of some vegetation and fallow land. Agricultural land would stagnant due to rainfed agricultural practice which frequently disrupted from inconsistent rainfall. Water bodies are projected to increase slightly on agricultural land, while unused land remained unchanged in the future too, under business as usual scenario.

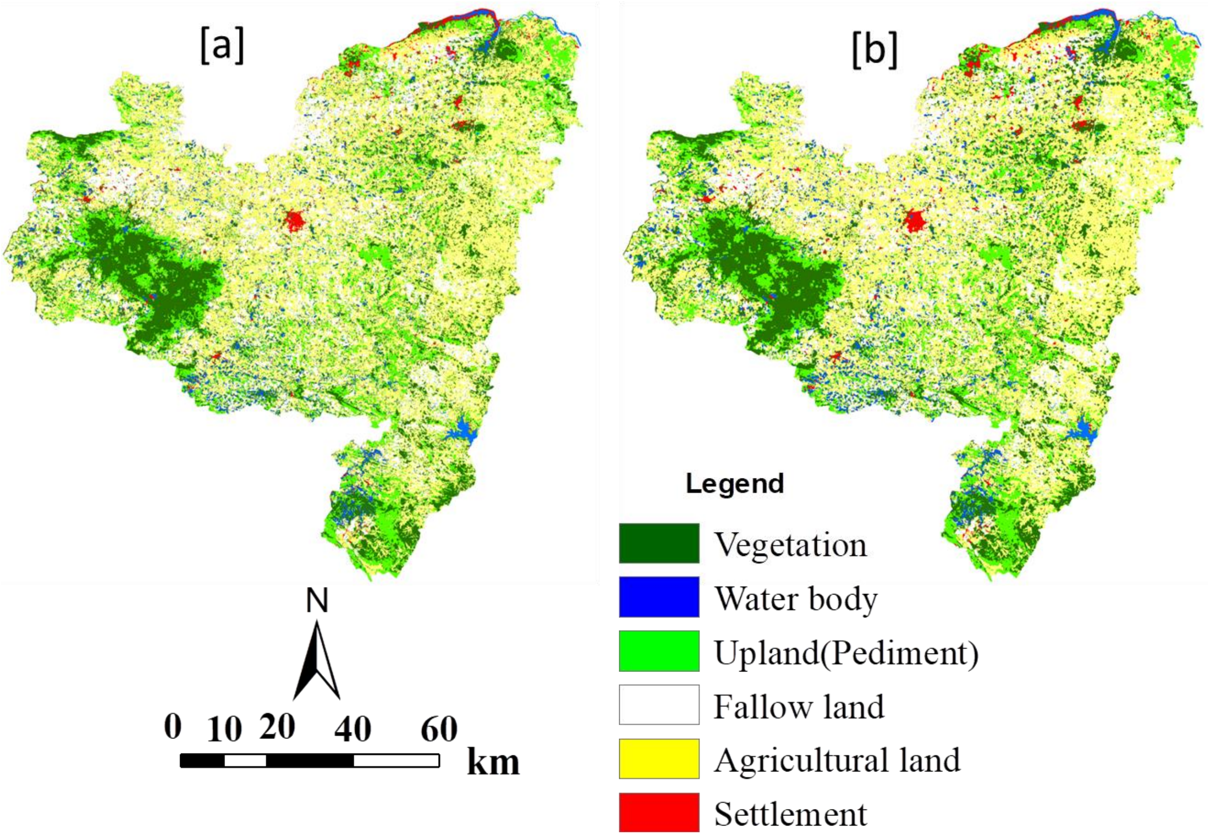

Fig. 3.9 Predicted Land Use Land Cover map of Purulia in [a] 2030 and [b] 2040

Table 3.5 Predicted area in different land use/cover categories in Purulia in 2030 and 2040

land use/cover categories	2030 (area in km^2)	2040 (area in km^2)
Vegetation	1073.32	1117.48
Water body	276.37	285.31
Upland	867.97	862.09
Fallow land	1113.35	1099.84
Agricultural land	2832.90	2791.81
Settlement	99.45	106.83

3.10 DRAINAGE

The Purulia district is a network of several streams. The main rivers of the district are Kansabati, Kumari, Darakeswar and Damodar (Fig 3.10). All the rivers are following the natural slope toward east and south-east courses. All the tributaries of these rivers are non-perennial and subject to flash floods. The Kansabati is the principal river of the district. In general, the drainage pattern of the district is dendritic.

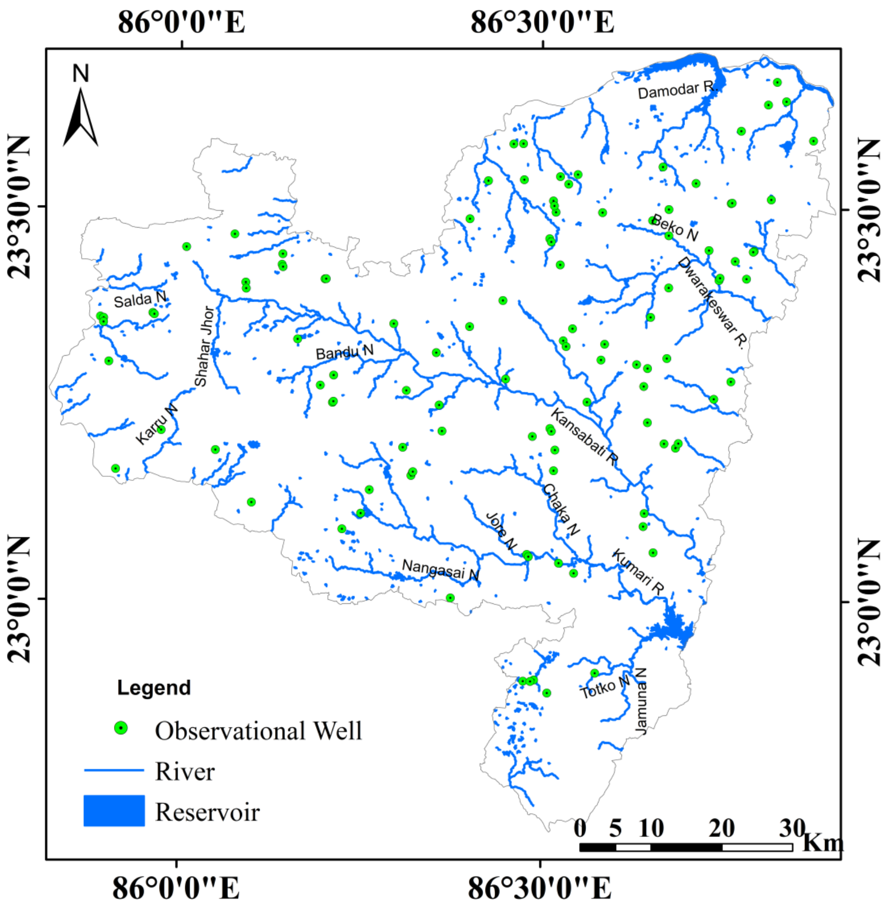

Fig. 3.10 Surface waterbody of Purulia

3.11 DRAINAGE DENSITY

Drainage density reveals the presence of the gaping of the channel as well as surface attributes (Maity and Mandal 2019). Relief, infiltration, runoff and permeability-related information are derived by assessing drainage density and drainage pattern. Drainage pattern provides information associated with surface and subsurface formation, for example dendritic drainage mainly denotes homogenous rocks, the trellis, rectangular and parallel drainage patterns are suggestive of structural and lithological controls (Horton 1945; Singh et al. 2019). Observations from different geologic and climatic zones signify that low drainage density is usually developed in a flat area with dense vegetation and permeable subsoil. High drainage density is occued in steep slope regions with impermeable subsurface under sparse vegetation. Low drainage density depicts coarse drainage texture while high drainage density indicates fine drainage texture (Waikar and Nilawar 2014).

The drainage density in Purulia shows variation from 0.18 to 0.54 per km^2. The low to moderate drainage density occurs in most of the Purulia (75% of the total area) and the highest drainage density (0.4-0.5 km/km^2) was found only in the central part of the district (Fig.3.11).

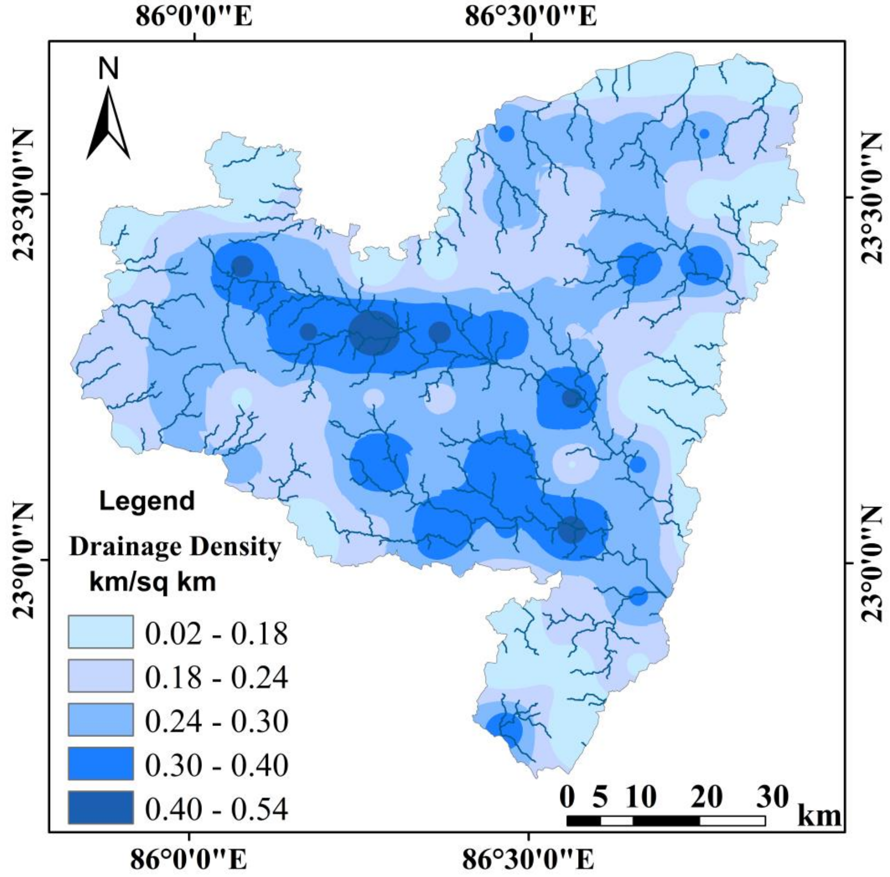

Fig. 3.11 Drainage Density map of Purulia District

3.12 GROUNDWATER LEVEL

The water levels in aquifers are not steady. Groundwater levels mainly are dependent on recharge from infiltration of rainfall**.** When rainfall is less than normal for several weeks, months, or years, the flow of streams and rivers declines, water levels in lakes and reservoirs fall, and the depth of water in wells increases.

The inconsistent monsoon rainfall is the only possible way to recharge the ground-water particularly in Purulia (Nag 1998). Most surface water bodies (river, cannel, and tank) dwindle during the summer season and groundwater becomes the only source of water in Purulia (Ghosh and Jana 2018). Groundwater is mainly tapped in drought-prone Purulia district (Kar et al. 2012) through open wells. Tank and Dug well are the main source of irrigation. Persistent poor rainfall over the years in combination with high temperature hinders ground-water recharge and reveals stress on ground-water, leading to severe drought in many portions during both the wet and dry seasons. Thus groundwater level acts as a causative and responsive parameter for drought analysis in Purulia.

The status of groundwater regions is generally reflected in the water table behavior from monitoring 1236 observation wells (CGWB) to delineate the spatio-temporal variation behavior of groundwater level in Pre-monsoon, monsoon and post-monsoon season. Usually, during the wet season, the water level in the wells rises to 1 to 4 m below ground level (bgl) till the end of October and as the dry season advances the water level gradually falls to a maximum of 7m to 10m *bgl* during April- May. The district is a 'White Zone' in respect of groundwater status though the yield per hour is not adequate. Groundwater resources in the district are 9972 tanks and 4312 wells, serving for irrigation purposes (district statistical handbook 2015).

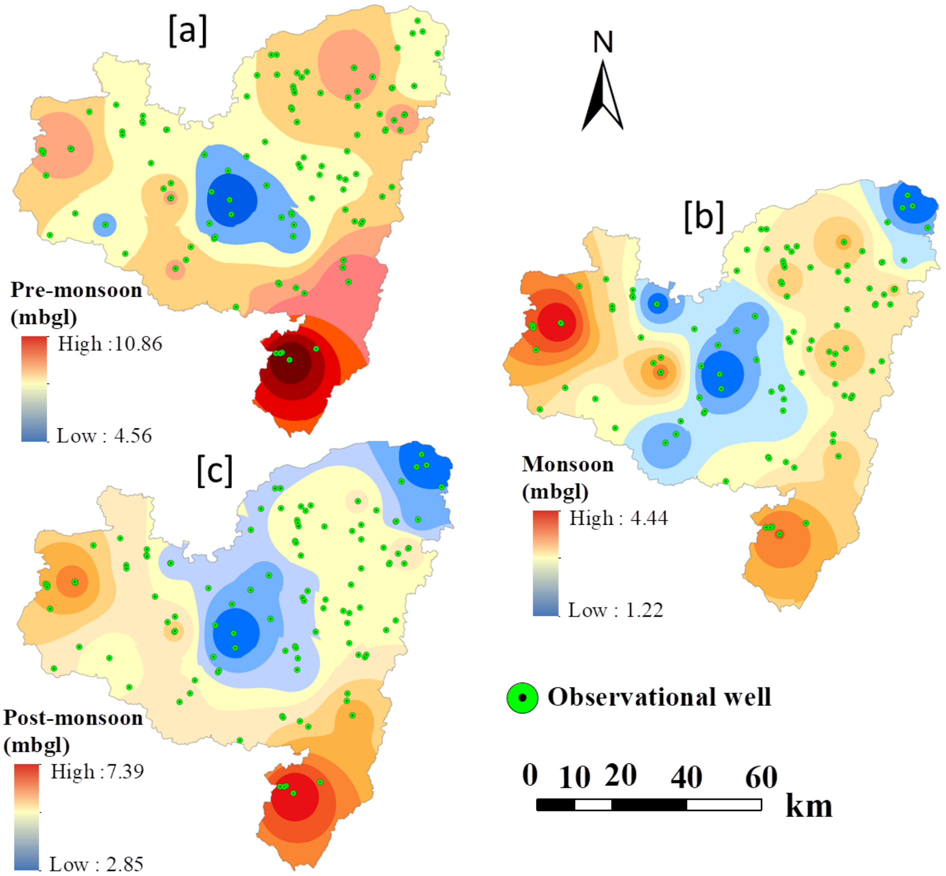

Fig. 3.12 Ground Water Level of Purulia in [a] Pre-monsoon, [b] Monsoon and [c] Post-monsoon seasons.

3.13 SOCIO-ECONOMIC CONDITION

The study of human resources is essential to know the number of people living in the district at a particular time, the growth rate and the composition and distribution of the population according to various criteria.

3.13.1 Demography

Purulia, the westernmost district of West Bengal, is girdled by the Tropic of Cancer. The district has a total population of 2927965 (as per 2011census) of which 2554584 (87.24%) are living in rural areas and 373381 (12.76%) in urban areas. About 51.15% are males and the remains are females. Scheduled castes and scheduled tribes constitute 18.29% (463956) and 18.27% (463452) of the total population respectively. Purulia district is having the second-highest percentage of tribal population (18.3 percent) after Jalpaiguri (18.9 percent) than other districts in West Bengal. People of different religious communities live in Purulia. The majority of the people (about 83.42%) believe in Hinduism. Others have faith in Islam, Christianity, and Jainism, etc.

Table 3.6 Growth of Population by sex on different Census years in the district of Purulia

Year	Total Population	No of Males	No of Females	No of females per 100 males
1901	777801	386741	391060	101
1911	884372	441874	442498	100
1921	831497	416347	415150	100
1931	972077	488804	483273	99
1941	1088201	550477	537724	98
1951	1169097	589507	579590	98
1961	1360016	689351	670665	97
1971	1602875	816544	786331	96
1981	1853801	947195	906606	96
1991	2224577	1142771	1081806	95
2001	2536516	1298078	1238438	95
2011	2930115	1496996	1433119	96

Source- Census of India-1901 to 2011

i) Population growth: Population in Purulia in 2011 increased by 15% over the population in 2001 (Table- 3.6). The sex ratio (the number of females per 100 males) decreased continuously. The block-level study revealed that Kashipur has the lowest population growth (6.9%) and Manbazar – I have the highest population growth (20%). According to Census 2011, Jaipur block has the lowest sex ratio (93) and Bandwan has a heist sex ratio (98).

ii) Age Composition: The study of age composition helps determine the proportion of labor in the total population. According to the 2011 census, the working-age group of the population is considered as 15-60 and 0-14 age group is the age group of child population which reflects the portions of non-productive consumers. A slight change has occurred in favor of the working-age group since 1971.

Table 3.7 Percentage of the population distribution by age group

Year	Age Group		
	0-15	15-60	above 60
1971	41	54	5
1981	39	55	6
1991	38	56	6
2001	35	57	7
2011	38	56	6

Source: District Statistical Hand Book (compiled 1971 – 2011)

iii) Population Density: Table-3.8 shows that the density of the population of Purulia increased continuously since 1971 in both rural and urban areas. The overall density of the population increased from 256 in 1971 to 468 in 2011. In 2011, the highest population density has been observed in Para block (653) and Bundwan has the lowest (259).

Table 3.8 Density of Population (per sq. Km.)

Year	Population Density
1971	256
1981	296
1991	355
2001	405
2011	468

Source: Census of India 1981-2011

iv) Literacy rate: The level of literacy can be judged as one of the determinants of the quality of life. From the figure below it can easily be said that the literacy rate for the district has improved significantly. Especially for the female, it has almost risen by about six times over the 40 years (8.25 in the year1971 and 51.29 in the year 2011). Kahipur block can boast of having the highest literacy rate (62%) with heist female literacy rate (40%). The lowest literate rate has been found in Arsha block (45%) and the lowest female literacy rate has been recorded in Jhalda II (32%).

Table 3.9 Literacy Rate in Purulia (%)

Year	Total Population	Male	Female
1971	21.5	34.27	8.25
1981	35.24	50.74	18.87
1991	43.3	62.2	23.2
2001	55.57	73.72	36.5
2011	65.38	78.85	51.29

Source: Census of India 1971-2011

v) Population Projection: Population projection is an estimate of a future population. The projection may be described as the numerical result of a particular set of assumptions regarding the future population, which deliver a tool for studying the factors of growth and the sensitivity of underlying assumptions. Projections can enhance our understanding of the causes of population change. The most significant use of population projections is in the decision-making processes. Changes in population size and composition have many social, economic, environmental, and political consequences (Miller 2001). Projections of population growth estimates for Purulia in 2021 and 2031 that population will keep growing, reaching an estimated 3310665 people in 2021 and 3748537 in 2031. The population of Purulia is currently growing by approximately 400000 people each year, the growth rate keeps increasing**.**

Table 3.10 Population Projection in Purulia

	Arithmetic	Geometric	Incremental	Logistic	Average
2021	3282884	3306719	3364544	3288514	3310665
2031	3635653	3731728	3880633	3746138	3748538

vi) Employment Scenario: It is evident from Table- 3.11 that the workers especially main workers have decreased and marginal workers have raised during the past two decades. Simultaneously the non-worker population has fairly increased. This implies that the district has been faced an unemployment problem which led to low economic development. The percentage of main workers was 57% of total workers in 2001 and it declines to 49 % in 2011 but The percentage of marginal workers was 43% in 2001 and it increased to 51% in 2011.

Table 3.11 Employment Scenario in Purulia

Category	% Distribution in 2001 Census	% Distribution in 2011 Census
1. Workers	44	43
a)Main Workers	57	49
b)Marginal Workers	43	51
2.Non Workers	56	57

Source: Census of India 2001-2011

vii) Agricultural Worker: Agricultural workers are also classified as cultivators and agricultural laborers. As per 2011 census data, 60% of total workers of the district are engaged in agricultural activity while it has been worked out to be 67% for the 1991 census data. Out of this 35% are cultivators and 65% are agricultural laborers Corresponding figures for the census year 2001 are 46% and 53%. Therefore we can say that the proportion of people engaged in agricultural activity is decreasing and there is a significant migration of occupation from cultivators to agricultural laborers. This is not at all a welcome trend for the agricultural economy. In *Rabi season* a major portion of agricultural laborers usually used to go to another agriculturally developed district for searching jobs.

Table 3.12 Agricultural Workers

	Cultivators			**Agricultural Labourer**		
	Total	**Male**	**Female**	**Total**	**Male**	**Female**
2011	268800	203535	65265	492205	239738	252467
2001	352712	231336	121376	406223	173011	233212

Source: Census of India 2001-2011

3.13.2 Irrigation potential

There are 32 (23 are completed and 9 are in different phases of execution) medium irrigation schemes (17 under Purulia Irrigation Division, 6 under Construction Division and 9 under Investigation and Planning Division) in the Purulia District. There are 135 RLI schemes with an effective command area of 138 ha., out of which 21 are electrified, 114 are diesel operated, of which 16 are permanently defunct and 17 mini RLI in different remote areas have been inducted so far. The water resources are mainly tanks. RLI, open dug wells, and shallow tube well. But these sources are again dependent on good rainfall, judicious and proper use of water. Thus irrigation scenario in the district is not very bright.

Table 3.13 Aera irrigated by different sources during 2014-2015.

Year	**Tank**	**RLI**	**ODW**
2009-10	9963	135	4312
2010-11	9972	135	4312
2011-12	10190	135	4312
2012-13	10441	135	4312
2013-14	10695	135	4297

Source: District Statistical Handbook, 2015

3.13.3 Agricultural land holdings

The average size of landholding in the Purulia district is 0.85 ha and most farmers belong to the marginal category.

Table 3.14 Size of landholdings(2010-2011)

	Marginal	Small	Semi-medium	Medium	Large
Year	Area of holdings	Area of holdings	Area of holdings	Area of holdings	Area of holdings
2010-11	130440	74490	39575	11145	157

Source: District Statistical Handbook, 2014

3.13.4 Infrastructure

Some basic facilities, commonly known as infrastructure, perform a vital task in the economic development of a district. The existing infrastructure of the district has been dealt with in terms of economic and social infrastructures.

1. *Transportations*: Railway and road constitute the transport network of Purulia.

a) Railway Network: The railway divisional headquarters is located at Adra and the broad gauge kilometer range is around 233 km within the division. The district is supplied by 3 rail connections provided by South-Eastern railway with a good number of railway stations. One line runs from Bihar in the south through the district up to Asansol passing through Adra. Another line runs between Bankura and Dhanbad via Adra. The third one connects Jhalda to Chas in Jharkhand. Major cities and towns like Ranchi, Tatanagar, Patna, Howrah, Dhanbad, Asansol, Puri, Bhubaneswar, and New Delhi, etc are now connected with Purulia by direct mail/express trains.

b) Road Network: The road network is not sufficient in terms of availability of bus and flow of goods. National Highway 32 connects Jamshedpur, Bokaro, Chas, and Dhanbad. The state highway (state highway 2 and 4) of the district cover around 211 km apart from Zilla Parishad and major district roads.

2. *Communications*: The total number of post offices is 443, the number of combined offices (Post & Telegraph) is 90, and the number of telephone exchanges is 20 in the district.

3. *Financial Institutions*: The banking and financial network is not adequate having concentration at the municipalities. United Bank of India is the chief bank in the district.

There are 124 branches of commercial banks, 29 branches of R.R.Bs, 7 branches of co-operative banks and 2 non-bank financial institutions. As per the performance report of the banks, the investment towards agriculture and allied sector is low – while that in the industrial sector is promising.

4. Social Infrastructure:

In the Purulia district, there are 2998 primary schools, 197 junior high schools, 163 high schools and 171 higher secondary schools. Besides these, the district also possesses 17-degree colleges, 9 technical schools including polytechnics, industrial training institutes and junior technical schools and 9 technical colleges including 4 B.Ed colleges. One university, named

Sidho-Kanho-Birsha University is newly established; side by side 5 study centers of open universities have in the district.

There is one District Hospital (Purulia), one State General Hospital (Raghunathpur), two State Special Hospital (Purulia), one Central Aided Hospital (Adra), four Private Aided Hospitals, five Rural Hospitals, 15 BPHC and 53 PHCs in the district rendering medical services for the people of the district.

3.14 CONCLUSIONS

In the present chapter, an effort has been made to present comprehensive knowledge of the Purulia as a representative of the sub-humid RLZ of West Bengal.

Monthly Rainfall and temperature trend have been analyzed using the Sen-Slope method for the periods 1901-2019. In the present study, the Rainfall trend showed negative in August and positive in May. Mean maximum and minimum temperature has an rising trend most of the months. Mean maximum temperature increases faster than the minimum.

The district showed diversity in physiography, mainly four types of geological formations have been found. The general elevation of the district ranges between 50 to 600 m above MSL. The gentle slope (< 3˚) occupies about 25% of the total area and the steep slope (> 10˚) is 30% of the total area. The natural slope towards the east and south-east. The alluvial areas are observed in very narrow strips along the rivers. The dominant soil texture of the district is loamy sand to sandy loam (31.87% area of the district). It is observed that very shallow to shallow and moderate shallow soil covers 18.9% and 11.5% area of the district. About 30.6% of % area of the district is under moderate to severe erosion. The pH values in the district vary from 5.7 to 7.8. Mainly NE–SW and NW–SE, N–S trending lineaments/joint features were observed in the study area. Areas with high lineament density were found in the central and western parts of the district.

Land use land cover maps have been composed using supervised classification for years 2000, 2010 and 2020. In 2020, the most extensive land use/land cover category of Purulia was agriculture land, which comprised 46.36% (2903.98 km^2). The second extensive land use category was vegetation, which covered 15.80% (989.65 km^2). land categories were found under fallow land 17.88% (1119.81 km^2), under upland 14.60% (914.24 km^2), under settlement 1.34% (83.78 km^2) and under water body 4.02% (251.96 km^2). Land use land cover change analysis denotes that agricultural land has been transformed to fallow due to very high summer temperature, low water retention capacity of the soil, insufficient water resources and variability of monsoon rains in recent years and settlement due to population growth. Similarly, the upland and fallow land have been converted to agricultural land, vegetation and settlement due to the demand for agriculture, social forestry and the increasing demand for land for settlement. LULC in Purulia has been simulated and predicted using the CA-Markov model for understanding the dynamics of land cover change in Purulia. According to the prediction results, the vegetation area would increase, mostly at the expense of pediment and fallow land. Agricultural land would stagnant due to rainfed agricultural pratic which frequently disrupted from inconsistent rainfall. Water bodies are projected to increase slightly on agricultural land, while unused land remained unchanged in the future too, under business as usual scenario.

In 2020, the area under these land groups was acquired about 15.80% (989.65 km^2) under vegetation, 46.36% (2903.98 km^2) under agriculture land, 17.88% (1119.81 km^2) under fallow land, 14.60% (914.24 km^2) under upland, 1.34% (83.78 km^2) under settlement and 4.02% (251.96 km^2) under water body.

The low to moderate drainage density occurs in most of the Purulia (75% of the total area). The Spatio-temporal variation behavior of groundwater level has been delineated in Pre-monsoon, monsoon, and post-monsoon seasons. In general during the monsoon season the water table range between 1 to 4 m below ground level (bgl) and during the pre-monsoon season the water level gradually falls to a maximum of 7m to 10m *bgl*.

The analysis and result of meteorological, agricultural, and hydrological drought have been described in the fourth chapter.

CHAPTER IV

Assessment of Meteorological, Agricultural and Hydrological Drought Characteristics in Purulia

[This chapter analyzes the changing characteristics of meteorological drought in the sub-humid red and laterite zone of West Bengal. The spatiotemporal variation of monthly agricultural drought during monsoon season is discussed in detail. Suitable indices for identifying different types of drought in the sub-humid red and laterite zone of West Bengal are also discussed herewith. The spatiotemporal variations of hydrological droughts are also included in this chapter. A comprehensive analysis of three types of drought-like meteorological, agricultural and hydrological using spatial-temporal evolution, frequency, duration, intensity, trends of the droughts and their interactions are also described.]

4.1 INTRODUCTION

Drought happens in almost all climatic regions of the world and it remains challenging to precisely recognize the beginning and end of the drought. It has a disastrous effect on human society, economy and environment (Rossi et al. 2000; Obasi 1994). Droughts naturally occur due to rainfall deficiency, it cannot be circumvented but can be forecasted and monitored to attenuate their negative impacts (Agnew 1990; Palmer 1965; Smakhtin and Hughes 2007).

Understanding drought from different perspectives is momentous owing to its complex nature and dealings with crop production, particularly in India (Zhang et al. 2017). In the present study, detailed analysis of meteorological, agricultural and hydrological drought has been carried out at different time series to identify dynamics nature and spatiotemporal distributions. The trends of drought were also analyzed. Additionally, the correlation between crop yield anomalies and drought indices was established to identify the most suitable drought index in the context of climate change. This novel approach to study drought from multiple views provides the knowledge of the most influential drought type, time and area which are essential for local drought mitigation.

Droughts are transmuting due to climate change, consequently, sub-humid east-central India has perceived severe droughts in recent decades and harmed agricultural production causing huge losses agro-base Indian economy. Thus in the present study, changing characteristics of meteorological drought for recent decades concerning far historical period over Purulia district of sub-humid Red and Laterite zone of West Bengal have been evaluated using Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI). SPI/SPEI was computed over 1, 3 and 12-month time scales based on rainfall and temperature to study variation in drought frequency, intensity, duration and spatial extent in Purulia from 1930 to 2019.

Rain-fed agriculture, the most important livelihood for Purulia is severely affected by recurrent droughts, particularly in the wet season. Droughts in humid red and laterite zones of Purulia of West Bengal have so far been assessed through annual variability of rainfall in the district. To improve on the spatial and temporal resolution of drought analysis, the monthly incidences of agricultural droughts during the crop growing wet monsoon seasons have been analyzed from MODIS-derived indices like NDVI, TCI, TVDI and Z_{PET} and SAR (Sentinel 1AC) datasets for the recent decade.

Low water holding capacity, excessive drainage, surface runoff and high soil erosion make RLZ extremely susceptible to slide departure of rainfall (Milly 1994; Milly and Dunne 1994; Sehgal 1998; Mukherjee and Banerjee 2009). In the years of less than normal rainfall, RLZ suffers from water shortage. In summer, most of the surface water bodies like tanks, streams, etc. completely dry up and groundwater becomes major source of water (Nag 1998). Thus, the present study attempts to monitor hydrological drought using the Standardized Water Level Index (SWI).

This chapter makes meteorological, agricultural and hydrological drought analysis for better understanding the status and impacts of drought dynamic.

4.2 METROLOGICAL DROUGHT ASSESSMENT

Globally, climate change has exacerbated drought risks and associated crop failure in recent times (Zhang et al. 2017; Lesk et al. 2016). In India, this risk is greater due to various factors like the variability of monsoon rains (Sharma and Mujumdar 2017; Thomas and Prasannakumar 2016), dominantly rainfed agriculture (Viramarjun et al. 2019; Ward and Makhija 2018), and the livelihood of 75%, people depend on agriculture (Rao et al. 2018) and the growing demand for food population (Kumar and Joshi 2016). In India, the occurrence of meteorological drought is reported to be linked with the shortage of monsoon rainfall while the rising temperatures can potentially increase the drought (Pandey et al. 2019; Bhunia et al. 2020). Due to the erratic and uneven distribution of monsoon rainfall with increasing temperature, drought conditions are prevalent even in the sub-humid regions of India (Pathak and Dodamani 2019). Various studies (Zhai et al. 2020; Sam et al. 2020; Nath et al. 2017; Pai et al. 2017) on drought analysis in India signified an cumulative trend in drought intensity and frequency over the agriculturally important sub-humid eastern part of the country in recent decades. Frequent occurrences of such droughts can threaten food security in this region (Sharma and Goyal 2020). The slight departure of average monthly rainfall from normal in red and laterite zone (RLZ) is very significant in affecting rainfed agricultural production considerably (Brahmachari et al. 2018; Mandal et al. 2018). Subash and Mohan

(2011) also obtained that the monthly monsoon rainfall has been influenced by the variability of Kharif rice yield. Hence an intensive study of the drought of various categories in sub-humid RLZ is very essential.

Although the RLZ understudy obtains an annual average rainfall of 1200 mm, it became more erratic and uneven during the 1990-2000 period compared to the early decades (Mukherjee and Huda 2018). An increasing temperature trend and uncertain rainfall projection over sub-humid RLZ emphasized high sensitivity to climate change (Shukla et al. 2017). In RLZ, monsoon rain has been decreased (Ghosh 2018) while an increase in minimum temperature (0.5-1℃) was recorded in recent decades (Mukherjee and Huda 2018). As a result, RLZ has been affected by recurrent drought (Bhunia et al. 2020; Patra 2020). Rainfed agriculture, low water retaining capacity, extreme drainage, high surface runoff and soil erosion, make such red lateritic zones are more vulnerable to drought (Roy et al. 2020; Asutosh 2019; Mukherjee and Banerjee 2009). The changed Evapotranspiration pattern due to increased temperature and absence of rainfall is expected to increase incidences of drought during recent periods in RLZ (Mandal and Chakrabarty 2013). Latest studies (Bhunia et al. 2020; Banik et al. 2020) indicated that the increase of drought frequency with severe impact on crop production in the RLZ. In the context of climate change, frequent droughts are considered as limiting factors for the growth of agriculture and socio-economic development in this area (Goswami 2019).In recent times, with 43% draught frequency (Nath et al. 2017) over the sub-humid region in India, agricultural production is progressively getting affected (Kumar et al. 2019). A comprehensive study is thus required to identify changing spatiotemporal characteristics of drought occurrence at the regional level in the context of climate variability for better mitigation planning and preparedness.

Various indices for meteorological drought analysis have been formulated based on various parameters (Gupta et al. 2018; Guhathakurta et al. 2017). A detailed description of the drought indices can be obtained in Heim (2002), Mishra and Singh (2010) and Sivakumar et al. (2011). The Standardized Precipitation Index (SPI, Mckee et al. 1993) is one of the most widely used among various drought indices. SPI can be calculated by rainfall data in different time scales (1, 2, 3, 6, 9, 12, 24… months) to assess drought duration, intensity, and frequency (Bhunia et al. 2020). Compared to other indices the SPI has simple calculations and is decisively performed space-independently (Bhunia et al. 2020). Therefore, SPI has already been extensively applied to detect and characterize drought conditions in various countries and regions, such as Turkey (Dabanli et al. 2017), Iran (Awchi and Kalyana 2017), China (Li et al. 2020; Zhang et al. 2019; Xia et al. 2018; Zhang et al. 2017), Bangladesh (Rahman and Lateh 2016), Italy (Marini et al. 2019) and Ethiopia (Belayneh et al. 2016).

The main shortcoming of SPI is that it applies only rainfall data and does not account temperature. Though rainfall is the leading causal factor for drought in sub-humid regions, recent investigates have demonstrated the significance of temperature in affecting the recent propensities in water resources of the region (Gupta et al. 2020; Nath et al. 2017, 2018). The drought index must determine for variations in moisture requirement caused by increased temperature (Pathak and Dodamani 2019). Recently, the standardized precipitation–evapotranspiration index (SPEI) has become popular (Begueria et al. 2010; Vicente-Serrano et al. 2010a, b) to measure the drought characteristics in the context of increasing surface warming (Monish and Rehana 2020; Gupta et al. 2018). The SPEI considers both rainfall and temperature; thereby, performed to be a better index for researching the influences of climate change on drought incidence (Shaik et al. 2020).

Every region has individual climatic characteristics that interact differently with the effect of human activity and climate change. Thus, several recent studies (Li et al. 2020; Pei et al 2020; Wang et al. 2019; Liu et al. 2018; Tirivarombo et al. 2018; Labudova et al. 2017; Xu et al. 2015; Vicente-Serrano et al. 2015) compared SPEI and SPI to identify drought occurrence at the regional level from various climatic regions (Gupta et al. 2019).

Several studies analyzed the occurrence and distribution of meteorological droughts using SPI in India (Das et al. 2019; Adarsh et al. 2019; Joshi et al. 2016; Panday et al. 2020; Aadhar and Mishra 2018; Guhathakurta et al. 2017; Kundu et al. 2020). However, in recent times, various researches used both SPI and SPEI to evaluate the influence of climate change on drought occurrences in India (Singh et al. 2020; Singh and Sukla 2020; Singh et al. 2019; Pathak and Dodamani 2019; Gupta and Jain 2018; Aadhar and Mishra 2017; Alam et al. 2017; Mallya et al. 2016).

The RLZ of Purulia, West Bengal is a sub-humid drought-prone region, numerous researchers analyzed meteorological droughts only with the aid of SPI in long-term time scale (Keskin et al. 2011; Mishra and Desai 2005; Banik 2002 Mishra and Singh (2009) prognosticated that Purulia is likely to experience severe drought with more areal extent during 2001-2050. Analysis using SPI in annual and seasonal time scales also were used to analyze meteorological drought incidences in Purulia for the period 1901–2017 (Patra 2020, 2017; Bhunia et al. 2020; Asutosh 2019).

Previous studies in Purulia only used a rainfall-based single index (SPI) to assess meteorological drought and mainly focused on its long-term (annual and seasonal) behavior. In the perspective of climate change, however, the role of temperature and evapotranspiration appear to have a greater influence (Shah et al. 2015) on meteorological drought, especially for sub-humid regions. Thus evapotranspiration-based SPEI is taken to be a more suitable index for analyzing the influences of climate change on drought circumstance by various recent researchers (Monish and Rehana 2020; Alam et al. 2017; Das et al. 2016). Due to increasing temperature and variability in monsoon rainfall, droughts in India are becoming more regional and a spatial shift has been observed toward sub-humid regions (Mallya et al., 2016). RLZ has witnessed frequently short-term drought in the previous decades (Jha et al., 2013). A comprehensive study of these changing characteristics and trends of meteorological drought is still relatively unavailable in Purulia of RLZ. The effect of changing behavior of drought on crop production is also absent in the preceding studies in the RLZ of Purulia.

4.2.1 Aims and Objective

To address the aforementioned research gap in Purulia, the present study aimed to exemplify the changing characterizes of meteorological drought in terms of its duration, intensity, frequency and spatial-temporal evolution using SPI and SPEI (see Chapter 2.6 for detailed methodology) during the 1930- 2019 period and their influences on Kharif rice yield in recent times. The present study also intends to analyze the trend of meteorological drought and to suggest an appropriate drought index for Purulia. Additionally, for the first time, results have been validated by rigorous field surveys. Such an integrated approach would help to have a refined view on spatiotemporal variability of drought in the region which is necessary for decision-makers and planners to prepare appropriate strategies to reduce the effects of drought on the overall development of RLZ.

4.2.2 Temporal Variation in the SPI and SPEI

The 1-month SPI delivers a monthly valuation of rainfall (Ji and Peters 2003), while the 3-month SPI reflects medium-term (seasonal) propensities in rainfall patterns (Potop et al., 2012) and 12-months estimates provides an annual assessment of water condition. Hence, this study applied the SPI/SPEI values at 1-, 3- and 12-month scales to examine the drought variability and their duration, intensity and frequency at short and long term (monthly, seasonal and annual time scales) respectively. The time-series of all drought indices were studied from 1930 to 2019 which were split into three intervals of 30-year (1930−1959, 1960-1989 and 1990–2019) duration to identify recent changes in meteorological drought events. The present study also focused on the impact of drought on rainfed agriculture of such low permeability RLZs.

Generally, the SPI/SPEI values at the 12-month and 3-month time scales signify the condition of annual and seasonal drought respectively (Wang et al. 2014). The pre-monsoon, monsoon and post-monsoon values were represented by the May, September and January SPI/SPEI values, respectively. Fig. 4.1 shows the annual and seasonal SPI/SPEI series of the entire Purulia during years 1930–2019.

Out of 90 years (1930 to 2019), an annual drought occurred in 47 years (52%). Severe to extreme annual drought (-1.5 to >-2) occurred in 1962, 1966, 1979, 1992, 2000, 2001, 2010 and 2015. The maximum number of severe to extreme annual drought years (63%) have been identified by the SPI/SPEI in the recent period (1990–2019) compared to the first (1930−1959) and second (1960-1989) periods.

Pre-monsoon, Monsoon and Post-monsoon drought events occurred 44, 49 and 41 times respectively during the period 1930 to 2019. In Pre-monsoon and Post-monsoon, the maximum number of moderate to severe droughts (-1.0 to -1.5) have been identified by the SPI/SPEI in the first (1930−1959) and second (1960-1989) periods. But in monsoon, the maximum number of severe to extreme droughts (-1.5 to -2.0) has been found by the SPI/SPEI in the recent period (1990-2019) only.

Monthly meteorological drought assessment found that 56% of the monthly drought was concentrated in June to August while other months experienced 42% of monthly droughts. Extreme droughts were prevalent from May to October, whereas severe droughts were found between February to April. Above 50% of the years, extreme to severe meteorological droughts occurred from June to October. Around 80% of the years, mild droughts concentrated in November and December.

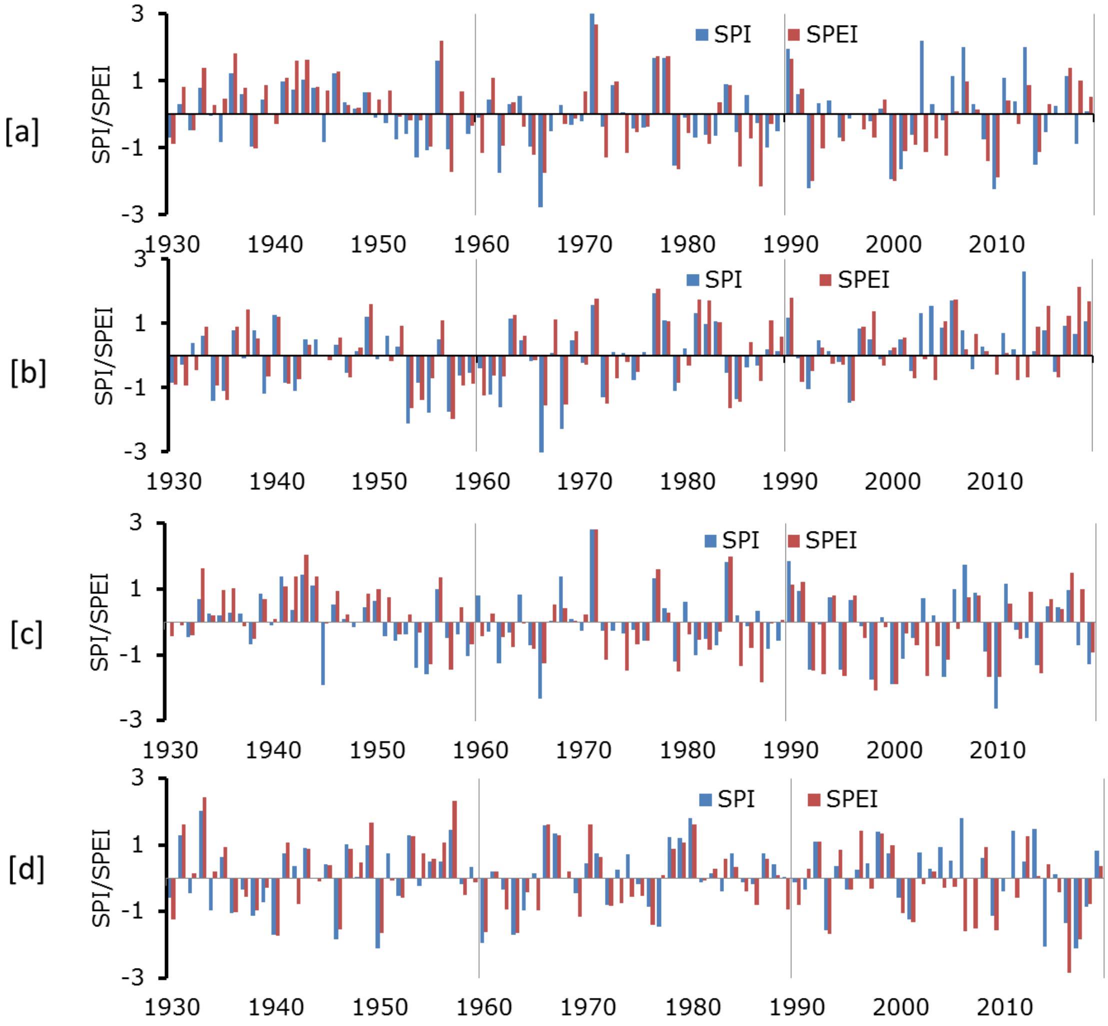

Fig. 4.1 [a]Annual variations of SPI and SPEI values at the 12-month time scale and pre-monsoon [b], monsoon [c] and post-monsoon [d] variation of SPI and SPEI values at the 3-month in Purulia (1930–2019).

4.2.3 Drought Duration

The drought duration recognized by the SPI is commonly regular with that by the SPEI. The annual drought duration identified by both SPI and SPEI was 6-8months during the years

1930–1990, but after 1990, the drought duration was 5-7 months. Maximum annual drought duration (37 months continuous) was identified by both SPI and SPEI from Sep 2000 to Aug 2006. For seasonal drought analysis, 5-7 months duration has been found in the recent period (1990-2019) and 3-5 months duration has been identified in 1930-1990 years.

4.2.4 Drought Intensity

Drought intensity evaluated from the SPI for most years was greater than those from the SPEI in Purulia. For the 12-month timescale, Extreme drought intensity (> -2) was found to occur for times during the years 1990-2019 (1992, 2000 and 2010). In the 12-month timescale, mild drought (i.e., - 0.99 to 0) intensity was observed in 73 % of years, while 20 % of the years were under moderate to severe drought conditions (i.e., - 1.49 to -1.0) and 7% of the years exhibited extreme condition (>-2), 80% of them occurring after 1990.

For seasonal drought conditions, 65%, 24% and 11% years belonged to mild, moderate to severe and extreme intensity respectively in the post-monsoon. While 58% and 41% years under moderate to severe and mild intensity in the pre-monsoon and 53% and 45% years under moderate to severe and mild intensity in monsoon.

Most Extreme to severe droughts have been found in the monsoon season, 85% of them occurring during the recent years (1990-2019). Moderate drought years occurred mainly in the monsoon and pre-monsoon season with a concentration in the first (1930−1959) and second (1960-1989) part of the century. In the second part, around 60% of the years experienced mild droughts in all seasons.

4.2.5 Drought Frequency

The frequency of drought events in the area has been estimated in 1, 3and 12-month time scales by SPI and SPEI. Annual and monsoon extreme drought frequency increased in Purulia for the 1990–2019 period compared to the period of 1930–1990. For Pre-monsoon, monsoon, post-monsoon and annual time scales, moderate and severe drought frequency gradually increase for 1990–2019 compared to the period of 1930–1959 and 1960-1989. But mild drought frequency gradually decreases for 1990–2019 compared to the period of 1960-1989.

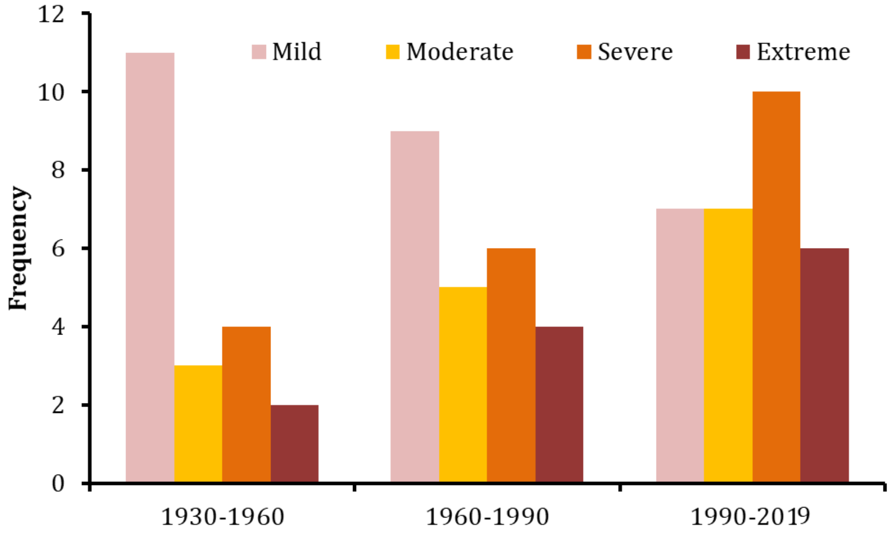

Fig 4.2 Drought frequency

4.2.6 Spatial variability of Meteorological Drought

The spatial distribution of drought maps has been generated by Inverse Distance Weighting (IDW) interpolation method in the ArcGIS platform. A spatial extent with the intensity of seasonal drought was analyzed in three recent drought years (2010, 2015 and 2019) by SPI and SPEI to understand the spatial variation during the recent decade (Fig. 4.3). Drought in the area seems to affect the area first in the west and progresses further to the east and south.

In the pre-monsoon of 2010, the district was under mild to no drought conditions. Due to the deficit of monsoon rainfall, the scenario changed considerably in the monsoon, with 91.45% of the area found to be under extreme to severe drought as identified by SPI while 55 % area could be identified under severe drought by SPEI. However, post-monsoon rainfall drought conditions recovered significantly with the prevalence of mild-moderate drought over 85% of the area in 2010.

In 2015, in the monsoon season, 85% area came under severe drought and the other 10% area was under moderate drought conditions. In pre-monsoon and post-monsoon, all of the areas experienced mild drought to no drought at all.

Latest in 2019, severe drought was observed in the monsoon months in 80% area of the district. Drought beginning in western areas extended to east and southwards. In pre-monsoon, mild drought conditions prevailed in 90% area of the district. But in the post-monsoon, wet condition prevailed all over the area due to good post-monsoon rainfall.

Spatial analysis of propensity of drought incidence identified the western, eastern and southern blocks (Jaldhi, Joypur, Baghmundi, Arsa, Purulia II, Balarampur, Kashipur, HuraBandoyan, Barabazar etc.) to be prone to severe drought. The blocks of the northern part like Para, Raghunathpur, Nituria and Santuriof the study area were prone to mild or no drought.

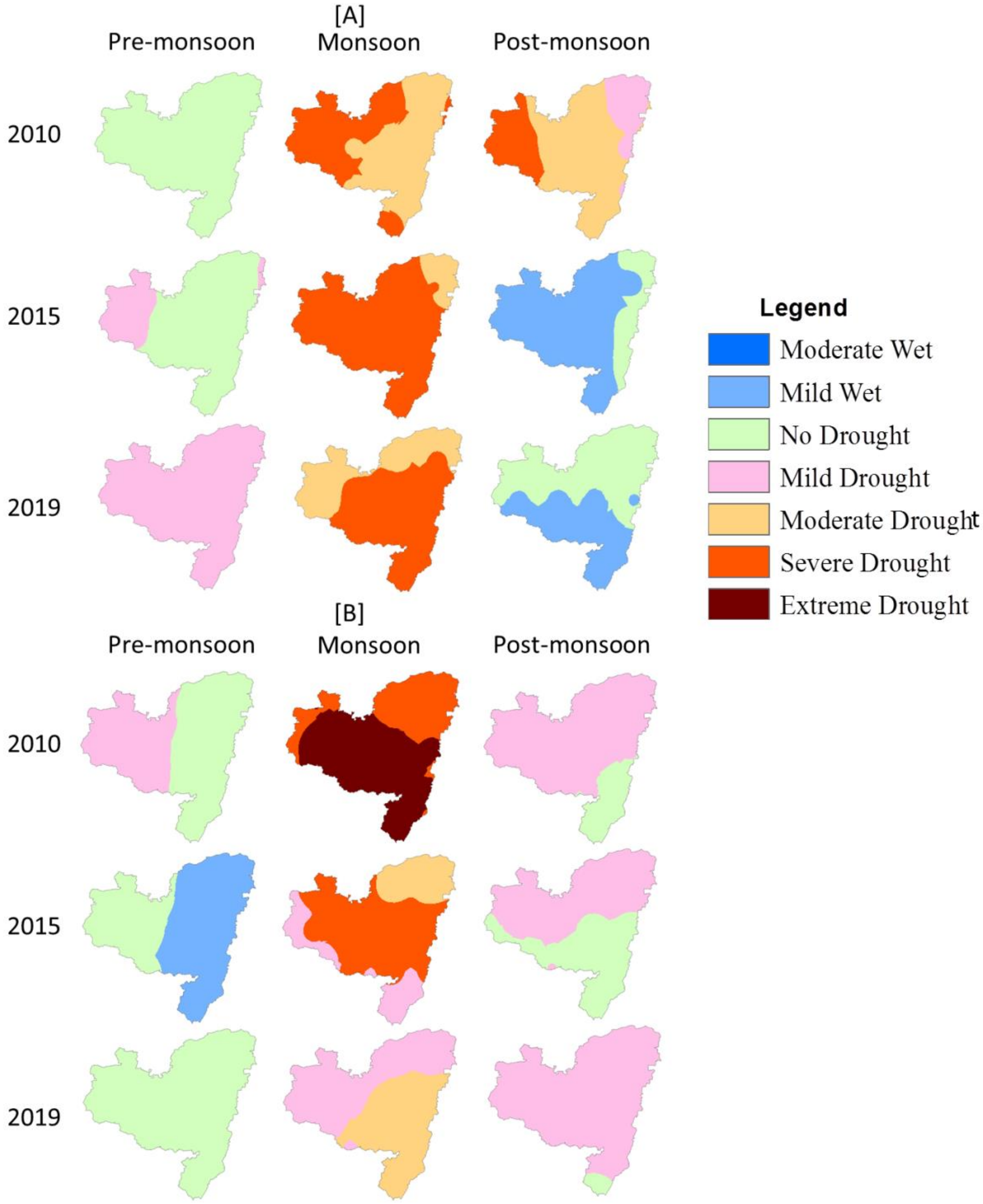

Fig. 4.3 Spatial Variation of drought indices (A) SPI and (B) SPEI for the season of pre-monsoon, monsoon and post-monsoon in the drought years 2010, 2015 and 2019.

4.2.7 Trend analysis

M–K trends and sen's slope were computed from the SPI/SPEI values at the1, 3 and 12-month time scales during the years 1930–2019 in Purulia. On a monthly scale, droughts identified by the SPI increased in August, decreased in May and no trends were obtained in other months. While, those estimated by the SPEI raised in February, July and August (Table 4.1). At the seasonal scale, drought analyzed from the SPEI has rising trends in monsoon seasons, but for that calculated from the SPI, no trends were identified in all seasons. At the annual scale, the increasing annual droughts were detected by the SPEI while no trend was revealed by the SPI.

Table 4.1 M–K trends determined from the SPI/SPEI at the1, 3, 12-month time scales during years 1930–2019 in Purulia

	SPI		**SPEI**				
Month/Season	May	August	February	July	August	Monsoon	Annual
S	917	-1149	-555	-754	-591	-903	-850
VAR(S)	99771	99787.66	71875.66	69416.66	71879.66	71881.66	71880.66
z	2.9	-3.63	-2.07	-2.86	-2.2	-3.36	-3.17
SEN SLOPE	0.11	-0.014	-0.009	-0.016	-0.011	-0.016	-0.016

Trends statistically significant at $P < 0.05$, S = Kendall's S, VAR(S) = Variance of S, Z = Mann-Kendall test

4.2.8 Effect on crop

Rainfed paddy cultivation is a major livelihood for this region. The rain-dependent nature of Kharif agricultural practices in the district makes it vulnerable to soil moisture fluctuations, which is a function of precipitation and temperature during the monsoon season. To understand whether the recent meteorological drought affected the agricultural production in the area, a simple correlation of monsoon-SPI and SPEI with Kharif rice production anomaly was performed. We found that the monsoon SPI and SPEI showed a significant correlation with Kharif rice production (r 2 = 0.6144 & 0.6542) (Fig. 4.4). Fig.4.4 demonstrates that the negative SPI and SPEI indices (<-1) indicating meteorological droughts recorded in the years 1998, 2000, 2005, 2010, 2015 were associated with Kharif crop failures in the Purulia district leading to agricultural drought.

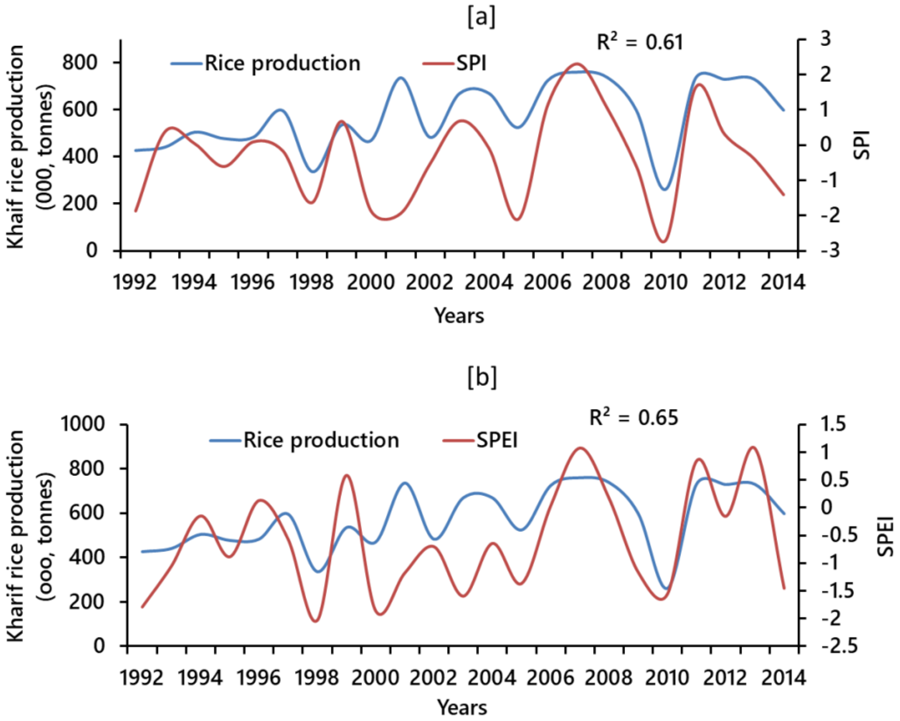

Fig 4.4 Correlation functions of the Kharif Rice production with monsoon (a) SPI and (b) SPEI from 1991 to 2015.

4.2.9 Discussion

Analysis of monthly and seasonal drought characteristics over the last 90 years in RLZ indicates that the most extreme to severe droughts were found in monsoon seasons in the recent century (1990-2019) while maximum moderate droughts were identified in monsoon and pre-monsoon seasons during the first(1930-1960) and second parts (1960-1990). The area was affected by long-term (8-10 month duration) droughts during the years 1960–1990, which were less frequent. But after 1990, the area experienced short-term(4-5 month duration) droughts more frequently. Since 1990, frequently experienced extreme to severe droughts for a short duration in monsoon months over the sub-humid district could be attributed to rainfall variability and rising temperature due to climate change at a regional scale. Climatic variability and occurrence of extreme events during monsoon season for the sub-humid region of India have been attributed to climatic change by various researchers (Sam et al. 2020; Parida and Oinam 2015; Udmale et al., 2014). An increase in evapotranspiration due to global warming would likely play a major role in affecting drought dynamics in the sub-humid region of India (Gupta and Jain 2018) also in the future.

Trend analysis of monthly drought also denotes that the increasing intensity and frequency of drought in July and August when maximum monsoon rainfall is expected. The statistically significant rising trend in monsoon and annual drought at 95% confidence level have been observed by the analysis of SPEI in Purulia. Kumar et al. (2013) had similar findings from Central India where drought frequency increased during the period 1990–2010. Similarly, an increasing trend of frequency and magnitude of the monsoonal drought was observed for the Eastern regions of India (Das et al. 2016). Drought events have increased also in South Asia during the recent decades (Aadhar and Mishra 2017).

From monthly and seasonal SPI/SPEI analysis, non-uniform spatiotemporal characteristics were observed in drought occurrences. In 1998, 2005 and 2015, severe monsoon drought leading to crop failure in the Kharif season could be detected but annually no drought condition was shown because annual rainfall was same as long-term annual mean. On the other hand, in 1993, 1996, 2004, 2007, 2011 and 2012, annual rainfall was greater than the long-term annual mean and drought condition prevailed for Pre and post-monsoon periods. The analysis indicates that the onset and monthly quantum of monsoon rainfall is the driver of drought notwithstanding whether the annual rainfall is greater or less than the normal rainfall. Thus monthly or seasonal SPI/SPEI estimation can be taken up as a more appropriate indicator of drought assessment and preparedness planning. Similarly, Guhathakurta et al. (2017) and Joshi et al. (2016) concluded that the Eastern regions of India showed an increasing incidence of monthly drought during the last half of the 20th century. Results display that the drought trend indicated by the SEPI is mostly compatible with those by the SPI during the years 1930–2019 in Purulia. Moderate drought conditions could be identified in five specific years (1993, 2003, 2004, 2005 and 2012) of the recent times (1990-2019) by SPEI, While no such drought conditions could be picked up by SPI. The correlation of Kharif rice production with SPEI is much significant compared to the SPI. The disparities between the SPEI and the SPI are primarily assigned to the rising of temperature in Purulia. A similar result has been found by several other researchers (Pathak and Dodamani 2019; Gupta et al. 2019; Aadhar and Mishra 2018; Tirivarombo et al. 2018).

Spatial analysis of recent droughts could identify community blocks (Jaldhi, Baghmundi, Balarampur, Bandoyan, Manbazar-II, Barabazar, Para, Raghunathpur, Nituria, Kashipur, Hura, etc.) of the districts to be prone to severe to extreme drought. The spatial analysis identified such blocks in need of special assistance at the time of drought and helps in preparedness planning by augmenting water and agricultural resources.

4.2.10 Conclusion

In the present study, multi-scalar meteorological drought indices, the SPI and SPEI have been used to identify the changing characteristics of drought conditions for 1, 3, 6 and 12-month time scale in sub-humid RLZ (Purulia) over 90 years (1930 to 2019). The Mann-Kendell and Sens's slope tests were employed to quantify trends in monthly drought and spatiotemporal drought characteristics obtained from SPI and SPEI during the recent decade. Further, the relationship between drought and Kharif(monsoon) rice production was analyzed to identify crop failures during identified droughts. Results indicate a minor change in the long-term droughts (12-monthly) condition while a major change is observed in short-term (1, 3-monthly) droughts On a monthly time scale, extreme droughts were found during May to October, while severe droughts were found in the lean periods of February to April. Mild droughts could be found in the months of concentrated in November and December. Among the cases of drought incidences in the region, 50% were found to be of extreme to severe (-2 to -1.5) nature which occurred from June to October between 1990-2019. A majority (53%) of the mild droughts could be identified to have occurred before the 1960s. The long-duration drought of 8 to 10 months prevalent during 1930-1960, appeared to have been replaced by frequent short-duration droughts in the region. Both drought frequency and intensity appeared to have increased in the recent decades. On a seasonal scale, extreme to severe droughts is observed to be more prevalent in the monsoon season of the post-1990 period. Frequent meteorological droughts in monsoon months consequently imparted the loss of the Kharif crop production of the RLZ. From the perspective of the persistent rise of temperature and variability in the monsoon rainfall the changing characteristics of meteorological droughts over the RLZ need immediate intervention to initiate drought preparedness and management planning. The relation between drought and Karif rice production indicates that SPEI functioned as a better index compared to SPI, especially in recent years, when the temperature is significantly higher promoting more evapotranspiration and dryness. Trend analysis of meteorological drought through SPEI index revealed a significant increasing trend in July, August in the monsoon season, which indicates that the sub-humid RLZs may undergo frequent droughts during monsoon months in the future due to increasing temperature. The close correspondence of monsoon meteorological droughts in the Kharif season in the lateritic terrain of poor percolation capability is significant for both water resource and agriculture management of the region The outcomes of our study can be helpful for policymakers, planners, and all the other stakeholders to obtain an initial idea into the better preparedness for droughts, to be monitored monthly for identification in higher resolution. The study also suggested suitable drought indices for RLZ in the context of rising temperature having more pronounced effect on drought incidences of recent times. This understanding of the changing nature of meteorological droughts and increased incidences of short-term droughts in the monsoon season is expected to enhance our ability to plan, manage and implement, sustainable water use and agricultural practices in the face of climate change.

4.3 AGRICULTURAL DROUGHT ASSESSMENT

The recurrent incidence of droughts due to global warming and climatic variability has become a significant concern in recent times (Surendran et al. 2019). The monsoon pattern in Southeast Asia has become highly uncertain in the 20th century. The amount of rainfall and the onset timing has become unpredictable (Loo et al. 2015). Frequent drought incidences have been reported even in sub-humid regions (Trenberth et al. 2014). A holistic understanding of the spatiotemporal variability of droughts in the sub-humid areas has become the need of the hour. Such assessments would help in drought mitigation and risk reduction (Amarnath et al. 2019) in drought-prone areas.

India receives 80% of its rainfall during the monsoon season. The nature of precipitation has become erratic. The onset of monsoon exhibited significant variability in the past decades. Monsoon drought intensity and frequency have increased significantly in the recent decade over India (Panda 2016; Kumar et al. 2013). Monsoon droughts have disastrous effects on agriculture, food security, and rural livelihoods dependent on agriculture (Sam et al. 2020). Therefore, monsoon drought assessment at higher temporal and spatial resolution is essential to improve our present understanding of such short-lived droughts and enhance drought mitigation and preparedness planning.

Even though the sub-humid red and laterite zones (RLZs) of West Bengal (Purulia, for instance) receives an annual average monsoon rainfall of 1000 mm, it rains for only around 30–40 days in a year or during intense storms with 48 to 72 hours span (IMD 2017). The lateritic soil covers the Pre-Cambrian granite gneiss of undulating topography, leading to high surface runoff and soil erosion, which makes Purulia vulnerable to climatic extremes (Das and Bhandari 2017; Ghosh and Jana 2017). As a result, the RLZ has experienced recurrent droughts (Ghosh and Jana 2017; Mukherjee and Palit 2013), which restrict rain-fed mono-crop cultivation in this region and lead to food scarcity. The RLZ has frequently been affected by short-term monsoon drought (Mishra and Desai 2005), often culminating in crop failure during the Kharif season. In the severe drought experienced during the monsoon of 2010, agricultural production in Purulia declined by 7%. For monitoring such droughts in higher resolution, several indices, such as Standardized Precipitation Index (SPI) (McKee et al. 1993) and Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al. 2010) for meteorological drought assessment, standardized runoff index (SRI) (Shukla and Wood 2008) and standardized soil moisture index (Carrao et al., 2016), are available. These indices are based on meteorological data which, even at the sub-district level, are limited due to large spatial coverage of operational weather stations and occasional discontinuity of data set. Advances in satellite-based remote sensing technology have now made such data of different resolutions available for use in agricultural drought assessment (Sanchez et al. 2018; Dutta et al. 2015). High-resolution remote sensing data have provided new directions in agricultural drought monitoring (Yoon et al. 2020; Zhang et al. 2017). MODIS data have been used widely to derive indices that represent agricultural drought intensity with spatiotemporal variation (Faisol et al. 2020; Kukunuri et al. 2020; Reddy et al. 2020).

Several drought indices like Normalized Difference Vegetation Index (NDVI), NDVI anomaly, Vegetation Condition Index (VCI), Temperature Condition Index (TCI), Temperature Vegetation Dryness Index (TVDI), and ZPET have been formulated using MODIS data, and have been accepted globally for identifying agricultural drought in sub-humid regions (Surendran et al. 2019; Junxia et al. 2018; Zhang et al. 2017).

The NDVI, VCI, and TCI have been used for drought monitoring in different regions of India (Reddy et al. 2020; Sarkar et al., 2020; Gumma et al. 2019; Dutta et al. 2015). Gopinath et al. (2020), Chaudhary and Pandey (2020), Sahoo et al. (2015), Sruthi et al. (2015) have used NDVI and TCI for the detection and monitoring of droughts over India. Spatiotemporal variation of the agricultural drought was assessed of using NDVI, VCI, TCI, and TVDI over Uttarakhand (Anjana et al. 2018), Rajasthan and Gujarat (Dhorde and Patel 2016), Telangana and Andhra Pradesh (Bhavani et al. 2017), and Jharkhand (Chaudhary and Pandey 2020).

Agricultural drought assessment is largely based on optical remote sensing because the optical images are easily interpreted. Unfortunately, agricultural interpretations from optical remote sensing are often adversely affected by cloud conditions during the monsoon season in humid regions. On the other hand, Synthetic aperture radar (SAR) can acquire cloud-free images in all weather conditions and obtain information even below the vegetation canopy cover and has better potential than optical data in agricultural remote sensing (Chang et al. 2021; Mandal et al. 2020). Thus, considering the different advantages of optical and SAR remote sensing data, a combination of approaches is expected to produce better results in the identification of agricultural droughts in the wet season.

4.3.1 Aims and Objective

Agricultural drought in Purulia using MODIS-derived vegetation indices has been analyzed by Palchaudhuri and Biswas (2020). They have examined agricultural drought mainly during the pre and post-monsoon season, using only vegetation indices (NDVI and VCI). But Patra, (2020) has observed that Purulia was affected by severe droughts during the 1960 to1980s mainly in the pre or post-monsoon season, while after 1990, Purulia experienced frequent drought in the monsoon season. Multi indices assessment for drought is found to be more efficient than any single or integrated index for short-term agricultural drought assessment in the sub-humid regions (Rhee et al. 2010; Jiao et al. 2019). Agricultural drought assessment in the wet season in the sub-humid RLZ, using higher spatial and temporal resolution, is absent in such earlier studies. The present paper attempts to address these issues through assessment of monthly variability of agricultural droughts during the monsoon season at the sub-district level using MODIS-derived multi-drought indices (NDVI anomaly, VCI, TCI, TVDI, and ZPET) for the period 2005-2015. As a pilot study, SAR data of 2015 and 2020 was used to identify agricultural drought in the monsoon months in the sub-humid RLZ. Such a novel approach might prove to be more efficient in the assessment and monitoring of droughts during the wet season when optical remote sensing data is scarce.

4.3.2 Temporal pattern of droughts

The spatiotemporal variability of droughts was evaluated in the crop growing season (June, July, and August) during the years 2005 to 2019. Monthly agricultural droughts were assessed by five remotely sensed drought indices (NDVI, VCI, TCI, ZPET, and TVDI) and those of 2015 were compared with the backscatter coefficient of SAR data to validate the existence of monthly drought through non-optical remote sensing.

The five indices (NDVI anomaly, VCI, TCI, TVDI, and ZPET) indicated that most parts of the district of Purulia experienced extreme to severe droughts in June (onset of monsoon) of the years 2005, 2009, 2010, 2012, and 2014. Out of the total agricultural land, 65-55% was affected by extreme droughts due to the delayed arrival of the monsoon.

For July 2015, all five indices indicated extreme drought conditions for 75-65% of the agricultural area. In the years 2005, 2009, and 2010, the ZPET, VCI, and NDVI anomalies for July indicated moderate to mild drought conditions with a smaller area suffering extreme drought.

In August 2015, however, the entire Purulia district was found to be under extreme drought, as evidenced by ZPET and TDVI indices. The VCI, TCI, and NDVI anomalies indicated severe to moderate drought conditions in 85-80% of the agricultural area during the same time. Extreme drought conditions in August could also be identified for the years 2009, 2010, 2012, and 2014 in 20% of the agricultural land area using ZPET, VCI, TCI, TVDI, and NDVI anomalies.

4.3.3 Spatial variation of drought

For June 2005, 2009, 2010, 2012, and 2014, all five indices identified extreme agricultural drought in the western upland part (Jaipur, Baghmundi, Balarampur, Arsa, Jaldha I, II, Para and Purulia I, II blocks) of the district and severe drought in the residual pediments of the eastern part (Kashipur, Puncha, Hura, Manbazar, and Raghunathpur). 75-65% of agricultural land suffered extreme to severe droughts (Fig 4.5) during the onset of monsoon.

For July 2005, 2009, and 2010 ZPET, TCI, TDVI, and NDVI anomalies indicated severe to moderate drought conditions in the central part of the district (Puncha, Hura, Kashipur, Purulia I and II blocks) (Fig 4.6). In July 2015, extreme drought prevailed in the western and northeast parts (Para, Raghunathpur, and Kashipur) of the district.

In August 2015, TCI, TVDI, VCI, and NDVI anomalies showed only the eastern part (Hura, Puncha, Kashipur, and Raghunathpur) to be under extreme drought conditions whereas ZPET values identified most of the district to be under extreme drought. For August 2005, 2009, 2010, 2012, and 2014, all indices identified severe to moderate droughts (30-25% of agricultural land) scattered over the region with extreme drought in the eastern part of the district (Kashipur, Hura, Para, Purulia I and Puncha blocks) (Fig 4.7).

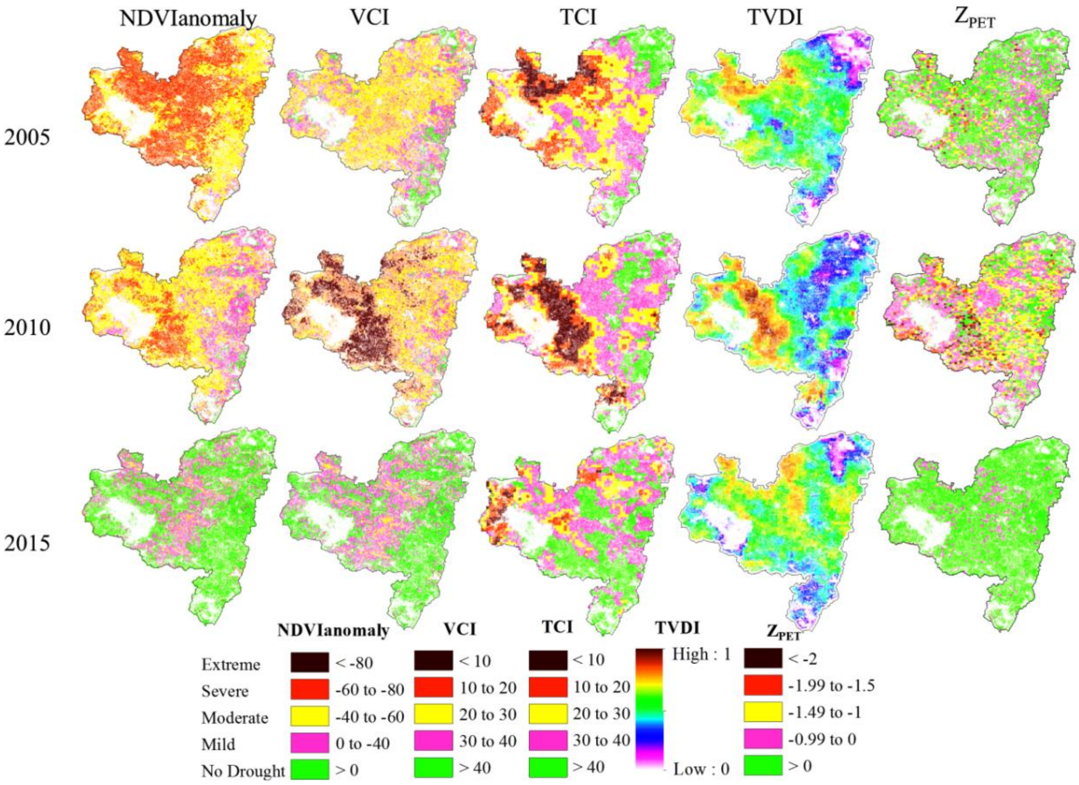

Fig. 4.5 Drought conditions assessment by multiple drought indices of Purulia for 2005, 2010 and 2015 in June.

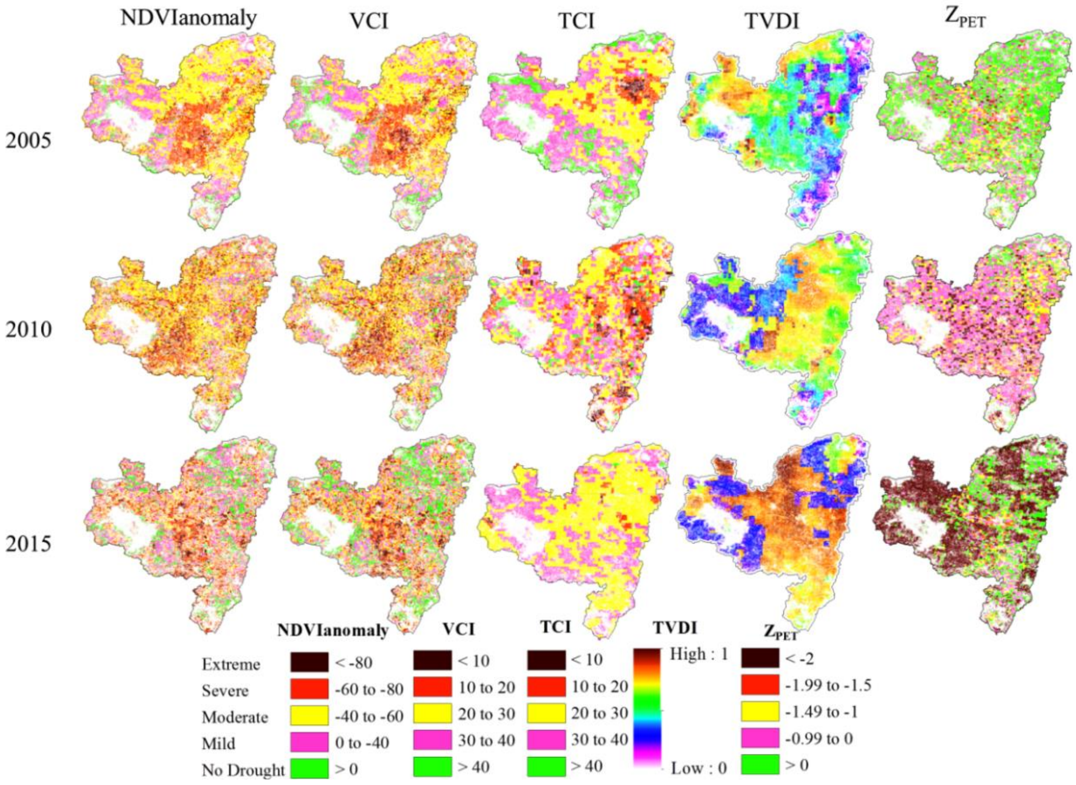

Fig. 4.6 Drought conditions assessment by multiple drought indices of Purulia for 2005, 2010 and 2015 in July.

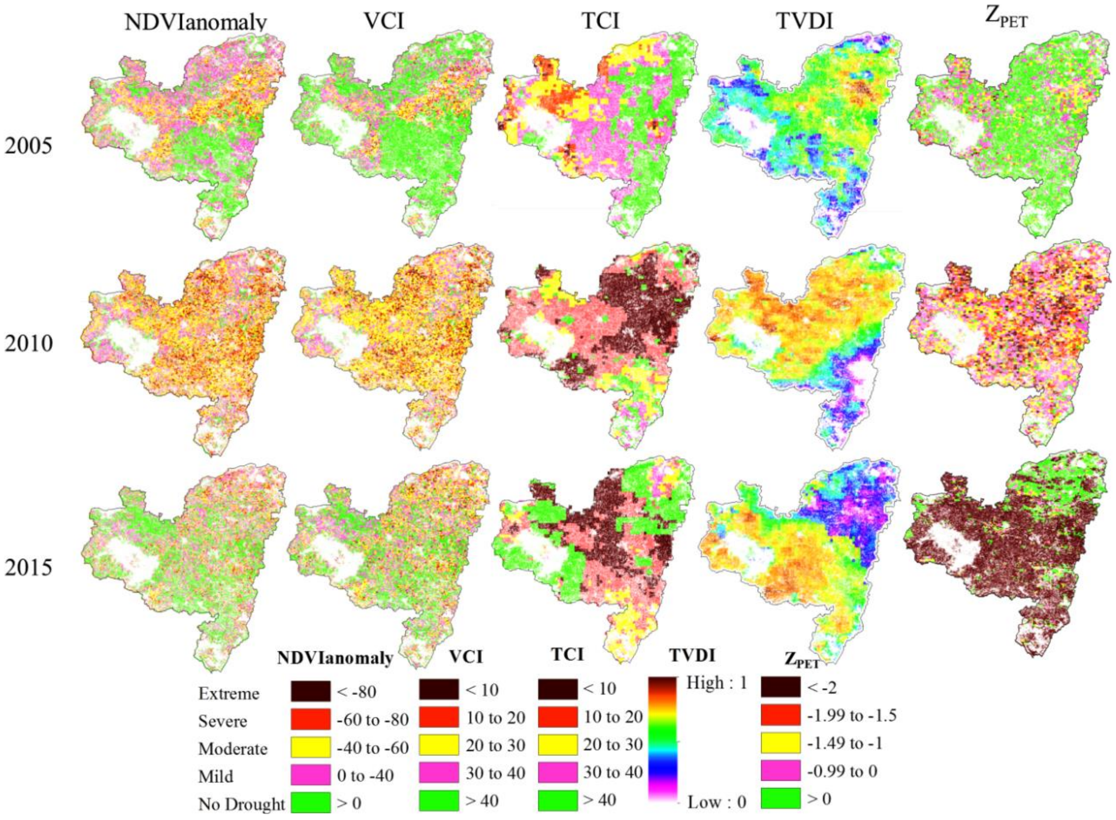

Fig. 4.7 Drought conditions assessment by multiple drought indices of Purulia Purulia for 2005, 2010 and 2015in August.

4.3.4 Monthly temporal correlation comparisons

Five remote sensing-derived monthly drought indices (ZPET, TVDI, TCI, VCI, and NDVI anomaly) were correlated and validated with in-situ meteorological indices like 1-month SPI and 2-months SPEI. Among the remotely-sensed indices, the correlation (r2-values) of ZPET with SPI-2 was maximum (0.851) with the lowest RMS error (0.72). As shown in Table 6, the r2-values of TCI and TVDI were also higher with SPEI-2 than with SPI-1. This suggests that the correlations ZPET, TVDI, TCI with SPEI-2 describe the temporal similarity of moisture conditions with the temperature-driven evaporation. The r2-value (0.596) of NDVI anomaly with SPEI-2 was lower than the TCI, TVDI, and ZPET (0.598, 0.686, and 0.801), but the r2-value of NDVI anomaly with SPI-1 was observed to be significantly greater (0.771). This indicates that the NDVI anomaly is linearly correlated with rainfall. Therefore, under warming conditions, ZPET is more preferable and has a significant advantage over the NDVI anomaly, unless the warming has been accompanied by monthly rainfall deficits.

Table 4.2 Correlation coefficients (r^2-values) and RMSE between in situ drought indices (SPI-1month and SPEI-2months) and five remote sensing derived drought indices. $p < 0.05$ in all cases.

Drought indices	**r^2 value n=5250**		**RMSE**	
	SPI 1-month	**SPEI 2-month**	**SPI 1-month**	**SPEI 2-month**
NDVI anomaly	0.771	0.596	0.82	1.13
VCI	0.323	0.378	1.40	1.35
TCI	0.581	0.598	1.03	0.96
TVDI	0.678	0.686	0.95	0.83
Z_{PET}	0.512	0.851	1.14	0.72

4.3.5 Monthly Drought Assessment Using SAR

As Paddy is the dominant crop in the wet Kharif season in Purulia, the monthly radar backscatter coefficients of rice fields indicated detailed growing profiles for the years 2015 (a drought year established from the previous analysis) and 2016, 2017, 2018, 2019, and 2020 (non-drought years). σVH0 values were compared for the identification of rice growth stages of the successive years. Fig. 6 shows the differences in monthly backscatter profiles of agricultural land chosen from the training data at VH polarization for drought year (2015) and non-drought year (2016, 2017, 2018, 2019, and 2020).

In 2015, the mean (of 450 paddy fields) σVH0 values during the monsoon crop growing season (June, July, August, and September) were −17, −16, −24, and −19 dB respectively, while in 2016, the same for the respective months were −19, −17, −14, and −18 dB respectively. In normal years, σVH° gradually increased and reached a maximum at the heading period in August. But in the drought year 2015, higher backscatter values increased in June but decreased significantly in July and August due to rainfall deficit (established from monthly SPI observations), signifying deterioration of health of the rice plants during the maturation period. Similarly, the maximum ANB of rice appeared in the heading stage of the rice growth in normal years. While in the drought year, the ANB values gradually decreased and appeared minimum at the heading stage.

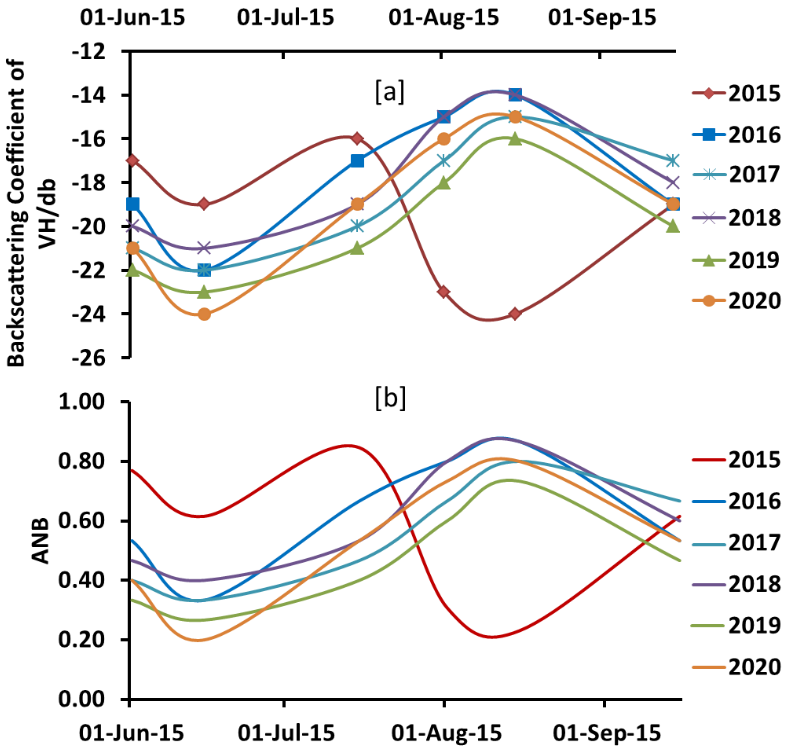

Fig. 4.8 [a]Backscatter coefficient (σVH°) and [b] ANB of paddy fields during their growth stages from 2015 to 2020.

4.3.6 Discussions

The present paper aimed to detect the quantum and variability of monthly agricultural droughts in the wet season by various remote sensing indices validated by meteorological data of the Purulia district in the RLZ of West Bengal, India. A pilot study using SAR data was conducted for drought and non-drought years to understand its efficacy, particularly during the cloud-covered period when optical remote sensing data is scarce. The crop failure index enabled us to assess the block-level impact of these monthly droughts (in the monsoon season) on crop production.

The result showed that ZPET, TVDI, NDVI anomaly, and TCI showed a comparable regional distribution of drought in the study region. From the monthly drought analysis, inconsistent temporal trends in drought variability were observed over the wet monsoon season in Purulia. In 2015, the wet condition in June was quickly succeeded by extreme drought during July and August, leading to crop failure, though, in that year, the district received a fair amount of rainfall (1000 mm) as a whole. On the other hand, in 2005, 2009, and 2010, the monsoon rainfall was less (81, 100, and 300 mm) than the long-term monsoons mean (1000), and moderate to extreme drought conditions prevailed in June and August, leading to crop failure. The analysis sheds light on the fact that it is not the total rainfall deficit in a year but the monthly deficit of rain in the wet months of crop growing season that perpetuate droughts in the RLZ and lead to loss of Kharif crop production.

Bandwan, Jaipur, Balarampur, Arsa, Baghmundi, Jaldha, Purulia, Barabazar, Puncha, Hura, and Kashipur blocks were most affected by drought-associated crop failure in the growing season during the years 2005 to 2019. The investigation showed that delayed onset of monsoon, spatial variation of monthly rainfall, rising temperature, low irrigation facility, moderately high topographic slope (35% of agricultural land with over 5° slope), low infiltration potential of the gravelly loamy soil, and high soil erosion are the main reasons of high drought incidence in such areas. These outcomes resulted in unemployment, chronic poverty, and high out-migration of agricultural labor (Ghosh and Mal, 2017). The correlation coefficient analysis suggests that ZPET has superior performance than other indices in most goodness-of-fit measures.

The pilot study used SAR backscatter coefficients for the first time in the region to identify monsoon agricultural droughts. Water layers are smooth and homogenous, causing reflected radar pulses to be weak and the backscatter coefficient is low in the sowing of the rice growth period. During the vegetative to heading period, the backscatter coefficient showed a significant increase, due to the volume scattering from within the rice canopy and multiple reflections between the plants and water surface. The backscatter then decreases slightly during the reproductive to harvest period, because the water content of the plant decreases (Chang et al., 2021). The declining $\sigma°$ value of paddy fields in July and August 2015 could bring out monthly droughts of 2015 compared to the normal or non-drought years. This finding matches the results obtained from MODIS-derived indices. Therefore, the present approach of using MODIS and SAR data in combination is proved to be more appropriate in identifying agricultural droughts in growing seasons in higher spatial (sub-district) and temporal (month) resolution, and thereby reaffirms the contention of Blaes et al., (2005) and Forkuor et al., (2014) on the use of SAR and MODIS data to evaluate monthly agricultural droughts with higher accuracy in the sub-humid region.

4.3.7 Conclusions

The present study applied a new approach for monthly agricultural drought assessment using multi-temporal MODIS and SAR data. Monthly drought analysis based on the remote sensing indices identified that drought has inconstant characteristics. Monthly droughts resulting in crop failures are not often decipherable from yearly rainfall deficit (as in the years 2005 or 2015 showing near-normal rainfall). However, in 2010, the monthly drought analysis for the monsoon months indicated crop failure, supported by less than usual yearly rainfall and crop failure data. Drought intensity was variable in the wet season months, peaking in June (2010) or August (2015). The comparison between MODIS-derived indices (NDVI anomaly, VCI, TCI, TDVI, and ZPET) and meteorological drought indices (SPI-1 and SPEI-2) revealed that ZPET, TVDI, TCI, and NDVI anomaly provides a reasonable accuracy. The monthly decline (July and August) in the backscatter coefficient in 2015 indicated the agricultural drought during the growing season. Assessment of the block level drought-affected area and crop failure showed that Bandwan, Jaipur, Balarampur, Arsa, Baghmundi, Jaldha, Purulia, Barabazar, Puncha, Hura, and Kashipur blocks experienced frequent drought and crop failure in the growing season during the years 2005 to 2019. The new approach (MODIS and SAR data combined) happens to be fruitful for drought assessment in higher resolution in a short time. It enabled us to pinpoint the areas (blocks) at risk of agricultural drought during the monsoon season. It is envisaged that drought preparedness planning for such regions requires a complete change in approach at the grass-root level, with scope for addressing spatial and temporal variability of drought impact. This study improves our understanding of agricultural drought in wet months and also helps in micro-level preparedness planning. This approach served as an effective tool for risk reduction, particularly in the face of climate change and water scarcity. Such analysis needs implementation for planning hydrological interventions at the micro-level for water security.

4.4 HYDROLOGICAL DROUGHT ASSESSMENT

Hydrological drought refers to a paucity of the surface and subsurface water source (Zhang et al. 2017). It might be a effect of the long-term meteorological drought that caused the reservoirs, lakes, streams and rivers become dry and falling-off in groundwater levels (Khanna et al. 2018; Rathore, 2004).

India is one of the recorded susceptible drought-prone countries in the world (Mishra and Singh 2010) and adversely affects agriculture, socio-economic activities, livelihood, human and animal health and sustainability of natural environments (IPCC 2007; Mishra and Singh 2010). In India, the southwest monsoon from June to September makes around 70–90% of annual mean rainfall (Kumar et al. 2013). Departure of the monsoon rainfall may lead to a scarcity of accessible water that may cause in droughts. In the previous five decades (1960–2010), droughts have appeared at least once every three years in India (Mishra and Singh 2010). Monsoon droughts considerably impact on agricultural production, water resources and the economy of the country. Thus the seasonal variation of hydrological drought is beneficial for the mitigation of extreme droughts and is supposed to reduce drought-caused losses. Therefore, study of the transmission from meteorological to hydrological drought has important practical meanings.

In the Purulia district, the agricultural productions mainly depend on the variation of southwest monsoon rainfall (Banik et al., 2002). Although Purulia receives high annual rainfall (1331 mm), the western and southwestern parts of Purulia are affected by drought (Ghosh and Jana, 2017. This drought-affected district lacks adequate water supply, even for drinking water, in years of below-normal rainfall. In the summer season most of the surface water suppliers like tanks, streams, etc., become dry and groundwater remains the only source of water source (Nayak et al. 2020). Due to lack of irrigational facility, cultivation of more than one crop is mostly not possible in most of the region (Nag 1998). In the recent decade, global warming is resulting in frequent extreme events such as droughts in sub-humid regions of India (Sajeev et al. 2021; Surendran et al. 2019; Pathak and Dodamani 2019; Pandey et al. 2008). Increased variability in precipitation and the frequency and intensity of drought tends to increase under a warming climate. Generally, the hydrological drought is occurred after the meteorological drought, and the corresponding transmission time varies on local landscape conditions (Pandey and Ramasastri 2001). Hence, analyses focused on the transmission from meteorological to hydrological drought and their associations (Vicente-Serrano and López-Moreno, 2005; Van Loon and Laaha, 2015; Barker et al., 2016) which is significant to reveal drought mechanism and progress process, thus helping establish drought early warning system.

The hydrological drought occurs when groundwater recharge deviates negatively from the normal events (Tallaksen and Van Lanen, 2004). Groundwater drought adversely affects water availability for agriculture, public supply and industry; and unlike surface, water groundwater takes a significantly longer time to be replenished (Khanna et al. 2018). Thus, groundwater levels can be used as a key variable to assess hydrological drought. Numerous studies employed SWI for evaluating hydrological drought over various regions worldwide. Mohammad et al. (2018) calculated SWI using the mean seasonal groundwater level of 22 years for evaluating hydrological drought in Yarmouk Basin (Jordan). Potopova et al. (2019) detected the impact of hydrological drought on agricultural using SWI in the Prut river basin, Europe. Hydrological drought conditions were assessed for pre-monsoon and post-monsoon seasons using SWI in different regions of India (Bhuiyan 2004; Sahoo et al. 2015). Mishra and Nagarajan (2013) estimated hydrological drought by SWI in Tel watershed of Orissa.

Drought usually starts from a deficit in precipitation, known as meteorological drought, which further translates to hydrological drought (Mishra and Singh 2010). Various previous studies (Kundu et al. 2019; Khanna et al. 2018; Huang et al. 2017; Barker et al. 2016) have emphasized drought monitoring, there is a gap in hydrological and meteorological drought. The gap in hydrological and meteorological drought is used in monitoring and early warning which helps in drought preparedness planning (Barkar et al., 2016). Xu et al. (2019) explored propagation between meteorological and hydrological drought using standardized indicators. Hence, it is essential to examine the hydrological drought is crucial to effectively manage drought risk (Van Lanen, 2006; Peters et al., 2006; Van Loon and Laaha, 2015).

4.4.1 Aims and Objective

In the present study, the spatial-temporal hydrological drought variability has been evaluated using SWI based on seasonal (pre-monsoon, monsoon, post-monsoon Kharif and rabi) time scales. The SWI was calculated based on 24 years (1996-2019) of groundwater level data from 1236 wells. The trend of the hydrological drought was also investigated.

4.4.2 Temporal variability of hydrological droughts

In the Monsoon season, extreme drought has been shown in the years 2002, 2005, 2009 and 2010. Severe to moderate drought occurred in 1998, 1999 and 2015. During the post-monsoon Kharif season, 2001, 2005, 2009, 2010 and 2015 has experienced severe to moderate drought. In the post-monsoon Kharif season, 2002 and 2015 face severe to moderate drought and remain years face moderate drought. In the years 2009 and 2010 experienced extreme to severe drought and 1999, 2000, 2006, 2011 and 2016 experienced mild to moderate drought.

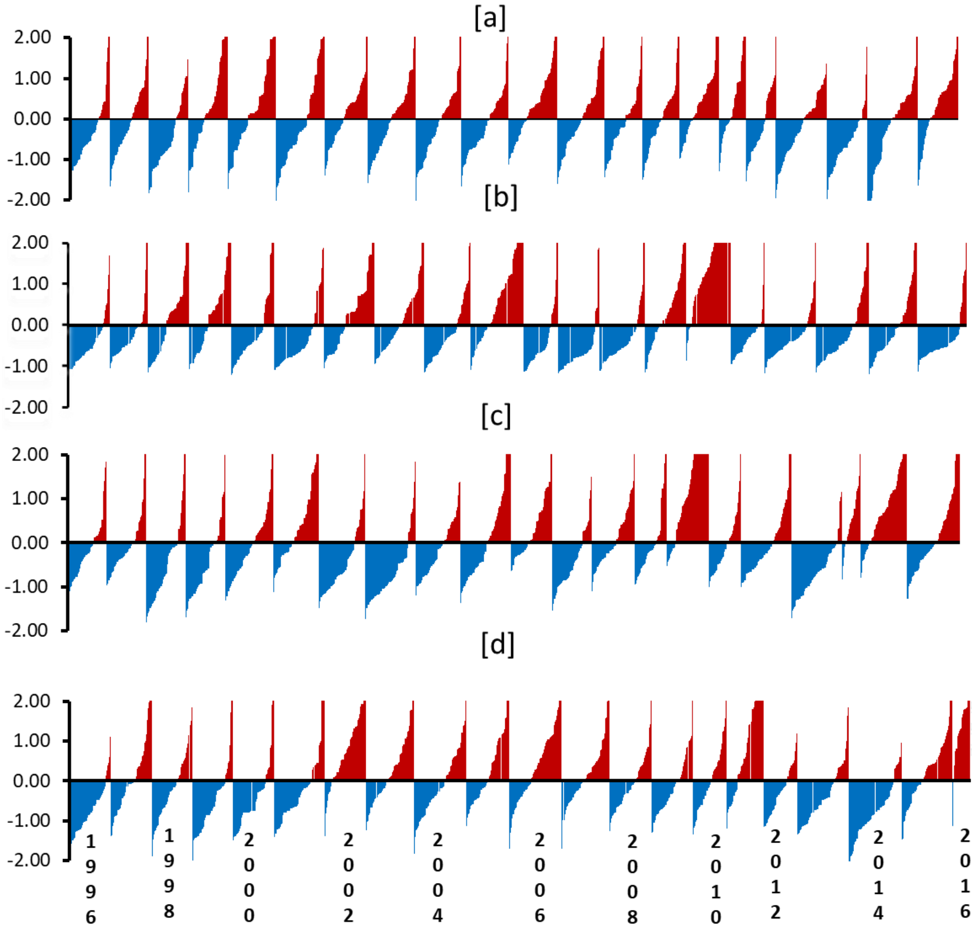

Fig. 4.9 Temporal variation of hydrological drought (SWI) in Purulia during Pre-monsoon [a], maonsoon [b], Post-monsoon Kharif [c] and Rabi seasons[d].

4.4.3 Spatial variability of hydrological droughts

For the year 2005, in the pre-monsoon season, 8% and 30% of areas of Purulia were under moderate to severe and mild drought. in the monsoon season, due to deficiency of rainfall 7 %, 27% and 50% area of the district under extreme, severe to moderate and mild drought conditions respectively. The drought progressed from the west to the east. In response to the improvement of rainfall in post-monsoon season area under mild to extreme drought has gradually decreased in post-monsoon Kharif and rabi season.

In 2010, during the pre-monsoon season, the entire Purulia district (80% area) experienced mild to moderate drought conditions with 10% area under extreme drought. In the sowing season, due to paucity of rainfall 65% of the area experienced extreme to severe drought conditions and in the post-monsoon Kharif season, 25%, 18% and 28% of the area came under extreme, severe and moderate drought conditions respectively which severely affected the agriculture potential. In the post-monsoon season good rainfall recovered the extreme drought condition, only 36 % area of the district experienced mild drought.

In the year 2015, Wet conditions prevailed in April, May, June and July which was reflected in the Pre-monsoon and monsoon season (only 30% area of the district under mild drought conditions). However, due to the rainfall deficit in August and September, 68 %, 21% and 7% area of the district came under mild, moderate, and severe to extreme drought conditions respectively. Mild hydrological drought conditions could be picked up during the post-monsoon rabi season in the entire district (80% area).

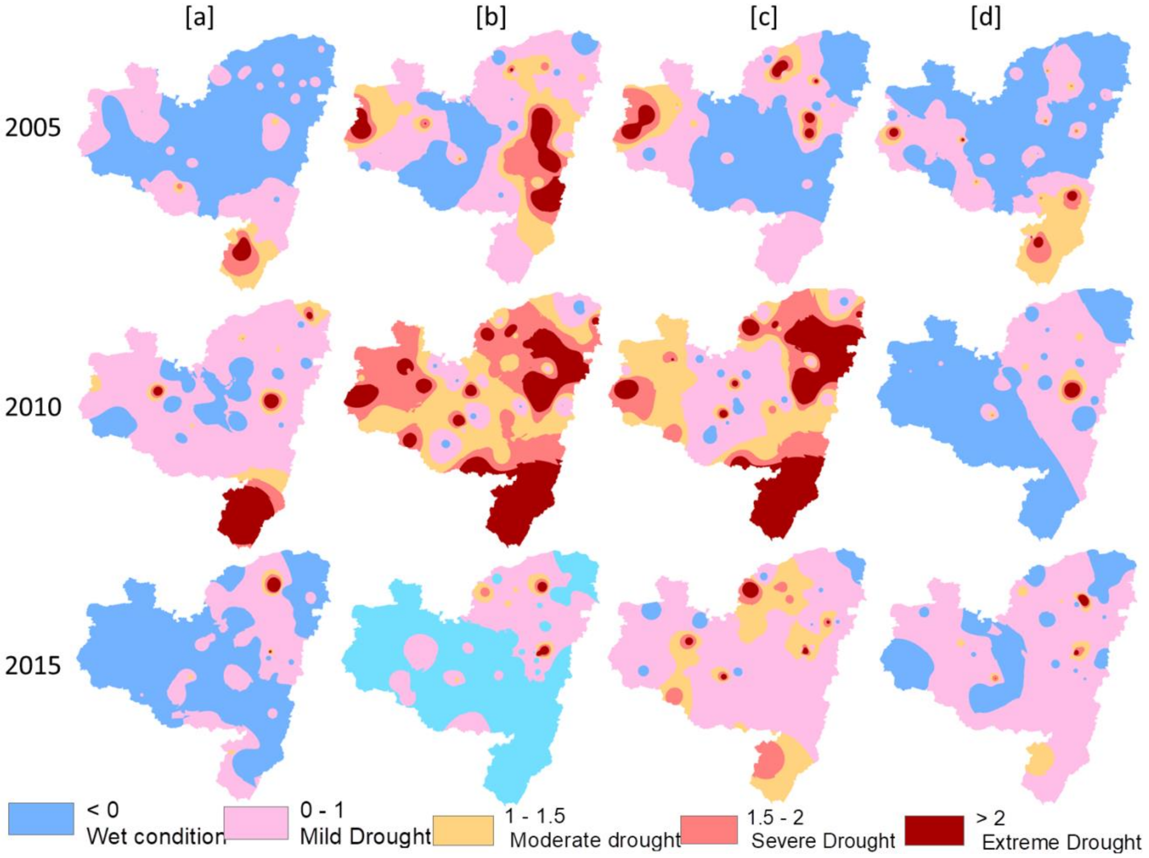

Fig. 4.10 Spatial variation of hydrological drought (SWI) in Purulia during Pre-monsoon [a], maonsoon [b], Post-monsoon Kharif [c] and Rabi seasons[d].

4.4.4 Trend analysis

The Mann-Kendall (MK) trend test and Sen's slope estimator were operated for trend analysis of the seasonal hydrological drought. The result shows that Purulia experienced a significant dry trend ($p < 0.05$) in the monsoon season (July- September) from 1996 to 2019. Whereas, the wet trend ($p < 0.05$) has been observed in post-monsoon rabi (January to March). No trend was found in Pre-monsoon (April –June) and Post monsoon Kharif (October –December) season. It should be noted that the positive values of SWI indicate the dry condition; therefore, an increasing trend in SWI implies drier conditions (droughts).

The Z values in monsoon and post-monsoon rabi exceeded the critical value of ± 1.96, indicating the positive /negative in seasonal hydrological drought were significant (significant at the 0.05 level).

Table 4.3 M–K trends calculated from the SWI during years 1996–2019 in Purulia

	Monsoon (June-September)	**Post-monsoon rabi (January to March)**
S	76	-70
VAR (S)	1096.67	948
Z	2.26	-2.24
Trend	positive	Negative
Sen Slope	0.80	-0.06
Significant level	95%	95%

4.5 CONCLUSION

This study described short-term (monthly and seasonal) meteorological, agricultural and hydrological drought in the Purulia district using rainfall and temperature (IMD), remote sensing (MODIS) and groundwater level data (CGWB). The SPI and SPEI reflect meteorological drought, NDVI anomalies, VCI, TCI, TVDI and Z_{PET} reflect agricultural drought, and SWI reveals hydrological drought were considered to evaluate the spatiotemporal variation of the different categories of drought. The study also assessed the association between occurrences of three successive types of droughts. Such findings can then be helped to enhance the identification of drought occurrences and to formulate strategic decisions for drought management and mitigation.

In Purulia, a good temporal similarity has been observed among meteorological, agricultural, and hydrological drought indices. Meteorological drought results showed that the years 2005, 2009, 2010 and 2015 experienced extreme drought during the monsoon season, a similar condition has existed in agricultural and hydrological droughts (Payano-

Almanzar and Rodriguez 2018). The analysis of monthly meteorological and agricultural drought brings out the fact that the monthly deficit of rain in the wet months of crop growing season perpetuates droughts in RLZ and loss of Kharif crop production. It was also found from the analysis of three types of drought that the sub-humid RLZ have been experienced short duration drought more frequently in recent years and extreme drought mainly concentrated in monsoon months.

Trend analysis of monthly meteorological and seasonal hydrological drought revealed a significant increasing trend in July, August month and monsoon season respectively which indicates that the sub-humid RLZ may undergo frequent droughts during monsoon months in the future due to increasing temperature.

Meteorological, agricultural and hydrological droughts have inconsistent spatial distributions. Overall, the spatial distribution of the all indices signified that the drought coverage area was progressing from west to east in the Purulia but each index was varied in terms of the drought intensity. Results indicated that 7 out of 15 drought years during the recent period with the greatest spatial extent are well associated with the most severe drought years. It is found that in August 2010 the largest area of meteorological and agricultural drought with extreme intensity occurred at the same time as the most severe hydrological drought. It is also noted that in August 2015 the largest area of meteorological and agricultural drought occurred at the same time as the moderate hydrological drought.

Comparing the time series for the three types of drought indices, the variability of meteorological drought indices (SPI and SPEI) have more significant with weaker persistence compared to agricultural and hydrological (Wane et al. 2011). This is because the rainfall and temperature variability has been partially filtered through the hydrological system of vegetation, topography, and soil. The intensity of meteorological drought events has higher than the agricultural and hydrological drought.

Meteorological drought (characterized by SPI and SPEI) has developed in agricultural and hydrological because of the decreased rainfall and increased temperature during the growing season, as well as the nonlinear hydrological responses to rainfall and temperature change. The agricultural drought is more sensitive to short-term (monthly) decrease precipitation and increases in temperature because of the soil moisture reduction. Long-term (seasonal or annual) decrease precipitation and increase in temperature are important factors to hydrological drought.

The impact assessment of meteorological, agricultural and hydrological drought at sub-district level has been described in the fifth chapter.

CHAPTER V

Evaluating the Impact of Drought on agricultural production and marginal farmers in Purulia

[This chapter illustrates the effects of drought on agricultural land, crop production and socio-economic condition at the sub-district level of RLZ of west Bengal. The monthly difference in drought impact on agricultural land has been determined. The crop and block-wise production loess due to drought has been discussed in detail. The agricultural drought-prone block has been detected. Farmers' perception of drought and its impact is also computed from rigorous field surveys.]

5.1 INTRODUCTION

Drought can result in significant losses to crops (Quiring and Papakryiakou 2003; Wang et al. 2014). Drought has negative impacts on the agricultural area, production, groundwater storage, and the socioeconomics of the area (Zarei et al. 2020). In the present circumstance of climate change and cumulative drought frequency and intensity (Misra 2013), being able to quantify the impact of a drought is important to preparing efficient management strategies for drought risk reduction.

Agriculture performs a principal function in the Indian economy socially and culturally which considers for around 20% of the country's GDP (Dar and Dar 2021). Agriculture is provided a major livelihood that occupies more than 75% of the labour force and supplied food. But agricultural production is highly influenced by seasonal characteristics and variables of rainfall and temperature (Sahasranaman 2021; Coffey et al. 2015). Furthermore, it is hindered by drought which generally first occurs in agriculture and then food production, water supplies and farmer's livelihood. Drought is a recurrent occurrence in India (Mishra and Liu 2014). The incident of drought has become more frequent since 1990 (Kumar et al. 2013). The increasing temperature and climate variability will intensify the risk of drought in India (Udmale et al. 2014). Drought has caused significant impacts on the agriculture and economy of India (Gadgil and Gadgil 2006). About 68% of the Indian agricultural area was drought-prone, of which 50% are severely affected (National Remote Sensing Center (http://www.dsc.nrsc.gov.in/DSC/Drought/). Hence evaluate the impact of drought is necessary because droughts are likely to endanger the economy of the area.

Drought is a reoccurrences phenomenon of sub-humid Purulia district (Goswami 2019). Drought is more frequent in the short time scale and affects the yeild (Mishra and Deshai 2010). Purulia faced drought conditions at least once every three years during recent decades (Mandal and Chakrabarty 2013). About 80% of rural people in Purulia which are predominantly small and marginal labourers depend on agriculture. About 75% of the total cultivated area in Purulia is a rainfed (primarily dependent on Southwest monsoon rainfall) hence slight change in rainfall is a considerable threat to agriculture. The constraints such as unproductive land, drought and poor micro-irrigation contain the yield of the Purulia district (Mishra and Chatterjee, 2017). Apart from the loss to crop, drought also causes increases in prices, unemployment, and reduces access to food for small and marginal farmers. Extreme poverty situation, food and employment insecurity to the tribal communities in the district are the facts (Dasgupta and Chatterjee 2008). In this context evaluating the impact of drought in the Purulia district assumes a vital significance for any planning for the amelioration of the living standards of the people.

Drought assessment in Purulia indicated that the frequent short-term monsoon droughts have greater impacts on agriculture (Mishra and Chatterjee 2017). Hence, it is important to examine the impact of drought on agricultural land and crop yields. However, no studies to date investigate the impact of drought on agriculture in Purulia at the farm level.

5.2 AIMS AND OBJECTIVES

This chapter is an attempt to understand the impact of drought conditions which concern agricultural area, crop and socio-economic conditions. The methods applied to assess the impacts of drought on agriculture have been based on crop production yields (Alexandrov and Hoogenboom 2000). Satellite-derived drought indices allow agricultural areas affected by droughts to be determined (Kogan 2001). The present study analyzed monthly variances in drought impact on agriculture in a sub-humid region of Purulia between 2005 and 2015. The study evaluates spatial variances in the effects of drought on the agricultural area using MODIS-derived indices (NDVI Anomaly, VCI, TCI, TDVI and SPEI), and Geographic Information Systems.

The analysis considered the effects of drought on the agricultural land, crops, socio-economic condition with spatial and monthly/seasonal variances. The findings should be valuable for the management of crops and location-specific planning for the development of superior drought mitigation plans. This approach also helps to measure the current situation of different socio-economic and physical conditions of the drought-affected area and reveals the comparison of drought resilience among sub-districts.

The study also intends to survey the amount of farmers' perception of drought, the nature of drought, and the impact of drought. The outcomes of the analysis will help government, NGOs and policy makers to select suitable drought adaptation strategies thus helping farmers in sustaining their livelihoods against future droughts.

5.3 DROUGHT-AFFECTED AGRICULTURAL LAND AREA

Recent studies revealed that although the Purulia districts experience sufficient (Average monsoon rainfall 1000 mm) rainfall, is affected by recurring droughts (Mukherjee and Palit 2013; Ghosh and Jana 2017). In Purulia, about 50% of the total land is under the net-cropped area of which only 17% is under multi-crop cultivation and 77% of the net-cropped area is under rain-fed Aman rice cultivation (Goswami and Basu 2016). Due to the erratic rainfall and lack of irrigation, agriculture becomes challenging and gets severely affected (Sehgal 1998; Mukherjee and Banerjee 2009; Mukherjee and Palit 2013). Therefore, assessment of drought impact on agriculture is extremely required to sustain productivity, reduces poverty and ensures food security in the areas.

The spatiotemporal impact of the monthly agricultural drought at the block level has been analyzed by calculating the percentage of the drought-affected agricultural area during the growing season.

5.3.1 Temporal pattern of drought-affected agricultural land

The temporal pattern of drought-affected agricultural land has been evaluated in the crop growing season (June, July and August) from the year 2005 to 2015.

For June 2005, 2009, 2010, 2012 and 2014, 75-65 % of the agricultural land of Purulia suffered extreme to severe drought. The western part (Jaipur, Baghmundi, Balarampur, Arsa, Jaldha I, II, Para and Purulia I, II blocks) of the district experienced extreme drought and the eastern part (Kashipur, Puncha, Hura, Manbazar and Raghunathpur) of the Purulia experienced severe drought.

For July 2005, 2009, 2010 and 2014, severe to moderate drought conditions were shown in the central and eastern part of the district (Puncha, Hura, Kashipur, Purulia I and II blocks). In July 2015, extreme drought was experienced in the western and northeast parts (Para, Raghunathpur and Kashipur) of the Purulia.

In August 2015, extreme drought identified most of the portion of the district with special emphasis in the eastern part (Hura, Puncha, Kashipur and Raghunathpur). For August 2005, 2009, 2010, and 2013, severe to moderate (30-25 % of agricultural land) drought was found in the eastern part of the district (Kashipur, Hura, Para, Purulia I and Puncha blocks) with scatter region of extreme drought.

5.3.2 Spatial variation of drought-affected agricultural land

Based on the various categories of monthly drought-affected areas, the area falling under each category was estimated for each block. In comparison to all years, July and August 2015 show the maximum area under extreme drought conditions. The extreme drought-affected agricultural area has been increased from July to August (Table 5.1).

In 2010, extreme drought was identified in June and August to have at least 15% of agriculture affected. Severe to moderate drought-affected agricultural area has been increased from June (35%of agricultural land) to August (45%). Table 5.1 shows the percentage of agricultural areas affected by drought at the sub-district level.

Analysis of the monthly drought-affected area in 2005, it is observed that 24% and 12%area affected by extreme drought in June and August respectively. Severe to moderate drought-affected areas gradually increased from June to August.

In the growing season, around 15 % of agricultural land was affected by mild drought every year during 2005-2015. Jaipur, Balarampur, Arsa, Jaldha, Purulia, Barabazar, Puncha and Kashipur blocks were frequently affected (above 40% of agricultural land) by extreme to moderate drought in the growing season during the year 2005-2015.

Table 5.1 Block-wise Drought affected agricultural area and crop failure index in drought years 2005, 2010 and 2015.

	drought affected agricultural land(%) in 2005							drought affected agricultural land(%) in 2010								drought affected agricultural land(%) in 2015					
	June		July		August			June			July		August			July			August		
Blocks	Extreme	severe	severe	moderate	Extreme	severe	moderate	Extreme	severe	moderate	severe	moderate	Extreme	severe	moderate	Exteme	severe	moderate	Exteme	severe	moderate
ARSA				6		3	10	5	4	22	7	9	6	24	37	64	2	5	89	1	
BAGHMUNDI			8	8	4	12	4	18	8	39		4		8	39	81		1	91	1	4
BALARAMPUR			2	2	3	3	2	7	4	48	7	7	7	11	39	79		3	88	3	1
BANDOYAN	38	15		4			8	4	14					4	35	37	4	13	77	4	7
BARABAZAR	10	3	3	1		3	2	19	14	43	3	11	6	11	28	51	4	12	93	2	
HURA	24	1		10		1	5	21	26	3	1		15	18	15	28	7	10	81	3	2
JAIPUR			2	15	4	2	15	4		2	2	2	13	31	29	91			87	2	1
JHALDA_I			7	7	5	5	9	7		19	2	2	2	12	14	81		4	62	1	2
JHALDA_II			4	4		4	8			2			10	24	24	96			86	2	1
KASHIPUR	13		1	22		2	31	27	34	3		3	9	22	27	57	3	3	58	3	2
MANBAZAR_I	28	18		5			3	14	17	1		1	4	13	29	34	6	15	72	3	5
MANBAZAR_II	63	19		2			0	15	15			3	2	10	17	24	1	5	85		1
NITURIA	38			5			3	25	21					8	22	52			26		7
PARA	12	3		3		1	3	25	8	17		4	11	28	21	41		12	42	3	9
PUNCHA	10	2		7			7	22	13	1		3	4	53	22	37	10	8	91	1	1
PURULIA_I			4	6	3	1	11	2	3	21	4		3	28	25	49	6	13	87	6	2
PURULIA_II				15		1	18	16	1	18			8	25	29	29	7	6	86	2	
RAGHUNATHPUR_I	11			13			18	40	8	2		2	2	34	32	37		1	25		1
RAGHUNATHPUR_II	30	10		5			2	37	20	5			3	18	20	84		1	22	4	2
SANTURI	33	5		7			17	30	40	3		7		20	37	56		1	39	1	3

5.4 AGRICULTURAL DROUGHT IMPACTS ON CROP PRODUCTION

Agriculture forms the backbone of Purulia's economy. A considerable quantity of the income arrives from agriculture through the per-capita income is considerably low. On the other hand, agriculture is the principal source of livelihood of the major portion of (nearly 72%) of the population living in rural areas. Maximum rural households occupy in subsistence farming under detrimental and risky environmental circumstances. The natural resource base can be characterized as inadequately suited to agriculture due to climatic, water, and soil conditions. As per 2011 census data, 60.91% of the total workers of the district are engaged in agricultural activity. Out of this 21.51% are cultivators and 39.40% are agricultural laborers.

Cultivation in the district is mainly mono-cropped and rainfed. Paddy is the primary crop. Around 77% of the net cropped area is under Aman cultivation with low fertilizer consumption per unit area. Thus production per hectare is also low as per other districts of West Bengal. The cropping system during the Kharif season is mainly rice-based followed by other crops. The agricultural economy depends on potatoes, vegetables, oilseeds and orchards. Vegetables and commercial crops are grown in relay systems throughout the year in Raghunathpur, Manbazar and Hura blocks. The cropping intensity of the Purulia district is about 118%.

5.4.1 Crop wise drought impact on agricultural production

Purulia was suffered consecutive droughts in the years 2000, 2002, 2005, 2010 and also recently in 2015 during monsoon, which has significantly affected agricultural production.

In the year 2000, the actual production of Aman rice was about 469 (23%) thousand tonnes against the normal production of 603 thousand tonnes. For severe drought years 2005 and 2015, the actual production of Aman rice was 524 (reduce 15%) and 515 (reduce 14%) thousand tonnes respectively against the normal production of 603 thousand tonnes in Purulia district. In extreme drought year 2010, Aman rice production has been declined around 261 (43%) thousand tonnes against the normal production of 603 thousand tonnes.

The production of Maize, Green Gram, Small millets and Urad, have been also declined during the years 2005, 2010 and 2015. The crop productions affected by the severe dry spells in 2010 were about 52 (60%), 1950 (55%), 55 (44%) and 5000 tonnes (35%) of Millet, Urad, Green Gram and Miaze respectively. In 2015, production of Millet, Green

Gram, Urad and Maize production were fallen about 43(50%), 24 (20%), 623 (18%) and 3300 tonnes (24%).

The pro-long (5 monsoon months) extreme drought in 2010 substantially reduced Aman and other Kharif crops productions. The short-term monsoon drought in 2015 also extensively decreased aman and other Kharif crops productions.

Purulia experienced severe to moderate drought during the post-monsoon season in the years 2000, 2005, 2008 and 2015 which lead to rabi crop failure. In the year 2008, wheat, potato, linseed, masoor and gram production failure around 2221(45%), 9500 (50%), 79 (43%), 12 (25%) and 97 (26%) tonnes respectively from average production. For the year 2015, wheat, potato, linseed, masoor and gram production loses around 3200 (25%), 15000 (19%), 110(22%), 8 (50%) and 65(50%) tonnes respectively from normal production.

The 2010 drought in Purulia was one of the worst affected regarding the production of crops. Owing to deficit rainfall and prolonged dry spells, the major food crops like rice, maize, wheat, cereals, pulses and oilseed productions were significantly affected.

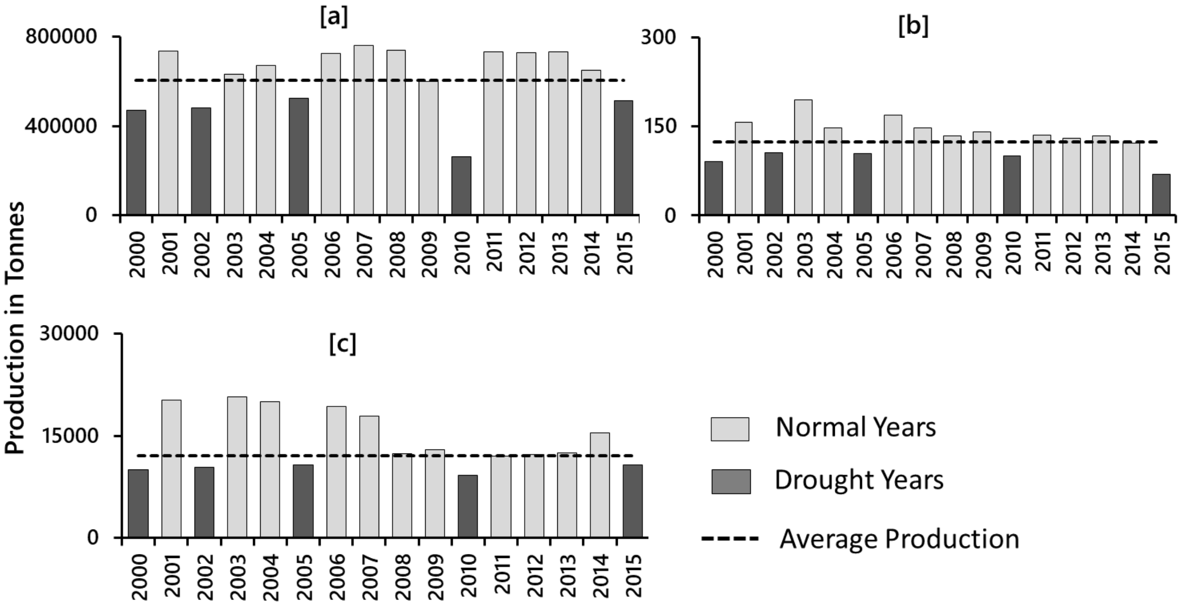

Fig. 5.1 Rice[a], Green Gram[b] and Maize[d] production affected by drought during Kharif season in 2000-2015.

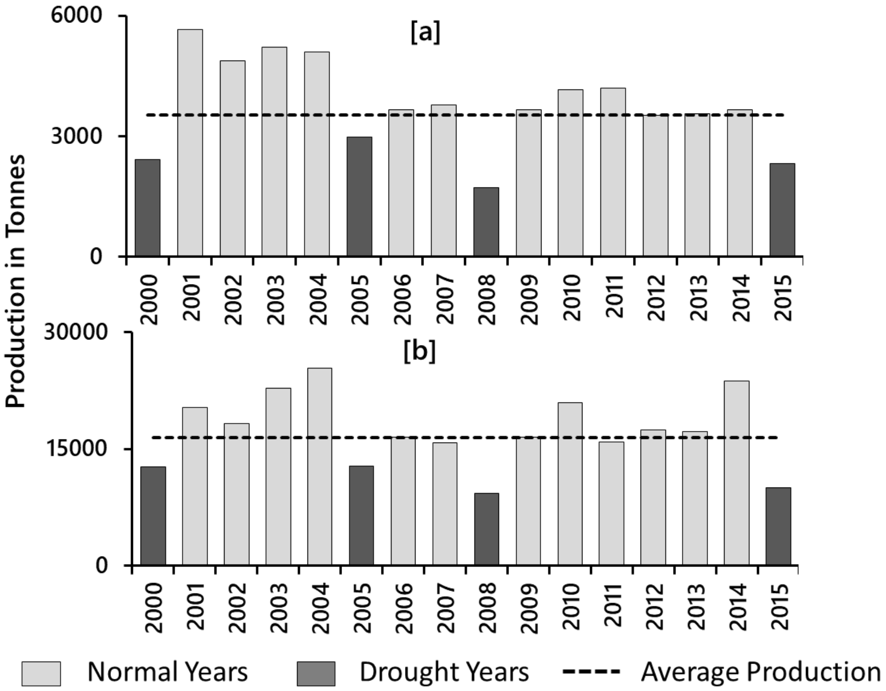

Fig. 5.2 Wheat[a] and Potato[b] production affected by drought during Rabi season in 2000-2015.

5.4.2 Blockwise drought impact on agricultural production

In the present study, the block-wise crop failure by the drought in the Kharif season was studied for the period 2000 to 2015.

With regard to crop failure index in 2005, result shows that the majority of western blocks (Arsa, Joypur, Balarampur, Bagmundi, Jaldha and Purulia-I) in Purulia experienced medium levels of crop failure with the Bandowan block of the south Purulia experiencing maximum crop failure.

For extreme drought year 2010, all blocks of Purulia face severe Aman crop failure. Bandowan, Bagmundi, Puncha, Kashipur and Joypur blocks show the highest crop failure. Arsha, Manbazar, Para and Raghunathpur blocks have a severe crop failure, and Balarampur, Purulia and Jaldha blocks have moderate crop failure.

In the year 2015, The majority of the Aman crop failure occurred in Balarampur, Arsa, Purulia, Jaldha and Bagmundi blocks of western Purulia and Kashipur, Manbazar blocks of eastern Purulia.

5.2.3 Discussion

In 2005, Bandowan Block of the southern part of Purulia has experienced extreme drought during pre-monsoon, monsoon and post-monsoon season which lead to maximum Kharif and rabi crop failure. Extreme to severe drought occurred in Jhalda I block of the western Purulia and Puncha, Manbazar, Huraand Kashipur of eastern Purulia during monsoon and rabi season. In the monsoon season, severe drought beginning in western areas had reassigned eastwards in July and August. Therefore, eastern blocks suffer severe Kharif crop failure.

In extreme drought year 2010, the analysis of drought impact in Purulia at sub-district level indicates that the Southern, Western and eastern blocks have experienced extreme to severe drought. Subsistence farming practice with rain-fed agriculture has been severely affected by the drought. Crop failure of the eastern blocks was higher than the western blocks. Comparatively good irrigation facilities, fertile soil, high groundwater level and productive agricultural land with gentle slope are reasons to decrease the crop failure of the western blocks. Therefore, Eastern blocks are the most sensitive than western blocks in terms of exposure to drought impact. Bandowan Block of the southern part of Purulia also experienced extreme meteorological, agricultural and hydrological drought during monsoon which lead to maximum Kharif crop failure. Low irrigation facility, low fertility and water holding capacity shallow soil, 40% agricultural land with a steep slope (>8˚) make this block more sensitive to drought.

In 2015, eastern, western and Southern blocks have experienced extreme agricultural and moderate hydrological drought during the end of monsoon and post-monsoon season. Thus maximum rabi crop failure occurred in eastern blocks of Purulia. The spatial analysis shows that the Southern and Eastern blocks are severely vulnerable to drought and the west blocks are moderately affected by drought.

5.5 DROUGHT IMPACTS ON SOCIO-ECONOMIC CONDITION

According to the National Rainfed Area Authority of India, The directly impact of drought on Indian agriculture is reduce in crop production which reduces the farmers′ income. Furthermore, drought increases the food scarcity, drinking water shortage, mental and physical health problems, migration for work, and debt, etc. These effects can differ substantially from one region to another region (Udmale et al., 2014, 2015). Human drivers, like increasing water pressure and inadequate water management can further intensify the drought impacts. Because of the interaction between a drought event and various human influences, drought perception differs amongst people from region to region (Kiem and Austin, 2013; Sam et al. 2020). The farmers of this region are the ones who are more prone to drought-related effects. Drought at any stage of crop growth has a profound effect on them.

The socio-economic effects are discussed in this chapter keeping this large portion of rainfed farmers at focus.

According to the Census of 2011, 18.45 % of the total population of Purulia has Scheduled Tribes and 18.27% Scheduled Casts. The educational status of the tribal people in the district is a matter of concern. The total literacy rate of the district is only 46.61% (male 67.97% and female 32.04%). Block-level study reveals that Kashipur has the highest literacy rate of 62.60% and the lowest literacy rate is recorded in Arsha which is only 45.5%. Jhalda II block has the highest male literacy rate of 67.2% and Kashipur has the lowest male literacy rate of 59.2 %. Kashipur can boast of having the highest female literacy rate (40.8%) and the lowest female literacy rate is observed in Arsa (34.8%). The population density of Purulia district for 2011 is 405 people per sq. km. The BPL family of this district is 43.65 %. Out of which SC family is 20.59 % and ST family is 24.15 %. About 90 % of the population is rural population of which 44 % are below the poverty line.

5.5.1 Drought-induced marginalization

The concern is the way people participate in the income-generating process. The main and marginal workers are two broad categories of the working population which has been attributed as involvement to the economy (Mishta, 2017). Main and marginal workers defined by the Ministry of Statistics and Programme Implementation, Govt. of India as ‘the workers who had worked for the most of the reference period (i.e. 6 months or 180 days) or more’; and ‘marginal workers’ as ‘The workers who had not worked for the most of the reference period’ (Manual on Labour Statistics (I), 2012).

According to Census 2011, 57.35% of the total population of Purulia is non-workers and only 42.64 % are workers, of which 49.09% are main workers and 50.91 % are marginal. The main working Population has been decreased from 57.25 % in 2001 to 49.09 % in the 2011 census whereas Marginal workers have been increased from 42.75 % in 2001 to 50.91 % in 2011 census. On contrary, the non-working population has been increased from 55.5 to 57.35% during 2001-2011.

Persons engaged in agriculture have been categorized into two sub-groups by the Census of India. These are cultivators and agricultural laborers. A person is categorized as a cultivator if he or she is involved in farming on land owned or held from government or held from private persons or institutions for payment in money, kind, or share (Census of India, 2011). A person who labors on another person’s land for wages in money or kind or share is considered as an agricultural labourer. He or she has no risk in the agriculture and has no right of lease or contract on land on which he or she works (Census of India, 2011). Main and marginal Cultivators of Purulia have registered a fall from 37.7% in 2001 to 27.2% in 2011 and 22.75% in 2001 to 16% in 2011 respectively. Main and marginal Agricultural labours have increased 2% during 2001 to 2011. This is justified the ongoing process of conversion of cultivators to agricultural labourers.

The most drought-affected southern block (Bundwan) has recorded the highest decrease in main workers and also a high increase of marginal and non-workers from 2001 to 2011. Frequently drought-affected western blocks (Jhalda-I, Bagmundi, Balarampur, Purulia-I, II, Jaipur and Arsa) and eastern blocks of Purulia (Manbazar, Kashipur and Hura) get a moderate negative increase of main workers during 2001 to 2011 while the positive increase has observed in marginal and non-workers.

Table 5.2 Decadal change of main, marginal and non-working population in different blocks of Purulia district during the census year 2001 and 2011.

	Rate of Decadal Change in %		
	Main Workers	Marginal Workers	Non Workers
Blocks	2001 to 2011	2001 to 2011	2001 to 2011
Jaipur	-5.1	-3.2	29.1
Purulia - II	-8.0	30.0	17.7
Para	4.0	19.2	13.8
Raghunathpur - II	2.5	11.2	16.1
Raghunathpur - I	14.9	5.6	12.3
Neturia	9.6	24.8	7.0
Santuri	-8.0	3.4	19.7
Kashipur	-4.8	20.9	4.6
Hura	-3.5	28.0	9.0
Purulia - I	-15.5	32.0	21.6
Puncha	6.3	37.1	1.3
Arsha	-2.2	23.3	21.3
Jhalda - I	-29.4	21.3	30.5
Jhalda - II	3.7	-2.1	28.9
Bagmundi	-24.5	31.4	25.5
Balarampur	-6.5	29.8	16.5
Barabazar	4.4	16.8	16.6
Manbazar - I	-13.7	36.6	16.2
Manbazar - II	-19.9	35.2	11.5
Bundwan	-57.0	36.8	25.2

5.5.2 Drought Impact on Consumers

The price of crops of Purulia has been analyzed to understand the impact of drought on economic conditions. Crops were generally hardest hit in times of drought. The markets for food crops are largely domestic, which limits the ability to compensate for reduced production in drought periods. Therefore, the price of crops has been increased.

In moderate drought years 2000, 2002 and 2005, crop production has been reduced due to drought which leads to crop production increased. In 2010, drought has been extreme that severely crop failure occurred in this season. This production loss is One-Third equal to the total crop production in good years. Crop prices have been increased in a drought year. Similarly in the 2015 drought, has reduced agricultural production and prices for food products have been increased. This would further adversely affect economic growth and exacerbate malnutrition.

5.6 FARMERS' PERCEPTION OF DROUGHT IN PURULIA: A FIELD EXPERIMENT

5.6.1 Outline of the respondent households

A total of 1500 households were interviewed which 83.1% were ST, 16.17% were SC and 1% only General. Out of the total household, 88.08% were male heads, 5.49% were women heads and 6.36% were widow heads. The average age of the respondents was 46 years (range was 18–90 years). The average household size of the sampled population was 6. The Survey revealed that the number of people in their 20s of both genders is significantly higher than the number of children aged 0-6 and 50 % of the total population found between the ages 20 to 50. Data on education indicated that 5.38%, 10.30%, 2% and 0.7% of respondents had completed their primary, secondary, higher secondary, and bachelor or higher education, respectively. Out of 1500 households, 55.4% are under BPL and 10.13% are AAY cardholders. Agricultural labour, farming, and livestock are income sources of 93.1%, 87.3% and 72.1% respondents respectively. The average annual household income of each respondent is 20,000 RS.

5.6.2 General perception of drought and its impact

Farmers' of Purulia defined drought as less rain or number of rainy days over the monsoon season resultant water deficiency for agriculture. It was obtained that about 80.5% of farmers have faced drought in 2015. About 85.5% of farmers remembered the drought event in the year 2009–2010, due to the extreme intensity. When enquired about the occurrence of severe droughts suffered by farmers, about 65.7% of farmers supposed that very severe drought happened once every 3-5 years. Numerous researchers (Pandey and Ramasastri, 2001; Kar et al., 2012) also obtained that the average drought frequency in Purulia is once in 3 to 5 years. About 95% of respondents assumed that drought has been becoming more recurrent in the area during the last 10–20 years. An increasing trend of drought frequency during the monsoon season was acquired over the eastern part of India by Sharma and Mujumdar (2017), Das et al. (2015).

Drying of surface water resources, crop failure, enhance in food prices, the decline in prices of livestock and poor health were the impacts of drought perceived by farmers of the study area. Around 85.5 % and 70.21% of respondents have experienced a reduction in crop production and income in the 2010 and 2015 drought respectively. Around 16% of farmers have irrigation facilities (10%, 4%, 1% and 1% farmer irrigated by pond, ditch, well and river respectively) although 2-3bigha land only irrigated by this facilities. Around 53.7% of farmers have low productivity, high erosional up terrace (Baid) agricultural land while only 10% farmers have high productive low terrace (bahal) agricultural land. Results show that drought mostly affected the low-income and resilient farmers.

When queried about the ability to mitigate drought impact, 49.66% of farmers expected that they were adept to cope with drought through migration. On analyzing 1500 household survey data it has been observed that the maximum number of people (50%) who migrate are daily labourers. Marginal workers are more vulnerable to drought. Analyzing the landholding and migration pattern it has been seen that the maximum migrating population belongs to the category of people who have landholdings of less than three bighas. While people with landholdings above 15 bigha households were observed to less migrate. The households with bigger ownership of land are less vulnerable compared to the ones with the lesser area of land. Analysis indicated that farmers' perceptions of drought supported district-level evidence. Characteristic of meteorological and agricultural drought, extent of groundwater depletion (hydrological drought), limited irrigation facility, farm size, inadequate access to climate information, and agricultural subsidies were significant factors underpinning farmers' decision to adopt.

5.7 CONCLUSIONS

Through this chapter assesses the impact of drought on agricultural areas and production during the growing season from 2000 to 2015 were done. The complexity of the drought event obstructs identification of their impact. Results show that the consequences of drought on agriculture can be highly varied, diverging with different components including the monthly climatic condition, land-cover type, slope, soil and irrigation facility. Moreover, their various factors also can influenced the spatial variances of the drought impact on agriculture.

From the monthly drought analysis, inconsistent temporal trends were observed in drought variability over the wet monsoon seasons in the Purulia. In 2015, 65% agricultural area was affected by extreme drought during July and August, though, in that year, the area received a fair amount of rainfall (1000 mm). On the other hand, in 2005 and 2010 monsoon rainfall was less (81 and 300 mm) than the long-term monsoons mean (1050 mm) and moderate to extreme drought affected 20% and 45% of agricultural land respectively in June and August. The pro-long (5 monsoon months) extreme drought in 2010 and moderate drought in 2005 decreased the Kharif rice productions (Aman) around 261 (43%) and 94 thousand tonnes (15%) respectively. While Kharif rice productions were also downgraded 79 thousand tonnes (14%) by the short-term monsoon drought in 2015. The analysis manifests the verity that the monthly deficit of rain in the crop growing season has been perpetuated droughts which lead to crop failure in Purulia. Rockstrom and de Rouw, (1997) and Rockstrom (2000) also revealed that water stress in short periods can have a damaging impact on yields. This analysis should improve drought management and mitigation plans.

Western (Jaipur, Balarampur, Arsa, Baghmundi, Jaldha, Purulia and Barabazar), southern (Bandowan) and eastern blocks (Puncha, Hura and Kashipur) of Purulia were experienced frequent severe to extreme drought and crop failure in the growing season during the years 2000-2015. The investigation shows that due to low irrigation facility, infiltration potential, 35% of agricultural land with over 5˚ slope, gravelly loamy soil and high soil erosion eastern and southern blocks are more vulnerable than western blocks. The frequent drought incidence and crop failure result in southern, western and eastern blocks unemployment, chronic poverty and high out-migration of agricultural labour (Ghosh and Mal, 2017).

The most drought-affected southern block (Bundwan), western blocks (Jhalda-I, II, Bagmundi, Balarampur, Purulia-I, II, Jaipur and Arsa) and eastern blocks of Purulia (Manbazar, Kashipur and Hura) have recorded a decrease in main workers and also increase of marginal and non-workers during 2001 to 2011. In the drought years 2000, 2005, and 2010 crop production has been reduced due to drought which leads to marginalization and unemployment.

The outcomes of the study are based on qualitative data derived from a questionnaire survey, which describes that farmers were conscious regarding drought and experienced various impact of drought in the Purulia. Farmer has experienced more frequent drought in the area during the recent years. Poor marginal farmers are more affected by drought. Failure of agriculture caused unemployment, which weakened farmers livelihood and eventually declined the financial condition of farmers.

The sustainable water resource management strategies for drought adaptation of the Purulia district have been discussed in the next chapter.

CHAPTER VI

Water Resource assessment to detect the optimum water management actions to deal with droughts in Purulia District

[In this chapter an attempt is made to recognize the suitable water management strategies to cope with the drought of sub-humid RLZ of West Bengal. Crop water requirement and water availability from a different source of irrigation have been carried out to envisage water supply and demand. The gap between demand and supply is quantified in this chapter to identify the best management practices. The surface water availability from rainfall was analyzed in this chapter to decrease the gap between water supply and requirement to mitigate the water stress produced by droughts in the RLZ]

6.1 INTRODUCTION

Frequently drought occurrences have intensified the water deficiency problem in recent decades (Xiao-Jun et al. 2012). Hydrological disasters, population growth, increasing water use and economic development are the leading reasons of water crises which expanding the gap between water demand and supply worldwide (Wang et al. 2016; Elmahdi et al. 2006; Poddar et al. 2014). Gebrehiwot and van der Veen (2013) mentioned serious consequences of drought for agriculture especially the livelihood of rain-fed agriculture-dependent farming communities. Drought-resilient strategies are important for rural livelihoods and the economy. Studies are required in different between water demand and availability to have a better understanding of farmers' adaptation behaviors and best management practices.

Purulia experience adequate but erratic annual rainfall, are influenced by recurring droughts (Mukherjee and Palit 2013; Ghosh and Jana 2017). Agriculture becomes challenging and is severely damaged due to rainfall variability and irrigation deficiency (Sehgal 1998; Mukherjee and Banerjee 2009; Mukherjee and Palit 2013). An increasing tendency in drought frequency and intensity is perceived in recent times (Sharma and Mujumdar 2017; Das et al. 2015). Livelihood in Purulia is intensely influenced by rainfall and land management practices among small and marginal farmers. Over 77 % of the land used for crops production is based on rainfed agriculture. The main ultimatum for the rural populations (around 78 % of the population in Purulia live in drought-prone blocks) is to improve the productivity and the available water resources. Thus, it is essential to take the required initiatives to subside the impacts of drought. In this chapter, an attempt is made to recognize the appropriate water management measures to manage droughts.

The water management strategies based on irrigation deficit and potential water availably can be the best possibility to face the challenges caused by the increased intensity of drought (Wang et al. 2019; Liu et al. 2015; Shen et al. 2013). The analysis is done based on demand and availability situations in Purulia, and the approaches utilized to mitigate to water scarcities. The qualitative analysis intended in this chapter to recognize the water management measures to reduce the gap between water demand and supply will assist in mitigating droughts and water shortages in Purulia.

6.2 CROP WATER REQUIREMENT

Accurate use of water in the agricultural sector will be necessary to improve productivity and water resource management in the context of increasing drought frequency and water scarcity (Ali 2010). Understanding crop water requirements in the drought-prone region is required for efficient water use and irrigation supply (Bouraima et al. 2015; Mondal et al., 2018). The irrigation practices have been ingeniously organized and renovated by evaluating irrigation demand precisely (Goswami, 2019).

Agriculture is the governing sector supporting the rural economy of Purulia and maximum water is consumed by agriculture. Utmost rural households exercise subsistence farming under difficult and uncertain environmental situations. Crop failure is proceeding frequently due to drought-induced water scarcity. To overcome the problem it is essential to recognize the crop water requirements (CWRs) to identify the irrigation demand. This study was conducted to estimate the crop and irrigation water requirements of the main crops in the district.

CROPWAT 8.0 is significantly used for the estimation of crop evapotranspiration (CWR), and irrigation water requirements (Ewaid et al. 2019). The Food and Agriculture Organization (FAO) was developed these software programs for calculate irrigation water and mainly in the managing and design of irrigation systems (Clarke et al. 2001). In the present study, the crop water requirements and irrigation water requirements of major crops (Rice, Maize, Wheat, Mustard, and Potato) in Purulia were computed using the CROPWAT model. The crop water requirement is the quantity of water that equivalents the water loss by ET. Crops have different water needs influencing by the climate, soil, cultivation method, effective rain, etc., and the total water needed for crop growth is not uniformly distributed over its entire growth period (De Azevedo et al. 2007).

The total crop water requirements (ET_C) for the different crops in Purulia are in the following order according to the (mm/total showing period) unit: Boro > Aman > Maize > Potato > Wheat > Mustard > Pulses. Tables 6.1 illustrate the total crop water of Boro, Aman, Maize, Potato, Wheat, Mustard, Pulses calculated by CROPWAT. The effective rainfall (Eff.rain) and irrigation requirement (Ir) is the water amount taken for the growth of the crop, or it is the amount of water essential to achieve the field capacity of the soil. Eff rain and Ir depends on the Rainfall. The different losses, like runoff, seepage, evaporation, and percolation, occur during the usage and transportation of irrigation water (Munoz and Grieser 2006). Water needed for irrigation requirement has been calculated by the equation:

$$NIR = ETc - Eff.rain$$

In the present study, Eff.rain and Irr of different crops have been computed from 2000 to 2015. Results revealed that in the drought year average of 130 mm and 80 mm irrigation water have required for Kharif crops (Aman and Maize).On the other hand in the normal years, average irrigation water requirements are 72mm and 24 mm only for Kharif crops. Table 6.1 shows that irrigation water requirement and effective rainfall for Major Kharif (Aman and Maize) and rabi (Wheat, potato, Boro, Pulse and oilseed) crops in drought and normal years.

Table 6.1 Average irrigation water requirement and effective rainfall of different crops in Purulia in drought and normal years.

		Drought Year		**Normal Year**	
Crops	ETC (mm)	Irr(mm)	Eff_rain(mm)	Irr(mm)	Eff_rain(mm)
Aman	609.3	130.4	479.0	72.3	537.0
Maize	360.9	80.0	280.9	24.4	336.5
Wheat	256.9	225.3	31.6	176.7	80.2
Potato	242.3	220.9	21.4	166.8	75.5
Boro	464.4	433.0	31.4	367.2	97.2
Pulse	236.4	221.4	15.0	184.1	52.3
Oilseed	278.5	256.5	22.0	205.0	73.5

In 2013 (normal year), the area under different crops production was maximum, therefore this area has been used for crop water requirement (irrigation and effective rainwater requirement) in drought years and normal years. The total crop water requirement is 1922.8 mcm in the Purulia district, where 449 mcm and 267.2 mcm irrigation water are required for drought years and normal years respectively.

Table 6.2 Net irrigation water requirement from the different crops in Purulia in drought and normal years.

	Drought Years		**Normal Years**	
	Irr(mcm)	Eff_rain(mcm)	Irr(mcm)	Eff_rain(mcm)
Aman	394.0	1447.7	218.4	1623.3
Boro	2.2	0.2	1.9	0.5
Wheat	2.7	0.4	2.1	1.0
Maize	5.2	18.3	1.6	21.9
Other Pulses	31.3	2.1	26.1	7.4
Mustard	8.2	0.7	6.5	2.3
Other Oil seeds	5.1	0.4	4.1	1.5
Potato	3.8	0.4	2.9	1.3
Total	449.0	1473.8	267.2	1655.6

The analysis of block-level crop water requirement for different crops revealed that frequently drought-affected western blocks (Arsa, Purulia I, Jhalda, Baghmundi, Balarampur, Barabazar and Joypur) and eastern blocks (Kashipur, Hura, Manbazar-II and Para) have high irrigation water requirements. Table 6.3 displayed the block-wise total crop and irrigation water requirement in drought and normal years. This analysis assists farmers to select the type of crops for cultivation based on the availability of water.

Table 6.3 Block wise crop water requirement and irrigation requirement (drought and normal years) in Purulia district

Blocks	irrigation Requirement	
	Drought years	Normal years
Arsha	27.03	16.53
Baghmundi	28.42	16.29
Balarampur	15.41	8.77
Barabazar	33.39	19.79
Jaypur	16.69	9.94
Jhalda-I	19.03	10.88
Jhalda-II	20.64	11.90
Bandowan	14.93	8.39
Hura	30.28	17.76
Manbazar-I	16.11	9.19
Manbazar-II	15.70	8.85
Puncha	24.60	14.21
Purulia-I	19.95	12.28
Purulia-II	20.08	12.10
Kashipur	30.17	17.34
Neturia	7.34	4.19
Para	24.60	15.20
Raghunathpur-I	12.04	6.88
Raghunathpur-II	10.65	6.11
Santuri	10.91	6.23

6.3 ESTIMATION OF WATER AVAILABILITY FROM DIFFERENT SOURCES OF IRRIGATION

Assessment of the gap between irrigation water requirement and supply is significant for optimizing sustainable water resource management in drought-affected Purulia. The present study has quantified the imbalance of irrigation water supply and demand in drought and normal years with spatial variation. Irrigation water supply has been estimated from different source irrigation (tank, ODW, RLI and others). In Purulia, surface water is used by tanks, river lifts and canal irrigation. Groundwater is drift by a different structure like an open dug well, ditch. The present study observed that tanks (10695) and open dug wells (4297) are the main sources of irrigation, which are again dependent on rainfall (district statistical handbook, 2015). Water availability depends on the rainfall, fluctuation of groundwater level, type of irrigation vary in a different block of the district.

Comparing the irrigation demand and irrigation supply result revealed that the water demand of 267 mcm and 449 mcm for normal and drought years respectively in Purulia. While, the irrigation availability (from tank 139 mcm, open dug wells 3.7mcm, RLI 2.2 mcm, other 2.1 mcm and canal 25mcm) is only 172 mcm in normal years which irrigated only 45 % cultivated area of the Purulia. Purulia has experienced extensive irrigation water deficiency in both drought and normal years. Table 6.4 shows the block level irrigation water availability in Purulia.

Table 6.4 Block wise water availability from a different source of irrigations

Blocks	**Water Availability(mcm)**				
	Tank	RLI	ODW	Other	Total
Arsha	8.72	0.11	0.21	0.05	9.09
Baghmundi	0.67	0.10	0.11	0.10	0.98
Balarampur	0.99	0.06	0.11	0.06	1.22
Barabazar	4.84	0.19	0.16	0.15	5.35
Jaypur	1.31	0.05	0.13	0.27	1.76
Jhalda-I	2.84	0.21	0.13	0.22	3.40
Jhalda-II	3.15	0.05	0.22	0.25	3.67
Bandowan	1.85	0.13	0.13	0.07	2.18
Hura	7.04	0.06	0.20	0.20	7.50
Manbazar-I	4.90	0.16	0.23	0.03	5.32
Manbazar-II	2.59	0.08	0.13	0.13	2.93
Puncha	4.94	0.15	0.23	0.02	5.34
Purulia-I	2.25	0.11	0.19	0.07	2.62
Purulia-II	5.74	0.13	0.20	0.11	6.18
Kashipur	1.04	0.23	0.25	0.11	1.62
Neturia	3.69	0.06	0.13	0.05	3.93
Para	8.88	0.10	0.29	0.06	9.33
Raghunathpur-I	2.88	0.06	0.26	0.07	3.27
Raghunathpur-II	1.42	0.06	0.24	0.04	1.76
Santuri	5.78	0.05	0.10	0.05	5.98

6.4 DIFFERENCE BETWEEN WATER DEMAND AND SUPPLY

The irrigation deficiency of each block has been computed by subtracting the irrigation supply from the irrigation requirement (Fig 6.1). The maximum irrigation deficit has been found in the Kashipur block (15.72 mcm) and the lowest deficit has been seen in the Santuri block (0.25 mcm). From the Block level assessment of irrigation deficiency, it is observed that the eastern (Kashipur) southern (Barabazar) and western (Baghmundi) blocks have maximum irrigation deficiency. These blocks have less than 30% cultivated area under irrigation (Fig 6.1). The Bagmundi block has an intense irrigation deficit due to the lack of all sources of irrigation (pond, RLI, Open Dug well and ditch). Although, Kashipur and Barabazar blocks have RLI facilities from Dwarakeswar and Kumari River, the number, area and depth of tanks (the main source of irrigation) are very low. Eastern (Hura, Puncha and Purulia I) and Western (Jaypur, Jhalda, Arsa and Balarampur) block under high irrigation deficit because of very low water holding capacity tanks and wells. Hence eastern and western blocks are more vulnerable to drought and crop failure. On the other hand, Northern (Santuri, Neturia and Raghunathpur) and Eastern blocks (Manbazar I) have low irrigation deficiency due to many reservoirs, large ponds, farm ponds and dug well which irrigated 50-60% cultivated area. Purulia II, Bandowan, Manbazar II, and Para have moderate irrigation deficits because of moderate irrigation water supply from Tanks and ditches. A similar result was also found (Water Resource Utilization –Sodhganga).

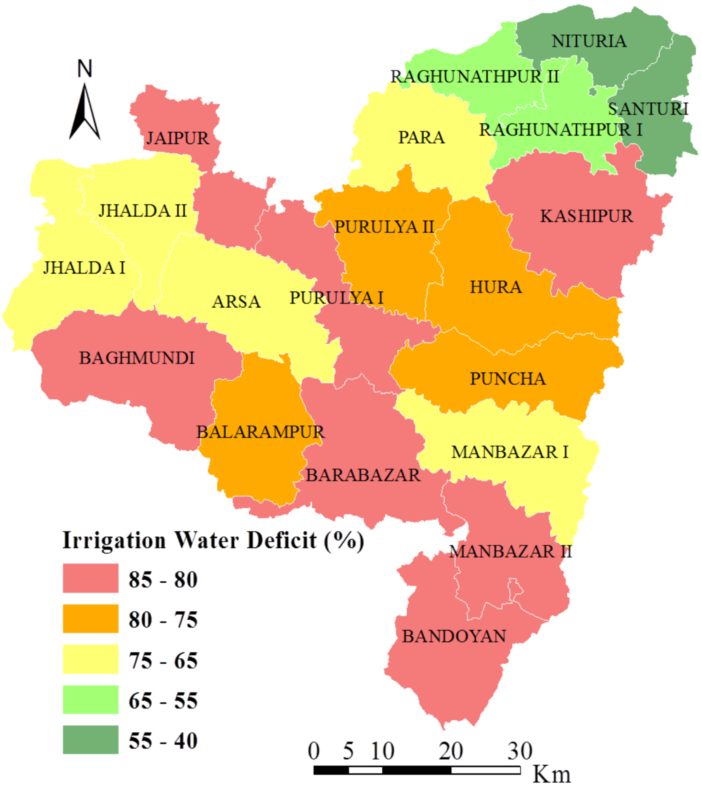

Fig 6.1 Block wise irrigation water deficit

Notwithstanding groundwater is the major drinking water source for Purulia district from deep tube wells. It is observed that agriculture in the Purulia has a larger dependency on tank water, than groundwater sources while the canals are either not adequate or not in practice. Surface water (tanks) thus perform vital role in sustainable agricultural development for the region and the execution of water harvesting structures of various sizes for different land sites can be considered to meet their water requirement for making these areas drought resistant in the future.

6.5 ASSESSMENT OF SURFACE WATER POTENTIAL FOR IRRIGATION

Irrigation would enhance crop yield and agriculture-led economy which provide farmers sustained livelihoods and well-being (worqlul et al. 2015; Belay and Bewket 2013). Irrigation water deficiency is a major reason constraining agricultural development in many areas in India (Santhanam and Abraham 2018; Ramakrishnan et al. 2009). Usually, the limited water resources will not be capable to meet the growing irrigation water necessities. Thus measure to improve water usage efficacy and irrigation scheduling are the most effective way of increasing irrigation efficacy to manage the deficiency of water resources (Li et al. 2017; Akhtar et al. 2013).

Providing irrigation water in adequate quantity on a sustainable basis remains indefinable for large area spatially drought-prone areas in India. Therefore water balance is essential to evaluate water availability in a region (Abraham and Mathew 2018). The water balance study has been formulated to measure the runoff that can be accumulating for efficient utilization (Satheeshkumar et al. 2017; Viji et al. 2015; Thakuriah and Saikia, 2014). Surface runoff, one of the most significant hydrological variables is applied in the planning of soil and water conservation measures (Patil et al. 2008; Tirkey et al. 2014). Assessment of surface runoff is essential for most water resource applications especially in the subtropical humid region (Viji et al. 2015). Water balance also helps to strengthen the decision-making about water management. The surface water harvesting and conservation approach deserve the maximum importance due to time consumption and coast effective nature in water management compare to other (Rao et al. 2010). Determining how much surface water is available, significant for water supply management in a region, especially where surface water is the major source of irrigation with large seasonal variations in water availability (Surendran et al. 2017; Karunanidhi et al. 2020).

The present study revealed that acute irrigation deficiency restricts agricultural prospects in the Purulia district. Irrigation deficiency often results in crop failure during the Kharif season and most of the cultivated area remains mono-cropped and less productive. Even though the Purulia obtains an annual average rainfall of 1200 mm, the rain is obtains in around 30–40 rainy days of the year or intense storms with a 48 to 72 hours life span(IMD 2017). As a result, considerable amount of rainfall is discharged from the undulating terrain as surface runoff (Roy 2014). The Precambrian granite gneiss hard rock, laterite soil, undulating topography may lead to high runoff in Purulia (Das and Bhandari 2017; Ghosh et al. 2016; Gour et al. 2014). Consequently, there is a necessity to harvest rainwater in various structures for enhances surface and groundwater recharge to fulfil water requires in the district.

Quantitative assessments of surface runoff from rainfall in the ungauged watershed were studied by geomorphological, physical, conceptual and empirical base approaches (Zhang et al. 2019; Dinka et al. 2019; Lal et al. 2017; Rawat and Singh 2017; Nigam et al. 2017; Meshram et al. 2017; Zelelew 2017). The numbers of the empirical method have been performing well or better than other approaches (Uwizeyimana et al. 2019; Gandhi et al. 2019; Rajashekhar 2018; Nidhi et al. 2017; El-Hames 2012).

The Natural Resource Conservation Service (NRCS) method has been produced by the United State Department of agriculture (Subramanya 2008) which widely used worldwide by numerous researchers to estimate runoff for an ungauged watershed (Kim and Shin 2019; Varma et al. 2017; Vannasy and Nakagoshi, 2016; Kumar et al. 2016; Devi and Katpatal 2016; Walega and Rutkowska, 2015). Mishra et al. (2018) concluded that the NRCS-CN curve model is applicable for high rainfall areas with various sizes of the watershed. The applicability of the NRCS-CN curve model was successfully demonstrated by many researchers for computing runoff all over India such as the Mahanadi and Kelo basin in Raigarh district, Chhattisgarh (Sujatha et al. 2017), Madhya Pradesh (Singhai et al. 2019) and Maharashtra (Sahu et al. 2012). NRCS-CN curve number technique applied for surface runoff estimation in various watersheds in Odisha (Wable et al, 2021; Behera et al. 2019), Tamil Nadu (Abraham and Mathew 2018), Gujrat (Tailor and Shrimali, 2016), Mahi river basin (Mohanty et al. 2015), Uttar Pradesh (Garg et al. 2013) and Karnataka (Shwetha et al. 2015). Gitika and Ranjana(2014) Used of NRCS-CN technique to assess runoff in Buriganga watershed, Asam. Kumari et al. (2019), Nidhi et al. (2016) and Tirkey et al. (2014) estimated runoff from rainfall in Jharkhand using the NRCS_CN method. Saha et al. (2021) computed surface runoff for the Kongsaboti river basin using the NRCS_CN approach. Kumar and Dhorde (2021), Santhanam and Abraham (2018) and Pandey et al. (2019) used NRCS-CN methodology for runoff estimation in Maharastra, (Thurinjalar watershed) Tamil Nadu and (Bhadokhar watershed) Uttar Pradesh respectively. The literature review indicated that the NRCS- CN curve method has been widely used to estimate runoff for an ungauged watershed in India and can provide convincing results. NRCS-CN curve approach with remote sensing and GIS technique was also utilized for estimation of surface runoff in the different basins of Bankura (Kiran and Srivastava 2014), Medinipur (Pal and Samanta 2011) and Bardhaman (Roy and Mistri 2013) districts, West Bengal.

Surface runoff study also conducted in Bandu basin (Kumar 2010; Sahoo 2013; Roy 2014; Das 2014) and Kumari basin (Vijayalakshmi et al. 2016; Das and Bhandari 2017) of Purulia District West Bengal. Chowdary et al. 2012 estimated daily runoff of monsoon season for the Kansavati basin of Purulia. Previous researchers were more emphasis on the effect of various empirical methods for simulation runoff from the small ungauged watershed of Purulia. The study for the volume of the surface runoff with spatiotemporal variation in the entire Purulia district remained so far unaccomplished. Many studies concluded that it is achievable to harvest, irrigate and manage surface water effectively if availability is estimated accurately (Abraham and Mathew 2018; Santhanam and Abraham 2018; Satheeskumar et al. 2017). Hence, the present study was conducted to simulate surface runoff in the Purulia district with a spatiotemporal variation using the NRCSS-CN model. This is envisaged to plan for optimizing the use of surface water irrigation and storage sustainably to enhance the productivity of agriculture under extreme weather conditions.

6.5.1 Estimation of Runoff

Surface runoff from rainfall for the Purulia watershed was evaluated for 20 years (2000 to 2019) by the NRCS model to estimate normal and drought year surface water availability. Linear regression measure was done for validation. Water used for irrigation and other purposes can be planned by knowing the usable water availability.

According to the hydrological soil groups, the Purulia district falls under hydrologic soil group ‘B’(Ministry of Water Resource, GoI 2013). The area comprised under each land use and the corresponding curve numbers has been computed for micro watersheds of Purulia (Table 6.5). The curve numbers for AMC conditions I, II (weighted curve number) and III were calculated for all micro watersheds of the Purulia district (Table 6.6).

Table 6.5 Land use/ Land cover area (sq km) of the watersheds in Purulia and corresponding curve number

Water shed	Block under the watershed	Forest	waterbody	Upland	Fallow	Agriculture	Settlement
1	Raghunathpur II	13.2	5.5	15.1	42.3	78.5	6.6
2	Raghunathpur I	32.5	8.4	16.0	36.0	101.2	5.1
3	Para	20.1	10.6	19.6	68.2	160.4	4.8
4	Santuri	20.7	2.1	28.1	8.7	49.8	0.7
5	Jhalda II	33.5	5.8	20.6	42.7	81.8	2.8
6	Purulia II	13.3	9.9	9.4	64.4	136.2	7.5
7	Jhalda I	59.2	11.7	62.4	44.0	95.1	3.5
8	Kashipur	86.6	12.2	72.3	97.0	325.8	3.1
9	Purulia I	14.0	10.6	23.1	66.6	158.8	5.2
10	Joypur	13.8	5.8	11.9	32.7	69.9	1.7
11	Hura	41.5	7.5	51.8	55.4	180.2	1.0
12	Baghmundi	100.6	8.0	56.5	27.6	66.6	1.6
13	Arsa	71.1	9.4	41.4	61.9	137.0	3.2
14	Puncha	19.1	3.8	18.3	29.5	78.1	0.6
15	Manbar I	64.5	16.3	66.9	83.4	206.8	1.8
16	Balarampur	44.3	22.8	48.1	63.6	154.2	4.1
17	Barabazar	38.3	20.2	47.8	61.1	140.1	2.4
18	Manbazr II	54.1	12.1	43.9	39.4	106.2	1.6
19	Bondwan	62.3	12.5	65.5	17.1	56.5	3.4
Curve Number		60	89	79	69	81	68

Table 6.6 Curve number of AMV group I, II (weighted curve) and III of watersheds in Purulia.

Watershed	AMC II	AMC I	AMC III
Watershed_1	75.6	57.6	87.9
Watershed_2	75.3	57.1	87.7
Watershed_3	76.6	58.9	88.5
Watershed_4	75.8	57.9	88.0
Watershed_5	74.4	56.0	87.2
Watershed_6	76.5	58.8	88.4
Watershed_7	74.3	55.9	87.1
Watershed_8	75.8	57.8	88.0
Watershed_9	77.0	59.4	88.7
Watershed_10	75.9	58.0	88.1
Watershed_11	76.3	58.5	88.3
Watershed_12	71.4	52.2	85.4
Watershed_13	73.9	55.4	86.9
Watershed_14	75.8	57.9	88.0
Watershed_15	75.5	57.5	87.8
Watershed_16	76.1	58.2	88.2
Watershed_17	76.2	58.3	88.2
Watershed_18	74.6	56.3	87.3
Watershed_19	73.4	54.7	86.6

Monthly (Fig 6.2) and annual runoff values have been simulated daily from the model for 16 years (2000 to 2015). The monthly assessment revealed that 89.9% of the runoff appeared during the monsoon months between July and October in the study area.

The high annual runoff recorded in 2007 and 2011 were 704 mm and 698 mm respectively due to excessive annual rainfall while the low runoff values were found in 2010, 2005 and 2000 as being206mm, 270 mm and 243 mm, respectively due to extreme to severe drought (Fig. 6.3). The annual runoff ranged between 22 and 40% of annual rainfall. On average, about 31% runoff of the annual rainfall was found. Previous studies (Roy 2014; Sahoo 2013; Das and Bhandari 2017; Chowdary et al. 2012) also adopted that a good amount of surface runoff has been yielded in the watershed of Purulia.

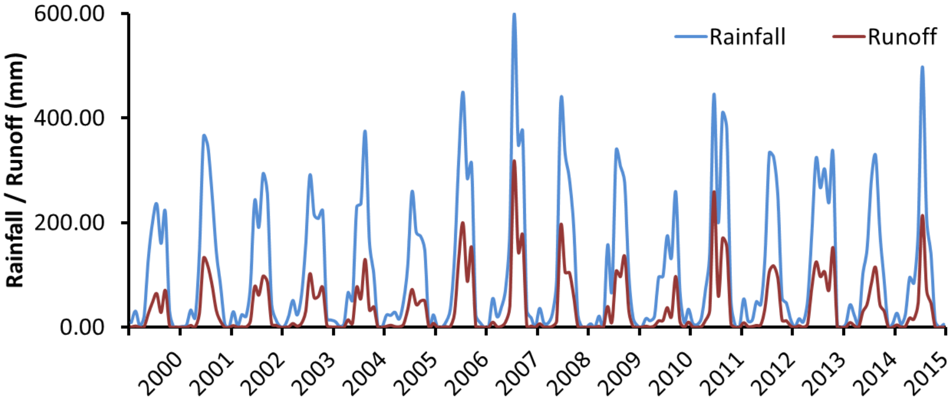

Fig. 6.2 Monthly rainfall and runoff by NRCS CN curve method for Purulia.

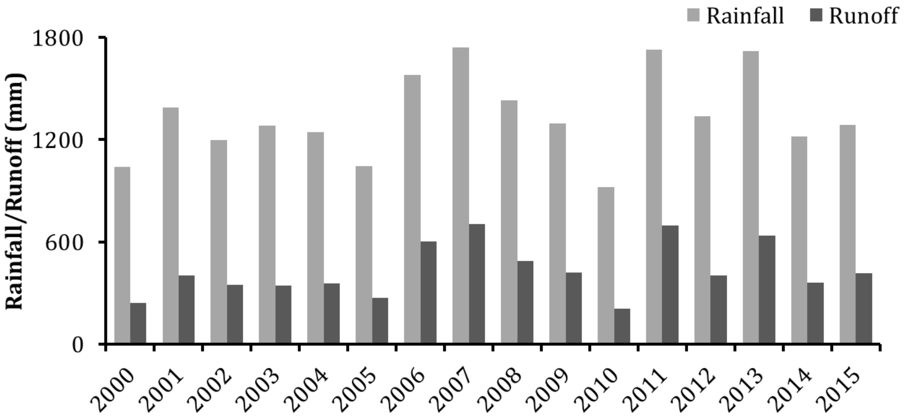

Fig. 6.3 Annual rainfall and runoff for Purulia during 2000 to 2015.

6.5.2 Validation by the regression model

Simple regression equations can be efficiently used for computing surface runoff in an ungauged watershed (Abraham and Mathew 2018). In this study, a regression equation was utilized to estimate monthly runoff from monthly rainfall based on runoff values acquired by the NRCS-CN curve model. Data from 11years were utilized for calibrating the regression model and data for 5 years were applied for validation.

The runoff estimates assessed by the NRCS_CN curve and regression approaches were statistically tested. The R^2 value for the regression equation was 0.96 during the calibration period and 0.92 during the validation period (Fig. 6.4). The Standard Error values were found to be 32.92 mm and 28.75mm, respectively, during the calibration and validation period. The *t*-test values for the linear regression equation were 0.34 and 0.26 respectively at 95% confidence during the calibration and validation periods. This reveals that there is no significant difference between the runoff values computed by the NRCS-CN and the regression methods.

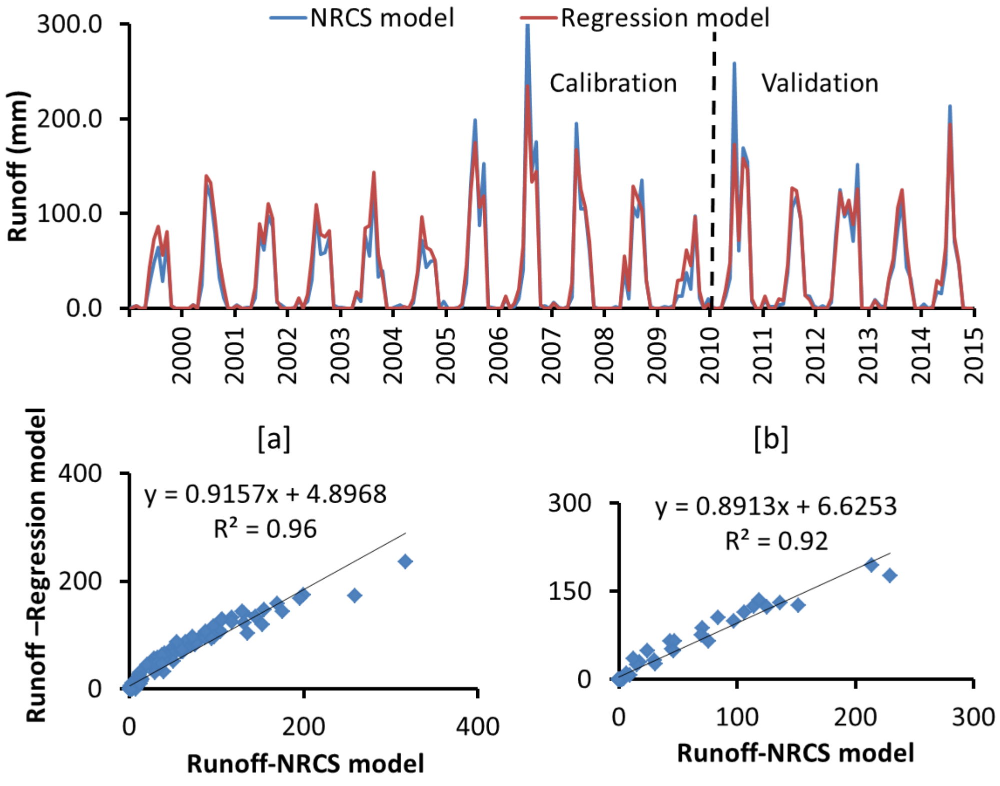

Fig. 6.4 Relation between NRCS-CN model runoff and Regression model runoff during calibration[a] and validation [b].

6.5.3 Surface Water Availability Analysis

The total volume of the surface water is estimated by considering 50% of the runoff can be harvested. The water used for irrigation is 25% of annual available water resources (Irrigation statistic yearbook India, 2018 Ministry of Statistics and Program Implementation). The average irrigation availability from surface runoff for normal and drought years in Purulia has been estimated to be 280 mcm and 168 mcm respectively. Results indicated that if 50% runoff can be efficiently harvested, there is sufficient water available in the normal year after meeting irrigation water requirement while in the drought year only 37% irrigation requirement is achieved.

Irrigation available from Surface runoff in micro watersheds was calculated to account for blocks level variation. In the normal years, the maximum average annual irrigation water available from the surface was found to Kashipur (20.6 mcm) followed by Barabazar (19.6), Bandowan (18.4), Hura (17.5) and Manbazar I (17.2) (Table 6.7). Results denoted that in the normal years, surface water availability can provide 60% of the irrigation water to the high irrigation deficit in eastern and western blocks. Around 80-85% of the irrigation water can be supplied to the moderate and low irrigation deficit blocks.

In drought years, 40% of irrigation requirements can be provided by the surface runoff for high irrigation deficit eastern and western blocks. Moderate deficit blocks are succeeding 60% irrigation from surface water and low deficit blocks are prospering 80% irrigation water requirement from surface water.

Table 6.7 Potential surface water availability

	Potential Surface Water	
	Drought years	**Normal years**
Arsa	15.4	8.3
Baghmundi	16.2	6.7
Balarampur	15.1	6.3
Bandowan	12.4	6.4
Barabazar	19.6	8.8
Hura	17.5	8.8
Jaipur	9.4	5.1
Jhalda I	12.0	4.9
Jhalda II	9.7	4.0
Kashipur	20.6	10.4
Manbazar I	14.2	6.7
Manbazar II	12.9	6.6
Nituria	6.9	3.5
Para	12.8	7.6
Puncha	14.9	7.6
Purulia I	12.3	6.5
Purulia II	13.5	7.1
Raghunathpur I	8.8	5.5
Raghunathpur II	8.6	5.4
Santuri	7.8	4.9

In the Purulia district, short-term drought prevails every year during the monsoon season due to erratic monsoon rainfall and high evapotranspiration. In the hard rock, undulating terrain area irrigation facility cannot meet the agricultural water requirement lead to crop failure. To overcome this problem, the harvest of surface water is proposed to augment both surface and groundwater storage. The study of surface water potential in Purulia indicates that even if only 50% of the available surface water could be successfully harvested there would be fulfil water available in normal years. But in drought years only 40% water requirement would be meeting by the surface water potential.

The Purulia contains considerable areas of unused land that could be utilized for rainwater harvest. There is huge scope to utilize surface runoff in the harvesting structures in the watershed and to employ the surplus rainfall for groundwater recharge. This will help in enhancing the surface and groundwater accessibility in the Purulia and also increase the productivity of the agricultural land.

6.6 CONCLUSIONS

Irrigation water deficit and drought are recurrent phenomena in Purulia and an increasing propensity in drought frequency and intensity is also perceived in recent years. Thus, it is essential to take the required initiatives to lessen the drought impacts. In this context, an effort is made to detect the suitable water management tactics to handle droughts. For this objective, the crop water demand, water available for a different source of irrigation and surface water potential from rainfall are analyzed. It is observed that the water availability for a different source of irrigation is 172 mcm which con does not meet the irrigation requirement of 267 mcm and 449 mcm in normal and drought years respectively. Frequently drought-affected blocks have experience high irrigation deficiency lead to crop failure which makes them more vulnerable to drought.

Purulia receives a high amount of annual average rainfall of 1200 mm. A good amount of rainfall discharge as runoff due to undulating topography, laterite soil and maximum rain is received in 4-5 intense storms with 48 to 72 hours life span. Hence, Surface water potential is a need to harvest rainwater for enhanced surface and groundwater recharge to satisfy water demands in the district. Assessment of surface water potential shows that 31% of the annual rainfall is discharged as runoff and 89.9% of the runoff occurred during the monsoon (July and October) in Purulia.

Results indicated that if 50% monsoon runoff can be efficiently harvested and 25% of available water resources are used for irrigation, there are 280 mcm and 168 mcm water available for irrigation in normal and drought years respectively. The irrigation water availability from surface runoff is sufficient for normal years. In the drought years, 40% of irrigation requirements also meet by surface runoff. The effectiveness of harvest of surface runoff (only 50%) from rainfall can also be dramatically improved irrigation deficiency and productivity to manage drought. Though, the structural supply-based management is not adequate to fulfil the growing water demand caused by population growth and economic progress. The growing water need due to changing environment, population expansion and economic improvement will make drought management difficult in the future. The demand-based water management has increased efficient water use which effectively stabilized the water require.

The key aspect found in the present study is that structural supply-based management only is not able to manage drought although the district is prosperous in rainwater. Demand-side management can stabilized water consumption efficacy and reduce the water emergency. Therefore, structural supply-driven with demand-side attempt can be an effective approach to mitigate the increasing frequency of droughts in addition to achieve sustainability in water management.

The next chapter has been attempted drought vulnerability and risk assessment to identify area-specific drought adaptation strategies.

CHAPTER VII

Drought vulnerability and risk assessment in rainfed agriculture of sub-humid RLZ for adaptation planning

[In this chapter an attempt to assess block-level drought vulnerability and risk comprising multidimensional bio-physical and socio-economic variables of Purulia. The computation of vulnerability and risk were based on the Intergovernmental Panel on Climate Change (IPCC) AR4 and AR5 frameworks, using exposure, hazard, sensitivity and adaptive capacity. The study would help to develop relevant areas-specific adaptation interventions for each vulnerability group of farmers.]

7.1 INTRODUCTION

More frequent and intense droughts have been observed over sub-humid regions due to climate change which affects the availability of water, food, agricultural produce, and aggravating poverty (Senapati and Gupta 2017). Small and marginal farmers of the developing countries are mostly influenced by climate change, because they have the inadequate adaptive capacity and lack of alternative ways of income (Kurukulasuriya and Rosenthal, 2003; IPCC 2007; Skoufias et al. 2011). Diminishing the economic, social and environmental impacts of increasing droughts and recognizing pathways towards drought resilient become a global primacy. A general knowledge of the drivers of drought and procedures of drought impacts is fundamental for developed risk assessments.

India is the most drought-prone country (Mishra and Singh 2010); around 68% of the cultivated area experienced severe to extreme drought (Kamble et al. 2010). In the 21st-century drought frequency and intensity have been amplified due to climate change which is changing the existing drought vulnerability profile of India (O'Brien et al. 2004). Frequent drought events in India have affected nearly 350 million people and 30% loss in crop production. The increased frequency and intensity of droughts are likely to threaten the water resources and food security of the country in present and near future. The sub-humid red and laterite zones (RLZs) of India frequently experienced short-term droughts (Nath 2017), affecting rainfed crop production during the monsoon season. Increasing temperature has produced more evaporation and deficiency in moisture which has created RLZs increasingly drought-prone in recent decades. Therefore, identification of the drought risk areas is necessary for the rainfed farming system of India.

Purulia is the most drought-prone district of RLZs, West Bengal (Hazra et al. 2017; Kundu and Nag 2018; Raha and Gayen 2021). Since 1990, Purulia is affected by frequent and recurrent droughts impacting agriculture and allied activities. Purulia experienced a maximum number of severe droughts in monsoon months during the recent time (Asutosh 2019). Increasing drought frequency and intensity have been observed in the recent decade (Patra 2020). Recurrent drought has reduced agricultural production and farmers' livelihood which also derives regional poverty (Kar et al. 2020). The recent droughts in Purulia such as 2010 and 2015 have devastated agricultural production (around 50% Kharif crop failure) and rural households (45% livelihood). Besides this, according to (Sam et al. 2020) the undulating topography, low water containing capacity soil, high surface runoff and soil erosion, irrigation deficiency and limited livelihood are also the regular affecting factors that ensuing people being more vulnerable to drought risk. The marginal farmers continuing about 60% of the cultivator and their economy mainly depend on rainfed single-crop agricultural production. A substantial portion of people (above 26%) belongs to below poverty level and sufferer of unemployment. Thus there is essentially required the assessment of drought vulnerability, risk and adaptation at the micro-level to diminish the negative effects of drought on the rainfed farming system.

Vulnerability assessment is essential to recognize the most risk area to harm and provide valuable information for preventive and adaptive actions designing (Garschagen and Kraas 2010, Birkmann et al 2015) to minimize the drought impacts. The recognition of vulnerability is crucial to more efficiently address the acute need area to plan for drought adaptation. Various literatures concluded that risk assessment act as a critical consideration in the overall drought reduction planning effort (Wilhelmi and Wilhite 2002). Drought vulnerability and risk assessment are necessary for the recognition and formulating of targeted drought risk reduction and alteration options to alleviating the farmers' livelihood (Yaduvanshi et al. 2015; Abid et al. 2016). Vulnerability and risk are highly multifaceted events with both biophysical and socio-economic indicators influencing exposure or hazard, sensitivity and adaptive capacity. Numerous studies have applied the IPCC method to evaluate the multi-dimensional drought vulnerability (Ravindranath et al. 2011; Gizachew and Shimelis 2014; Feroze et al. 2014; Maiti et al. 2015; Varadan and Kumar 2015; Rao et al. 2016; Sendhil et al. 2018). Nonlinear principal component analysis (NLPCA) is a comprehensive approach, together with various biophysical and socio-economic components to vulnerability assessment. PCA has been highly efficient in vulnerability assessment across a range of components at a variety of scales (Abson et al. 2012). Using data on multidimensional bio-physical and socio-economic factors with PCA has provided results in a more robust elucidation of vulnerability (Abson et al. 2012).

Regional drought vulnerability was produced by an integration of exposer, sensitivity and adaptive capacity using PCA in various regions such as South Korea (Kim et al. 2021; Yu et al. 2021), Southern Africa (Abson et al. 2012), Texas (Rajsekhar et al. 2015), Chile

(Nunez et al. 2017), China (Liu et al. 2013), Iran (Keshavarz et al. 2017; Zarafshani et al. 2020), Bangladesh (Xenarios et al. 2016), Pakisthan (Fahad and Wang 2018). Ghimire et al. (2010), Dahal et al. (2016) applied PCA to prioritize the components and assess household-level drought vulnerability in rainfed agriculture of Nepal.

Numerous studies (Kimani et al. 2015; Maiti et al. 2017; Rajesh et al. 2018; Sam et al. 2019; Gupta et al. 2019; Yadava and Sinha 2020) have been appraisal drought vulnerability for rural communities in India using multidimensional bio-physical and socio-economic components. Balaganesh et al. (2020), Jeganatha et al. (2021) evaluated drought vulnerability and risk based on the IPCC approach using exposure, sensitivity and adaptive capacity in Tamil Nadu. The district-level vulnerability was developed for the northeast region, India by Ravindranath et al. (2011). Dhamija et al. (2020) used the IPCC framework to assess drought vulnerability in central India. Murthy et al. (2015) analyzed agricultural drought vulnerably in Andhra Pradesh based on multiple indicators in the IPCC framework. Sendhil et al. (2018) used the IPCC framework to assess wheat vulnerability in India. District level agricultural vulnerability was assessed using multi indicator based IPCC approach in Karnataka India Kumar et al. (2016).

Senapati et al. (2015) applied different drought indices to make drought vulnerability zonation using the analytic hierarchy process in Purulia. Bera et al. (2014) groundwater vulnerability was assessed using the DRASTIC index with an overlay weighted technique in the Nangasai basin of Purulia. Likewise, Mondal et al. (2019) also estimated groundwater vulnerability in Jangalmahal using the DRASTIC index with the overlay weighted method. Basu (2020) identified the district-level vulnerability of West Bengal using exposer, sensitivity and adaptive capacity of the IPCC framework.

Surprisingly, no previous studies concerning the block level drought vulnerability and risk have been executed in Purulia, which is one of the most drought-affected district of West Bangle. To fill the paucity of literature discussed above, the present study has been undertaken to assess the block level drought vulnerability and drought risk in Purulia for guiding the policymakers to develop area-specific adaptation plans. According to IPCC AR4 and AR5 frames, various biophysical and socio-economic elements have been applied for vulnerability (AR4) and risk (AR5) appraisals in the blocks of the Purulia employing principal component analysis (PCA). The biophysical and socio-economic factors were studied under exposure, hazard, sensitivity and adaptive capacity and vulnerability and risk maps were prepared for the Purulia based on the index.

7.2 DROUGHT VULNERABILITY AND RISK ASSESSMENT

Exposure index for 20 blocks of Purulia revealed that the higher exposure (> 0.8) was observed in western blocks (Arsa, Bagmundhi, Purulia I, Bandoyan, Balarampur, Barabazar, Jaipur, Jhada) while lower (< 0.15) was found in northern blocks (Raghunathpur, Santuri, Nituria, Para). Block-level exposure indicates that eastern blocks of the district constitute high to moderate exposure to drought. This might be owing to erratic rainfall, high evaporation driven by rising temperature (Varadan and Kumar, 2015); high groundwater fluctuation and significant crop failure due to frequent drought. Higher Sensitivity (> 0.45) was found in eastern blocks Kashipur, Puncha, Hura and Manbazar I and lower (<0.20) was in northern blocks Raghunathpur, Santuri, Nituria, Para. Most of the blocks in western, central and southern zones comprised high to moderate sensitivity. The reasonable cause may be caused by greater the area share of unirrigated cultivated area, more is the sensitivity to drought (Varadan and Kumar, 2015; Sendhil et al. 2016), the share of tribal population, small and marginal farmers' (Panda 2017; Kumar et al. 2020), agricultural labour and non-workers. The adaptive capacity was higher (> 0.5) in Arsa, Bandoyan, Balarampur, Barabazar, Jhada and Manbazar II while lower (< 0.15) was observed in eastern blocks Jaipur, Manbazar I, Barabazar, Hura, Para, Baghmundi and Kashipur. The northern blocks Raghunathpur, Santuri, Nituria, and Para were classified as moderately adaptive to drought. The possible reasons are the higher cropping intensity, irrigation and drinking water availability, literacy rate (Gizachew and Shimelis, 2014), the share of the population associated with fishery, poultry and other livestock sector income, percentage of fertilizer and seed consumption, number of ration shop (Maiti et al., 2015) and electricity and other infrastructure (Maiti et al., 2015).

Based on the results of NLPCA, a block-level drought vulnerability map has been prepared (Fig 7.1). One component of exposure, two factors of sensitivity and three factors of adaptive capacity have been computed for 70.05%, 84.93% and 80.43% of the total variance respectively (Table 7.1).

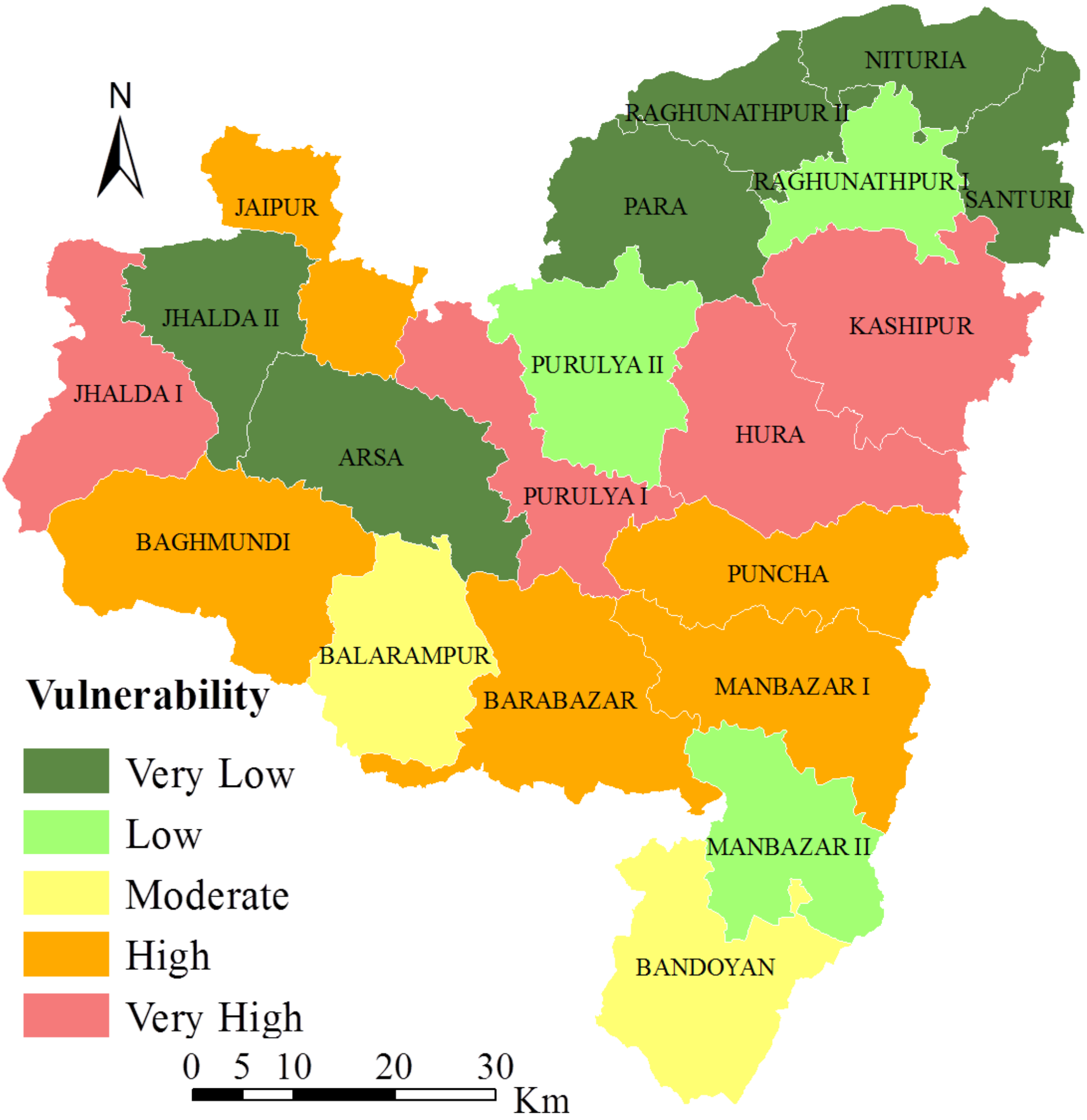

Fig 7.1 Drought vulnerability map (following the IPCC AR4 approach, 2007).

The spatial assessment of drought vulnerability in the Purulia displayed that blocks Kashipur, Hura, Purulia I and Jhalda I were at very high vulnerability. The block Puncha, Manbazar –I, Barabazar, Jaipur and Bagmundhi have fallen under high vulnerability owing to greater sensitivity and lesser adaptive capacity. The moderately vulnerable consists of few blocks in the southern part of the district. In the instance of northern blocks, the lowermost potential impact combined with high adaptive capacity was the principal reason behind the lowest vulnerability to drought. Despite the high exposure in western bocks Arsa and Jhalda II, these blocks have come under very low vulnerability due to low sensitivity and high adaptive capacity.

Table 7.1 PCA results for drought vulnerability and risk assessment in Purulia: Varimax rotation factor matrix.

	Component (AR4)				Component (AR5)		
Variables	1	2	3	4	1	2	3
Rainfall	0.46						
Maximum temperature	0.81						
Minimum temperature	0.35						
Evapotranspiration	0.64						
Drought frequency	0.78				0.88		
Drought effected area	0.85				0.82		
Crop failure	0.88				0.78		
Population density	-0.63				0.46		
Female population				0.75	0.47		
Child mortality rate			0.86		0.80		
Scheduled tribes	0.74				0.80		
Scheduled caste		-0.84				0.84	
Crop water stress				0.94			0.96
Groundwater level fluctuation			0.65				0.56
Upland	0.82				0.46		
Marginal workers			0.64	0.58	0.58		0.68
Nonworkers		-0.60	-0.54			0.57	
Small farmer	0.60				0.55		
Marginal farmer	0.82				0.87		
Cultivator		0.83			0.62		
Agricultural labour			0.65	0.56	0.65		
Main workers	0.75				Same		
Safe drinking water	0.86						
Electricity	0.86						
Ration shop				0.70			
Fertiliser	0.80						
Net irrigated area	0.76						
Crop diversity			0.79				
Seed store				0.66			
Waterbody		0.73					
Fallow land				0.45			
Literacy rate			0.43				
Livestock population			0.91				
Fisheries		0.75					
Forest			0.71				

Percent of variance								
Exposure	70.05				Hazard	72.15		
Sensitivity	23.66	21.94	21.53	17.80	Exposure	63.24		
Adaptive capacity	25.66	23.85	19.57	11.36	Sensitivity	32.65	22.71	22.43

The drought risk has been recognized at the sub-district level using the IPCC framework AR5 approach. The results of the risk analysis (AR5) presented a nearly comparable scenario. For hazard and exposure, one component expressed 60.33% and 63.24% of the total variance respectively. Three components of sensitivity and adaptive capacity supported 77.79% and 80.43% of the total variance, respectively.

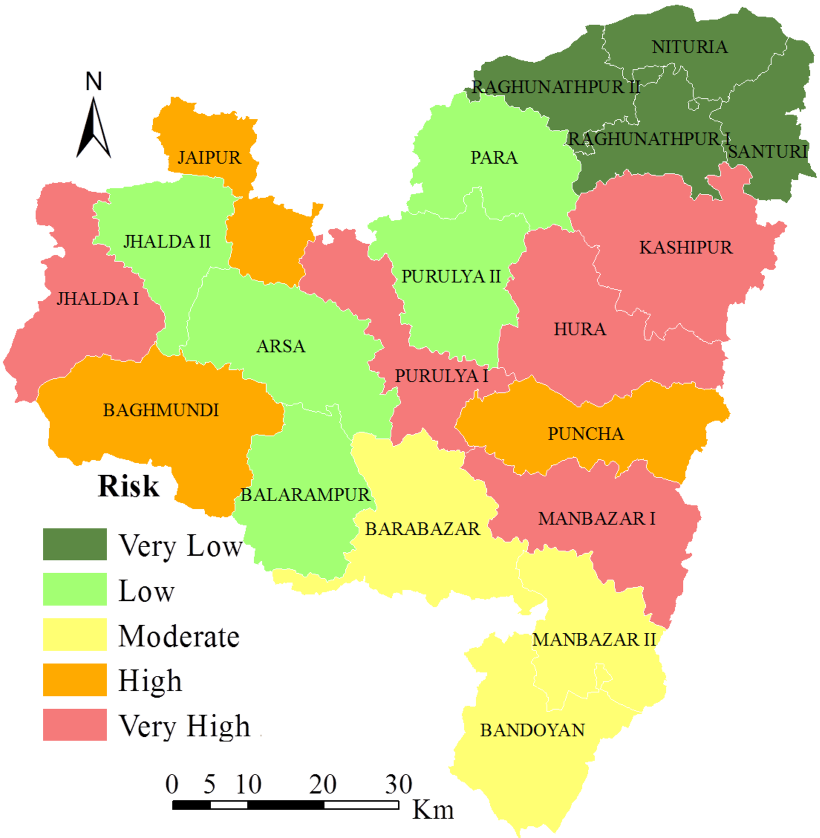

Fig 7.2 Drought Risk map (following the IPCC AR5 approach, 2014)

About five blocks were categorized as very high risk to drought; three blocks as high risk, three blocks as moderate risk, five blocks as less risk and four districts as very low risk. In the case of eastern blocks, greater sensitivity and moderate exposure along with very low adaptive capacity were the main reasons behind the very high risk of drought. The Western blocks, its high exposure and sensitivity with low adaptive capacity resulting in the high drought risk area. The southern blocks, the high potential impact coupled with high adaptive capacity resulting moderate risk to drought. However, in the Arsa, Balarampur, Jhalda II blocks, exposure is high but high adaptive capacity along with low sensitivity led to the low risk to drought. Very low risk to drought in northern blocks was mainly owing to its less exposure combined with less sensitivity, and high adaptive capacity.

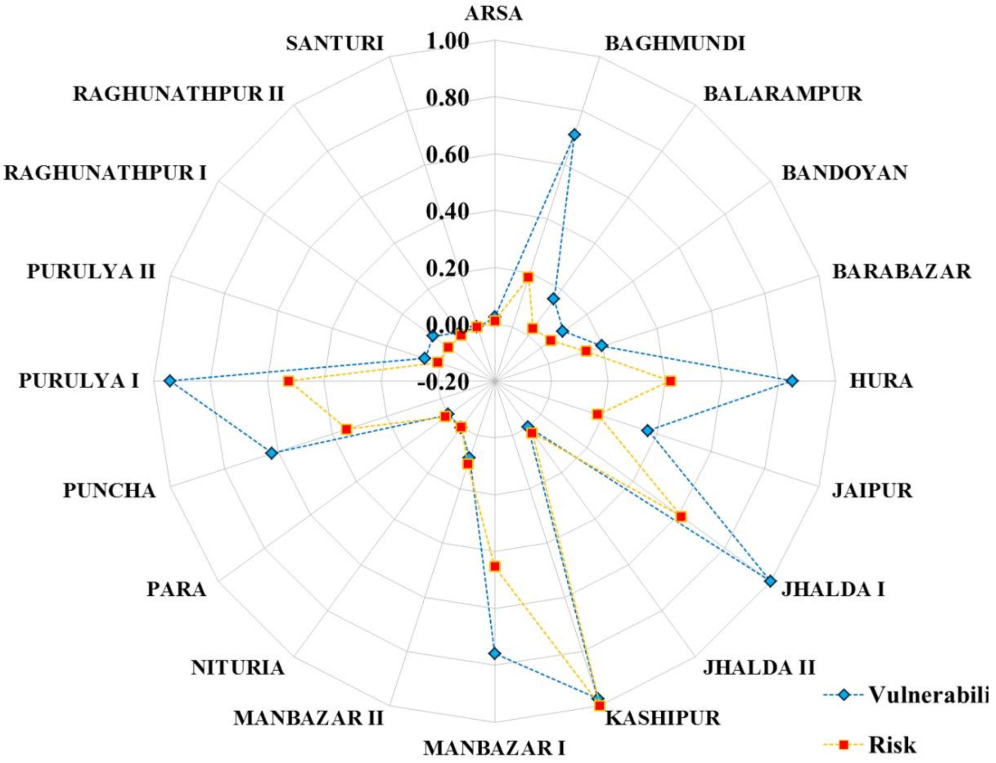

Fig 7.3 Block level relative ranking of Purulia.

Results revealed that the majority of the blocks in the eastern part and few blocks in the western part of the district represented a very high vulnerable zone, whereas most of the blocks in the north are less vulnerable to drought. The result of risk analysis also indicated that all blocks in the eastern, and some blocks in the western part are at higher risk, as these blocks are also obtained in high drought vulnerable zone. This might be attributable to high sensitivity joined with the deficient adaptive capacity to drought vulnerability although exposure is comparatively lower than western blocks. Extensive irrigation deficit, limited livelihood opportunities of marginal and small farmers, poor socio-economic of the tribal population higher the area share of moderate to steep slope cultivated area make eastern blocks most vulnerable and exposed to highest risk. Conversely, all the districts in the north portion are less vulnerable because the Damodar river dam is located nearly which marks enhancements in water availability, employment opportunities and acquired frontline services. The low vulnerable/risk consists of two blocks (Arsa and Jhaldha II) in the western part of the district, its high adaptive capacity and low sensitivity together reducing the effect of exposure.

7.3 CONCLUSIONS

Addressing the drivers of vulnerability suggests a consistent approach to reduce vulnerability and manage potential risk. Therefore diminishing drought risk and related impacts through risk reduction and modification have become a global significance. Warming induced frequent drought is negatively affecting the rural farmers in Purulia and might be a immense threat to the agronomy in the future. Small and marginal farmers are the most underprivileged group in the rainfed farming system, who are highly exposed to drought. Hence, the present study has been attempted to assess block-level drought vulnerability and risk of Purulia district comprising indicators based on IPCC AR4 and AR5 approaches. It was formulated using exposure, hazard, sensitivity and adaptive capacity containing various influences to identify the blocks under different vulnerability/risk categories to drought. The results of the study revealed that higher exposure and adaptive capacity were observed in western blocks compared to eastern blocks. Sensitivity was higher in eastern blocks compared to western blocks. The vulnerability analysis indicated that eastern blocks are highly vulnerable to drought, while the lowest vulnerability to drought was observed in northern blocks. Drought risk mapping also indicated that most of the eastern blocks and few blocks in the western part were prone to high risk. All blocks in the north were very low risk, whereas the remaining southern and central blocks of Purulia were identified under the moderate to low drought risk category. High irrigation deficit, small land holding, a higher proportion of small and marginal farmers, less occupation diversification and low access to markets are the major constraints of highly vulnerable farms. Access to live-saving irrigation, crop-livestock integration, quality of seeds, fertilizer, changes in crop varieties and access to electricity and other services were the main adaption techniques adopted in the study area. To mitigate the damaging consequences of drought, the attention should be specified to farm-level adaptation approaches and coping procedures like water-conserving practices and water consumption efficiency. The concerned authorities at the governmental and non- governmental level should execute certain strategies to facilitate and encourage the farmers to implement adaptation activities in their farming practices.

The structural supply-based management (surface water harvesting site and groundwater potential zone) and demand-based management (agricultural land suitability, effective irrigation and climate-proofing agricultural system) for drought mitigation have been described in the next chapter.

CHAPTER VIII

Drought Adaptation and Mitigation through Water, Agriculture and land use management in Purulia District

[This chapter deals with some adoption interventions and practices that have a great possibility to enhancing crop production and food security under drought conditions in RLZ of West Bengal. Mitigation and Preparedness strategies to drought include: (a) identified ground water potential zone b) agricultural land suitability analysis (c) identified potential locations for rainwater harvesting structures d)drought tolerate crop cultivation, forestation, nutrition grading using drip irrigation are discussed in detail. The changes in the socio-economic condition of farmers, before and after drought adaptation measures are also discussed herewith. The chapter presents successful case studies employing these innovative approaches where clear implications are revealed to cope with drought and food scarcity in RLZ.]

8.1 INTRODUCTION

Drought is a slow onset and complicated natural hazard that cannot be prevented, but preparedness for drought can help for prepared to manage drought, progress resilience to recover and mitigate from drought and its impacts. Drought is a recurring feature (varies with the occurrence, intensity, duration and spatial extension) and is largely unpredictable. Therefore, adaptation and mitigation strategies for drought are essential to reduce drought impacts. Surprisingly the humid area of India (Orissa, Gangetic West Bengal, Jharkhand, RLZ and Northeast area of India) received a good amount of rainfall in the monsoon season also experienced numerous incidents of drought (Pandey et al. 2008; Nagarjan 2010; Pathak and Dodamani 2019; Gopinath et al. 2020) which leads to adverse impact on agricultural and food security (Parid and Oinam 2015; Nath et al. 2017). In the red and laterite zone of West Bengal, monsoon climatic variability is a prevalent feature in recent years (Mukherjee and Huda 2018; Mukherjee et al. 2018) Thus, it is essential to take required initiatives to diminish the effects of uncertain climate variability.

Drought is a recurrent and prevailing phenomenon in Purulia. In the perspective of climatic variation, an intensifying propensity in drought frequency and intensity is found in Purulia in recent years. Drought is one of the main limitations of agricultural production and occupations of more than 75% of people that inhabit in drought-prone areas which comprise 68% of the total agricultural land of the district. Frequent drought has caused significant negative crop production during drought years 2000, 2002, 2005, 2009, 2010 and 2015. In Purulia, monsoon drought is a prevalent feature in recent years (Patra 2020; Dey et al. 2021) and undulating topography, poor inherent soil fertility, rainfed mono-cropped make this area more vulnerable to drought (Raha and Gayen 2021). Thus area-specific drought adaptation strategies have needed for robust to deal with drought.

Consortium Research Program (CRP) on “Integrated and Sustainable Agricultural Production Systems for Improved Food Security and Livelihoods in Dry Areas” (Dry land Systems), headed by ICARDA, was introduced in 2012 (CGIAR, 2013). It focuses on farming practices in arid regions, globally, and contains 80 partners. This approach contains crops, livestock, rangeland, tree, soil, water and policies which have lessened the overall impact of drought and sustainably enhance people's livelihoods.

Solh and Ginkel (2014), Panigrahi et al. (2017) have identified some interventions and practices that have a great possibility for mitigation to improve food security under the adverse environs of the sub-humid drought-prone area in developing countries. Numerous interventions and practices (preserving the soil moisture by decreasing evaporation, using drought and drought-tolerant yields and conservation agriculture, inter cropping, using suitable land for agriculture, rainwater harvesting, developing the efficient surface irrigation practices, shifting low-water requiring crops) have been adopted for resilience to drought in Australia (Kiem and Austin 2013), South Africa (Lottering and Mafongoya 2020), Iran (Khayyati and Aazami 2016), Bangladesh (Abdullah and Rahaman 2015) South Asia (Aryal et al. 2019, 2020). Such adaptation practices also implied drought risk mitigation all over India (Das 2005; Patnaik et al. 2019; Sundar 2018; Birthal et al. 2019; Bird et al. 2016; Udmale et al. 2014; Gupta et al. 2011).

Patnaik et al. (2019) concluded that adaptation leads to significant gains in the livelihood of farmers in rural ref and laterite zone of India. Recent empirical studies (Bird et al. 2016; Rao et al. 2019; Sam et al. 2019, 2020; Kumar et al. 2020) based on household surveys in drought-prone rural eastern India suggest that implication of farm-level drought adaptation approach reduced the drought risk and enhance income from crops. Previous research represents efficient research outcomes and case studies employing some innovative approaches where observable results are represented to cope with drought and food security in humid drought-prone areas.

8.2 AMIS AND OBJECTIVES

The present chapter aims at micro-level strategies developed at managing drought and water shortage to improve food security and decline poverty in drought-prone areas of the district through an assimilated agro-ecosystem process. Adaptation strategies to drought in the sub-humid Purulia district include (a) suitable agricultural land use for sustainable agricultural (b) assessment potential groundwater zone making irrigated systems more efficient; (c) identified optimum sites for Rainwater Harvesting Structure to expanding the intermediate rainfed–irrigated systems; (d) rural land use management including reforestation, using the traditional drip irrigation in nutrition garden, less water-intensive crops cultivation for ensuring food security and improving farmers' livelihoods. This study represents a feasible technique to focus farm-level adaptation approaches and delivers multiple pathways to increase smallholders' adaptability. Suitable agricultural land practice, land use management and reforestation would help to mitigate the risk to agricultural production and also improve the eco-environment. Drought tolerant crop cultivation, nutrition gardening using drip irrigation diversified their income sources and improved food security. Rainwater harvesting and ground water have mitigated the drought effect on irrigation practices, and it has intensely enhanced crop yields and farmers' revenues. This robust alteration stratifies in the agriculture should jointly reflect the economic improvements, and societal well-being and ecological advantages for agricultural sustainability.

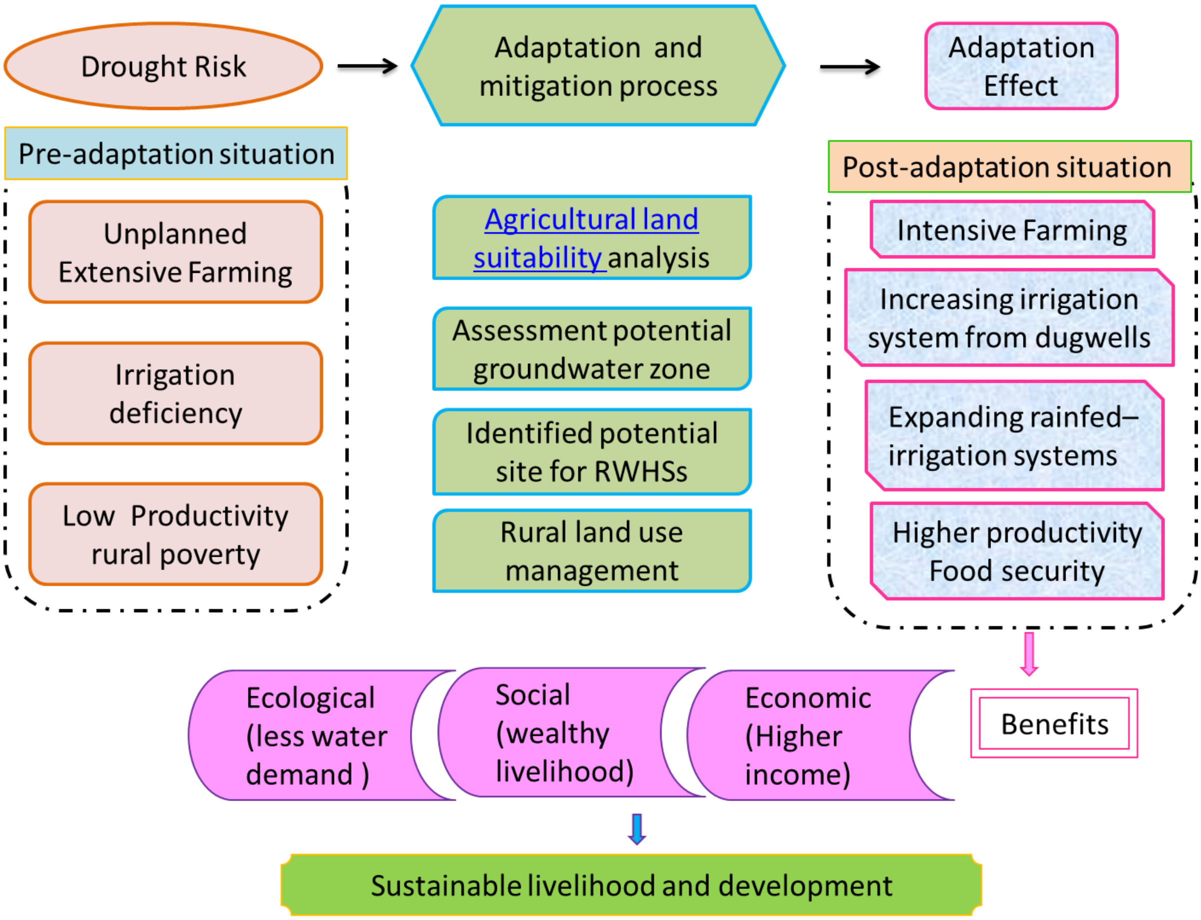

Fig 8.1 Micro-level adaptation strategies in Purulia

8.3 LAND SUITABILITY ANALYSIS FOR SUSTAINABLE AGRICULTURE

In the context of adaptation to drought risk and rural poverty, suitable agricultural land use can provide an operative modification approach in the agricultural sector at the local level (Shirsath et al. 2017; Lei et al. 2014). Suitable agricultural land use is evidenced to poses a potent adaptive capability to drought in a sustainable manner (Briassoulis 2019; Azadi et al. 2018). Sustainable agricultural land optimized crop production with water-saving efficacy and economic profit, which assists rural poverty diminution and socio-economic progresse (Amadou et al. 2018; Lei et al. 2014). Imbalanced use of land resources, associated degradation, water shortage and climatic irregularity are significantly constricting agricultural growth of drought-affected sub-humid areas (Akpoti et al. 2019; Ujoh et al. 2019; Keshtkar et al. 2016). Unsuitable land-use practices may intensify droughts (Azadi et al. 2018) especially undulating red and laterite terrain areas (Srinivasan et al. 2020). The extension of crop land to marginal or less productive land, deforestation, mismanagement of slope soil and water are the main causes of increasing land degradation that deplete the rainfed agricultural productivity (Kumar et al. 2019; Sujatha et al. 2019; Prajapati and Devi 2018; Ahmad and Pandey 2018; Bhattacharyya et al. 2015). Thus sustainable agricultural land use patterns are necessary to cope with drought, including the use of less water requiring crop varieties, and plantation (Lei et al. 2016, 2014).

Drought is a common and recurring phenomenon in the RLZs of Purulia and Bankura districts, West Bengal, India. This region receives sufficient annual rainfall of around 1200 mm. However, in recent times, the nature of rainfall patterns has become erratic (Mukherjee and Palit 2013; Ghosh and Jana 2018). Around 50% of land in RLZ consists of residual upland cultivation on slopes without adequate spatial planning, inadequate bounding, and witnesses rampant deforestation (Das and Sarkar 2016; Mahala 2019). Due to recurrent droughts, erratic rainfall, undulating topography, and land degradation (Senapati and Das 2020) compounded by the increasing practice of agriculture on a steeper upland slope, forest, and low potential fallow land (Mahala 2018), rain-fed cultivation has become potentially challenging in Bankura and Purulia districts (Sarkar et al. 2011; 2014). Characterization and appropriate use of agricultural land according to its suitability for particular crops are altogether absent in the area resulting in a decline of productivity, soil fertility, water availability, and an increase in drought impacts (Mandal et al. 2018; Mahala 2020). The overall economic backwardness of these two districts essentially demands proper drought management strategies to uphold the agriculture-based economy of this region (Bhunia et al. 2020; Dey et al. 2021). Agricultural development through reliable land resource utilization concerning the nature, extent, and spatial distribution of agricultural land can perform a pivotal role in sustaining the livelihood of farmers (FAO 1996; Mura 2018). Thus, land suitability assessment for agriculture in such RLZs is essential to enhance productivity and food security in a sustainable way.

Land suitability assessment is fundamental to minimize the unwise utilization of land (Jiao et al. 2017; Mesgaran et al. 2017) by recognizing its inherent potentials and limitations (Bagherzadeh et al. 2016; Mousavi et al. 2017). Land evaluation plays a significant role in land use planning by enhancing the efficiency of crop production and sustainability of investments (Qureshi et al. 2018; Vasu et al. 2018; Seyedmohammadi et al. 2019). Integrated information from various branches of science for multiple criteria selection (Daneshvar et al. 2017; Otgonbayar et al. 2017) regarding a common framework (Kahsay et al. 2018a) formulated the protocols for the analysis of land suitability. The multiple-criteria decision-making (MCDM) tool has provided advanced decision support capabilities of the GIS system (Barakat et al. 2017) by integrating multiple factors (Harper et al. 2017) with the rank assignment of alternatives (Zavadskas et al. 2018; Halder et al. 2020). MCDM coupled with GIS technique offers a systematized and spatially precise evaluation framework (Singha and Swain 2016; Owusu et al. 2017; Qureshi et al. 2018) and facilitates findings with greater accuracy for sustainable land use management practices (Yalew et al. 2016b; Musakwa 2018). Analytic Hierarchy Process (AHP) finds extensive use in MCDM techniques in GIS-based suitability procedures (Yalew et al. 2016a) due to its appropriateness for calculating weightage for different land-use based on pair-wise comparisons of multiple factors according to their relative significance (Wijenayake et al. 2016; Das et al. 2017; Qureshi et al. 2018). The weighted overlay technique using AHP in GIS is quite convenient to the hierarchical structure of multi-criteria analysis (Pramanik 2016; Kazemi and Akinci 2018; Negi et al. 2020). AHP-based MCDM integrating the weighted overlay model provides promising agricultural land suitability assessment (Burian et al. 2018; Hussien et al. 2019; Purnamasari et al. 2019).

Several researchers used the AHP-based MCDM-integrated GIS technique in land suitability evaluation for agriculture all over the world, such as in California (Paul et al. 2020), Ethiopia (Yalew et al. 2016a; 2016b; Kahsay et al. 2018a; Nigussie et al. 2019), Iran (Kazemi and Akinci 2018), Morocco (Barakat et al. 2017; Ennaji et al. 2018), North Africa (Mesgaran et al. 2017), Malawi (Li et al. 2017), Cihanbeyli (Bozdag et al. 2016), China (Zhang et al. 2015; Yu et al. 2018; Geng et al. 2019), and Turkey (Akinci et al. 2013). Various studies (Zolekar and Bhagat 2015; Pramanik 2016; Dadhich et al. 2017; Jamil et al. 2018; Parry et al. 2018; Rath et al. 2018; Akram et al. 2019; Mistri and Sengupta 2019; Singh et al. 2019) were conducted in India to assess the land suitability for agriculture using multi-criteria-based GIS approach.

Previous studies in the study region undertook the natural resource inventory of the Manbazar block of Purulia district (Sarkar et al. 2011) to evolve site-specific technologies for sustainable agriculture. Sarkar et al. (2014) analyzed the wheat crop suitability in the Beko watershed of Purulia using only four basic parameters (slope, land use, soil properties, and rainfall). However, Mesgaran et al. (2017), Dadhich et al. (2017) and Roy and Saha (2018) concluded that hydrogeological factors (drainage, groundwater depth, and geology) are essential for land suitability assessment in drought-prone regions. Santra and Mitra (2016) and Bera et al. (2017) discussed relative land suitability for main crops of Purulia district using slope, drainage, geology, and soil texture. Parry et al. (2018), Herzberg et al. (2019), and Tercan et al. (2020) considered soil depth, pH, erosion, moisture, drainage, groundwater level, and geology as significant factors in undulating terrains area. Recent studies in other regions (Otgonbayar et al. 2017, Zolekar 2018; Ennaji et al. 2018; Geng et al. 2019; Ostovari et al. 2019) have integrated soil moisture, soil erosion, and hydrogeological factors to effectively recognize land suitability for agriculture. The combined use of a large number of criteria provides more specific results to delineate agricultural land suitability (Bozdag et al. 2016; Singha and Swain 2016; Li et al. 2017; Maddahi et al. 2017; Owusu et al. 2017; Kahsay et al. 2018a, 2018b; Roy and Saha 2018; Vasu et al. 2018; Akpoti et al. 2019; Mistri and Sengupta 2019). Earlier studies in RLZs identified suitable land for specific crops on the total land area (including forest, upland, fallow areas, and settlement) by fewer parameters. The present study assessed the relative suitability of existing agricultural land in the drought-prone Kashipur (Purulia) and Chhatna (Bankura) blocks in the RLZ of West Bengal (India) to overcome the shortfalls in the previous studies. This study considered all the factors like the slope, land use, land cover, soil erosion, depth, texture, pH, soil moisture, drainage, geology, and groundwater depth. Rigorous field surveys with GPS validated the findings.

8.3.1 *Land use/Land cover (LULC)*

The land use/land cover map was classified into six classes: agricultural land, vegetation, fallow land, upland (pediment), settlement, waterbody, and river (Fig 8.2). Agricultural land constituted the most extensive type of land use/land cover in Purulia as of 2019. Accordingly, agricultural land comprises 2898 km^2 (46%). The second extensive land cover category is fallow land which constitutes 1126 sq. Km. (18%). land use/land cover under forest, waterbody, settlement, and upland cover around 998 sq. Km (15.71%), 250 sq. Km (4 %), 85 sq. Km (1.3%) and 907 sq. Km. (14.5%) respectively.

The present land suitability analysis was carried out in available cultivated land after eliminating non-agricultural areas (forest, upland, fallow land, water body, and settlement) from further analysis. Thus, for the present study, only the cultivated areas of Purulia (2898 km2) was considered for land suitability assessment.

8.3.2 *Slope*

The potential location for agriculture (Zhang et al. 2015; Bozdag et al. 2016), types of crop, and cultivation techniques are vastly dependent on the slope (Teshome and Halefom 2020). The slope of the study area ranges from 0º to 54º. Steep slope (> 8º) covering 15% of the total area is given low rank for agriculture due to the presence of eroded, shallow, and drainage soil or open rock and high runoff. Out of the total area, only 15% fell under flat slope (0º–2º) and attained high ranking for agricultural land suitability because of good soil characteristics, high infiltration, and low erosion, while 30% and 25% area under gentle (2º–4º) and moderate slope (4º–6º) were assigned moderate ranking (Fig. 8.2)

8.3.3 *Soil depth, texture, erosion, and pH*

Soil characteristics play a significant role in agricultural land suitability analysis (Dominati et al. 2016; Olson et al. 2017; Juhos et al. 2019). The soil depth in agricultural land ranged between 20 m and 150 m in the study area. The result showed that shallow to very shallow soil (20 m - 50 m) covered 28.5% area of these blocks, followed by medium to deep (75 m - 150 m) soils in 25.84% area.

Many studies (Mustafa et al. 2011; Jafari and Zaredar 2011) used soil texture for agricultural land use assessment. The dominant soil texture of these blocks is loamy sand to sandy loam (31.87% area of the blocks) (Fig. 8.2). The clay loam and sandy clay loam soil texture were given the highest rank owing to their water holding capacity, fertility, and nutrient enrichment, while sandy loam and loamy sand are given the lowest rank due to relatively low water holding capacity, fertility, and nutrient content.

Soil erosion acts as the main factor in reducing soil fertility (Zolekar and Bhagat 2015; Yalew et al. 2016a; Zolekar 2018). Soil erosion of the study area ranged from 5 to 40 t/ha/yr. About 38.42 % area of the blocks was classified under moderate to slight erosion, and 25.21% under moderate to severe erosion. Areas of severe erosion were assigned a lower rank due to loss of soil depth, nutrients, and fertility, whereas, the areas with low erosion were considered to be more suitable for agriculture and were assigned a higher rank.

Nutrient availability, plant growth, productivity, and land suitability for crops vary with soil pH (Mustafa et al. 2011; Aldababseh et al. 2018; Roy and Saha 2018). The pH in this region was observed to vary from 5 to 8. Soil with a pH range of 5 to 7.3 was given a higher rank than other sub-groups, considering this range to be the optimum suitable for agriculture (NBSS & LUP). Table 3 depicts the soil texture, soil depth, erosion, pH, and drainage of the study area.

Table 8.1 Soil properties of the district

Texture	Depth (cm)	Erosion (t/ha/yr)	Drainage	pH
sandy loam to loam	100 - 150	5 -20	excessively to imperfectly	5.1 - 6.0
sandy loam to sandy clay loam	75 - 100	10 -20	well to moderately	6.1 - 6.5
loamy sand to sandy loam	<25	5 -40	excessively to poor	5.6 - 6.5
sandy loam to loam	100 - 150	10- 20	excessively to well	5.1 - 6.5
sandy loam to loam	25-50	5 -40	excessively to imperfectly	5.6 -6.0
sandy clay loam to clay loam	75 - 100	5 -40	well to moderately	5.6 - 6.5
sandy clay loam to clay loam	25-50	10- 20	excessively to well	6.1 - 6.5
loamy sand to sandy loam	<25	10- 20	excessively to imperfectly	5.6 - 6.0
sandy loam to loam	<25	20 -40	excessively to well	5.6 - 6.5
sandy loam to loam	<25	10 - 40	well to moderately	6.1 - 6.5
sandy loam to sandy clay loam	100 - 150	10 - 40	excessively to well	6.1 - 6.6
sandy loam to clay loam	75 - 100	5 -20	excessively to well	5.6 - 6.5
loamy sand to sandy loam	<25	10 - 40	excessively to well	6.1 - 6.8
sandy loam to sandy clay loam	<25	10 - 40	excessively to well	6.1 - 6.9
loamy sand to sandy loam	25-50	10 - 40	excessively to well	5.6 - 6.5
sandy loam to sandy clay loam	100 -150	5 -20	moderately to poor	6.1 - 7.3
sandy loam to sandy clay loam	100 - 150	5 -20	imperfectly drainage	6.6 - 7.3

8.3.4 *Soil moisture*

Soil moisture is a crucial parameter in determining the suitability of agricultural land (Kahsay et al. 2018b). Soil moisture supports plant growth and nutrient uptake (Chadha et al. 2019). For the determination of ranking, the soil moisture map was classified into five sub-classes (Fig. 8.2). Limited soil moisture content negatively influences the availability of nutrients and crop production (Mahajan et al. 2018). Thus, a comparatively higher soil moisture-bearing area (0-0.2) was assigned a high rank.

8.3.5 *Geology*

Rocks and geologic materials become soil, which is fundamental to agriculture (Roy and Saha 2018). Soil depth, texture, fertility, nutrients for plants, and stored water has direct or indirect geological implications (Churchman and Velde 2019). Geology has a significant influence on soil for efficient agriculture (Li et al. 2018). The study area is composed of Granite Gneiss, Metabasic Rock, Mica Schist, Granite, Pyroxenite/Granulite, and Pink Granite/Biotite Granite Gneiss along with laterites of Sijua Formations (Fig.8.2). The prevailing geological features in Purulia are Granite Gneiss, Gneiss, and Mica Schiest respectively. For their moderate soil fertility, nutrient, and water storage, Granite Gneiss and Gneiss were given moderate rank for agricultural land suitability.

8.3.6 *Drainage*

During the land suitability evaluation for sustainable agriculture, the nearest cultivated area from the drainage network is used to assess the feasibility of supplementary irrigation (Pramanik 2016; Purnamasari et al. 2019). The nearest cultivated area from a stream has a high potential for agricultural land use because steams provide water for irrigation, fertile alluvial soil, and are situated in low elevation (Raza et al. 2018; Roy and Saha 2018). Hence, the shortest distance agricultural land from drainage (<0.25 km) is assigned the highest rank, and a low rank is given to the farthest area from drainage (1.5-2 km), due to low water availability and soil fertility (Fig. 8.2).

8.3.7 *Depth of Groundwater level*

The interaction between agriculture, surface water, and groundwater is essential to promote sustainable agricultural land use (Dadhich et al. 2017; Sheikh et al. 2017). Groundwater has a major influence on sustainable agricultural land use practice (Yu et al. 2018; Juhos et al. 2019). Groundwater depth is most relevant for assessing land suitability for agriculture in a dry region (Worqlul et al. 2017; Worqlul et al. 2019). The present study area experienced frequent droughts and water shortage in most of the surface water bodies like ponds, streams, etc. in the summer months when groundwater became the only option for water supply (Ghosh and Jana 2018). The depth of the groundwater level in the study area varied from 2.5 to 7 mbgl. The groundwater depth near the surface was considered to have the most potential, while that at a higher depth was considered to have a lower potential for groundwater (Worqlul et al. 2017; Roy and Saha 2018). Therefore, high groundwater depth (5-7 mbgl) was assigned a low rank and lower groundwater depth (2.5-3.5 mbgl) was given a high rank in the context of agricultural land suitability.

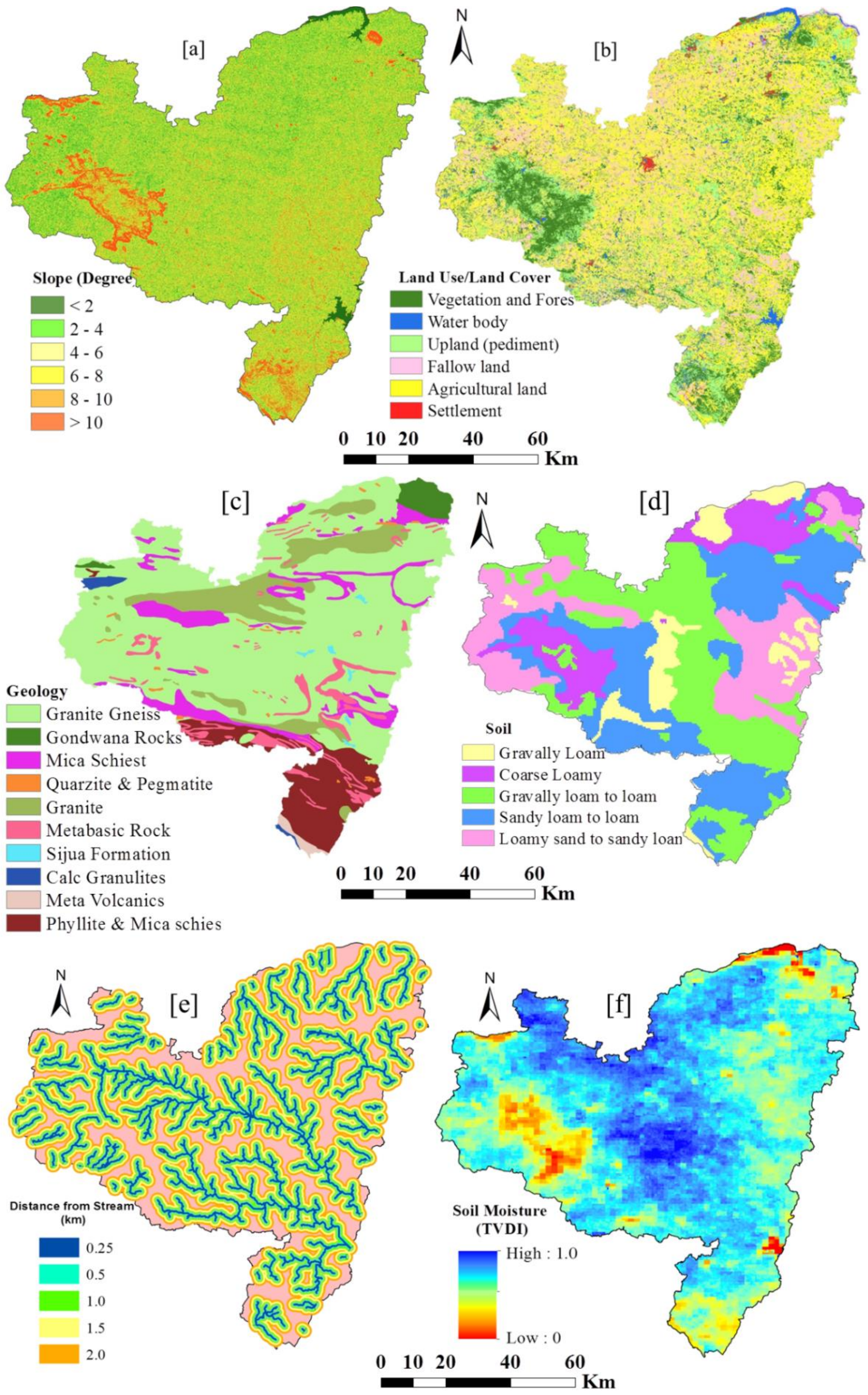

Fig 8.2 Thematic layer showing slope (a), land use/land cover (b), geology (c), soil texture (d), distance from stream (e), and soil moisture (f).

8.3.8 *Agricultural land suitability map*

Land suitability for agriculture, in this study, was identified as belonging to four separate categories (Pramanik 2016; Roy and Saha 2018), i.e., unsuitable, marginally suitable, moderately suitable, and highly suitable. The unsuitable zone covered 396 sq. km (13.43%) of the study area, marginal suitable zone covered 1138 sq. km (38.58%), moderately suitable zone covered 946 sq. km (32.10%), and highly suitable zone covered 468 sq. km (15.89%) only of the total agricultural land of Purulia.

Table 8.2 Areal distribution of agricultural land suitability

Categories	Agricultural Land		Characteristics	Preferable Utilization
	sq km	(%)		
Highly Suitable (Bohal)	468.59	15.89	Low land, surface runoff and seepage from upper catchments.	Paddy cultivation with pulses
Moderate Suitable (Kanali)	946.79	32.10	Gentle slope, Soil is rich in moisture contain and organic matter	Mixed cropping
Marginal Suitable (Baid)	1138.16	38.58	Moderate slopes. Shallow top soil with low moisture contain and organic matter.	cultivation of maize, pigeon pea
Unsuitable (Tnar)	396.29	13.43	Steep slope, thin topsoil, very low moisture contain.	traditional varieties agro-forestry

The calculated weights of the nine criteria (slope, soil depth, pH, texture, erosion, moisture, drainage, geology, and depth of groundwater level) in the AHP method, and assigned scores of sub-criterion were used in the weighted overlay to produce the map of land suitability for agriculture in the RLZ. Among the parameters, the slope gets the highest weightage because the slope has significant control on soil characteristics, drainage, moisture, water holding capacity, and land use in this area. Soil moisture deficiency may lead to an agricultural drought affecting agricultural yield in drought-prone RLZ (Rossato et al. 2017).

Thus, soil moisture was given higher weightage to understanding the suitability of agricultural land use in this region. Drainage is a potential resource for irrigation in a cultivated area and highly influential in determining agricultural land suitability, especially in drought-prone areas (Mishra et al. 2015; Yalew et al. 2016a, b; Karimi et al. 2018). Various studies (Das and Bhandari 2017; Ghosh and Guchhait 2020) have indicated that a good amount of rainfall is discharged as surface runoff in the study area, and streams have a large potential as a source for surface water irrigation. Thus, proximity to drainage water is considered an important parameter for agricultural land suitability in drought-prone RLZs. Soil depth has a significant influence on infiltration (Singha and Swain 2016; Li et al. 2017), soil nutrients, texture, and water holding capacity (Selassie et al. 2014), which affect agricultural productivity (Zolekar and Bhagat 2015; Maddahi et al. 2017). Thus, deep soil was assigned a high rank for agricultural land suitability. Groundwater provides access to water during the dry season and reduces impediments in rain-fed agriculture (Owusu et al. 2017; Aldababseh et al. 2018). Drainage was assigned more importance than groundwater because surface water is the major source of irrigation in the study area. Soil pH, structure, and nutrients are changeable with soil texture and erosion (Mustafa et al. 2011; Bhagat 2014), which affect the growth of crops. Thus, Soil texture and erosion were assigned lower weightage. Geology and soil pH were considered as little consequence.

The randomly allocated highly suitable area is characterized by the flat slope (<2º), high soil moisture content, surface and groundwater availability, deep loam to clay loamy soil, neutral pH value, and very low soil erosion. Moderately suitable agricultural land covers the considerable portion of the district. The moderately suitable area is characterized by the gentle slope (1.5-3º), soil moisture range of 0.6-0.8, 0.35 km distance from stream, groundwater depth of 4-4.35 mbgl, soil depth of 75 to 100 cm, loamy texture of soil, neutral pH level, and soil erosion range of 10-15 t/h/yr. A extensive amount of marginally suitable agricultural land is found with moderate slope (3-5º), lesser soil moisture, lower depth (50-75cm), slightly acidic pH, higher erosion (8-10 t/h/yr), higher distance from drainage (0.5 km), higher depth of groundwater level (4.35-4.5mbgl) and sandy loam to loamy soil texture. Comparatively lesser unsuitable agricultural land is characterized by steep slope area (>6º), very shallow soil depth (25cm) with sandy loam texture, highly erodible (>20t/h/yr) soil with low moisture contain (0.3), and more than 5mbgl depth of groundwater table. The analysis has identified a considerable amount of land suitable for agriculture in the RLZ.

Similar studies conducted in Ethiopia (Kahsay et al. 2018a), Turkey (Bozdab et al. 2016), China (Geng et al. 2019), Telangana (Vasu et al. 2018), Jharkhand and West Bengal (Roy and Saha 2018), and Malda (Mistri and Sengupta 2019) have evaluated agricultural land suitability in the respective areas and identified 30 to 40% area under moderate to marginal suitability for agriculture.

Previous research on the Purulia district (Santra and Mitra 2016; Bera et al. 2017) had identified a larger portion of the total area to be highly suitable for agriculture. While analyzing the wheat crop suitability in the Beko watershed of Purulia, Sarkar et al. (2014) had determined that over 90% of the area is under moderately suitable conditions. However, ground validation of the present agricultural land suitability analysis in the RLZ of the study area did not reveal such an encouraging proposition. The higher accuracy of ground validation suggested that the multi-criteria approach adopted in the present study to identify the suitability of agricultural land use is ideal in achieving superior results in RLZ.

8.3.9 *Validation of agricultural land suitability map*

During the field survey, it was observed that the agricultural lands with multi-cropping practices were accompanied by low elevation, good soil properties, and availability of water resources while the rain-fed single croplands were associated with higher elevation, low soil quality, and lower water availability. Thus, the cropping intensity (single crop, double-crop, and multi-crop) of agricultural lands based on field survey were taken into consideration for validation parameters of agricultural land suitability. Accuracy assessment was performed by verification of the classified data (output) with training set data (Stehman and foody 2019; Foody 2020). Error matrix (Rwanga and Ndambuli 2017) was prepared using cross-tabulation of classified data against reference data. A total of 235 ground reference points were verified from the study area using a GPS survey and were compared with classified data. The overall accuracy of the classified map was estimated to be about 85%and the kappa coefficient was 0.80 (Table 8.3).

Table 8.3 The error matrix for agricultural land suitability and ground data

	Reference data					
Classified data	Highly suitable	Moderate suitable	Marginal Suitable	Unsuitable	total	User accuracy
Highly suitable	33	6	4	2	45	73.33
Moderate suitable	5	60	3	2	70	85.71
Marginal Suitable	1	3	49	2	55	89.09
Unsuitable	1	2	4	58	65	89.23
total	40	71	60	64	235	
product accuracy	82.50	84.51	81.67	90.63	Overall accuracy	85.1

8.3.10 *Conclusions*

The present study principally focused on the identification of suitable agricultural land in existing cultivation areas in undulating drought-prone RLZ of West Bengal. GIS-based AHP model was applied to decipher agricultural land suitability using multi-criteria analysis (slope, soil depth, texture, erosion, pH, moisture, drainage, geology, and groundwater table) for sustainable agriculture in the region. Based on such analysis, the agricultural land of 506 km2 of the RLZ was classified as highly suitable (11.7%), moderately suitable (38.2%), marginally suitable (41.6%), and unsuitable (8.5%) for appropriate agricultural planning in the area. The highly suitable areas are appropriate for paddy cultivation in both summer and winter seasons, with pulses in between, using the residual soil moisture. For moderately suitable lands, rotation of crops (e.g. ragi, maize, groundnut, mustard, sesame, etc.) with leguminous crops (e.g. cowpea, green gram, black gram, and horse gram) can be suggested for maximum yield. In-situ water harvesting tanks and land shaping would help to increase the moisture content and irrigation potential (Kumar et al. 2012). Marginally suitable lands need not be considered for paddy cultivation; instead, cultivation of maize and pigeon pea may prove to be profitable in such areas. Green manuring (through field bund plantation or cultivation of sun hemp) for the conservation of soil fertility (Srivastava et al. 2010) may also be promoted. Rainwater harvesting (5% model, 30 x 40 model) can improve the crop yield in marginally suitable lands, enhancing the soil moisture. The agricultural land found 'unsuitable' in the present analysis (i.e. not suitable for paddy or other cultivation) is mainly situated on the undulating pediments and hillocks where traditional varieties of agroforestry, with a combination of trees and grasses with horticulture and grazing, are to be implemented.

Plugging of gullies and their stabilization would help to prevent soil degradation in such areas (Srivastava et al. 2010). The authors of the study envisage that the findings will serve as an important tool to aid micro-level planning and management of natural resources, crop production, and drought mitigation sustainably in such RLZs. The present micro-level analysis may also benefit farmers with small landholding through the process of crop rotation and alternation, addressing sustainable land and water management in a high-risk environment. The present methodology can be replicated in the wider RLZ or several other drought-prone states with comparable physiographic characteristics in India and other subtropical areas.

8.4 ASSESSMENT POTENTIAL GROUNDWATER ZONE FOR EFFICIENT IRRIGATED SYSTEMS

Groundwater potential zone feasibilities to locate dug well as an emergency source of water for drought mitigation (Mussa et al. 2015). The utility of ground water potential zone as water harvesting measures in the context of a proactive approach to drought management and mitigation is efficient in the drought-prone areas (Calow et al. 1997; Srinivasa Rao and Jugran 2003; Ahmed et al. 2021) water management in arid and semi-arid area of India. Groundwater wells have been the fundamental armament Indian farmers have used to cope with droughts (Shah 2009). This trend likely increased today with heightened climatic variability (GoI, 2018; Sahu and Nandi 2015).

Dug well as water harvesting structures facilitated ground water recharge and increased water availability for irrigation (Deora and Nanore 2019; Pal et al. 2020). Ground water potential zone also helps to determine the Suitable sites for dug well and dug-cum-bore well (Bera et al. 2020). Therefore, delineation of ground water potential zone is essential for sustainable use of ground water and intensive development of argo-economy of drought-prone area.

Purulia face rising temperature and irregular rainfall (Mukherjee and Banerjee 2009). Due to predominant rianfed agriculture, low water containing capacity, intense drainage, runoff and soil-erosion, Purulia is highly prone to climatic extreme (Milly 1994; Milly and Dunne 1994; Sehgal 1998; Mukherjee and Banerjee 2009). Recent studies signified that though Purulia experience adequate but often inconsistent rainfall, are influenced by recurring droughts (Mukherjee and Palit 2013; Ghosh and Jana 2017). In years of less than average rainfall, Purulia undergoes water stress. In dry season the majority of the surface water supplies as tanks, river etc. entirely dry and groundwater remain the only choice for water source (Nag 1998). The erraticism of rainfall and shortage of irrigation makes agriculture more challenging and severely affected (Sehgal 1998; Mukherjee and Banerjee 2009; Mukherjee and Palit 2013). Therefore, groundwater zone detection and sustainable usage in the RLZ is enormously required for drought risk diminution to intensify production, eliminate poverty and secure food supply.

Analytic hierarchy process (AHP) integrated with remote sensing and GIS is considered as an easy, efficient, consistent and cost-effective procedure for delineation of ground water potential zone (Machiwal et al. 2011; Ishizaka and Labib 2011, Maity and Mandal 2017).

Numerous analyses have been conducted in India for recognizing the groundwater prospective zones applying Remote Sensing and GIS for the assessment of groundwater resources by Jasrotia et al. (2016) in the hilly rocky region, Mallick et al. (2015) in Delhi, Madrucci et al. (2008) in Udaipur district, Rajasthan, Paschim Medinipur District, West Bengal (Bhunia et al. 2012), Theni district, Tamil Nadu (Magesh et al. 2012) and Unnao district Uttar Pradesh (Agarwal et al. 2013). Waikar and Nilawa (2014) used AHP for the recognition of GWPZ in the Maharashtra. In India, micro-level GWPZ assessments were performed by Ibrahim-Bathis and Ahmed (2016) in the Doddahalla watershed of the Krishna basin, Chandra et al. (2006) in Bairasagara Watershed, Karnataka and Nagarajan and Singh (2009) in Kattankulathur block, Tamil Nadu.

Finding prospective areas of ground water reservoirs is a difficult task mainly in dry mountainous or lateritic regions. In the present-day, remote sensing could provide assure to find surface and sub-surface water resources with less time and cost. The present assessment was performed in the drought-prone RLZ to recognize groundwater prospective areas. Multi-criteria method combined with remote sensing and GIS using six components, viz. lithology, slope, land use/land cover, drainage and lineaments density and fractional impervious surface (FIS) were employed in this study. Weights were given to the components using AHP and different categories within each layer were ranked as per their relative significance for groundwater potentiality.

8.4.1 *Lithology*

Lithology is determined by topography and underlying rock structure (Nayak et al. 2020; Patra et al. 2017) that influences a significant control over the potential of groundwater

(Senapati and Das 2021; Kumar et al. 2008). Purulia is mainly coverd by granite gneisses. The southern part of the area consists of phyllite and mica schists belonging to the Singbhum orogenic belt. The presence of muscovite and biotite schists has also been reported. Sandstone occurs as small bands in this area (Fig. 8.3).

Granite-gneisses are hard and the crystals are tightly interlocked, so the granite isn't very porous but having fracture zones which act as conduit for surface water percolation (Nayak et al. 2020). Therefore, the Granite-gneisses serve as low rank, leading to poor infiltration mainly due to compactness and steep slopes. Mica schists are intensely foliated, fractured and resulting in a decrease in secondary porosity thus have good groundwater potentiality (Bhattacharya et al. 2021). The area has good porosity and permeability but sometimes contain of clay attains it impermeable. Sandstones are rather Fine-grained rocks with tiny pores and can hold water therefore sandstone make good aquifers (Senapati and Das2021). The common occurrence of weak planes in mica schist and sandstones makes it more prone to porosity than granite gneiss. Hence Mica schists and sandstone are considered as higher rank and the Granite-gneisses is lower rank for high ground water potential.

8.4.2 *Slope*

Usually, plane and mildly sloping zones have great infiltration and are able to more groundwater recharge, while, steeply sloping areas promote high run-off and slight or no infiltration (Adiat et al. 2012; Rahman et al. 2012). Flate area (0 - 2˚) covered 15% area of the district that endorses high infiltration, therefore highest rank is assigned. Steep (>8°) slope covered 40% area of the district that allocated lowest rank owing to comparatively excessive runoff and little infiltration.

8.4.3 *Lineament*

Lineaments, fractures and joints are having good porosity and permeability (Hardcastle 1995; Das et al. 1997; Magowe and Carr 1999; Sree Devi et al. 2001; Rao et al. 2001). The lineament disposition of the area provides significant information about subsurface fractures that may impact the movement and recherge of ground water. Areas with very high lineament density (0.2–0.3 km/km^2) have good porosity and infiltration therefore consigned higher rank while, the zones with very low lineament density (0.02–0.08 km/km^2) are considered to have poor groundwater potentiality and consigned lower rank. The entire area is categorized into five classes based on lineament density as presented in Fig. 8.3.

8.4.4 *Drainage Density*

Drainage density and patterns provided the relief, infiltration, runoff and permeability-related knowledge (Manap et al. 2013), surface materials and formation, for example dendritic drainage mainly signifies homogenous rocks (Horton 1945). Observations from various geologic and climatic zones indicate that low drainage density is mosly found in plane regions with permeable subsoil under dense vegetation. High drainage density is occured in hilly regions with sparse vegetation and impermeable subsurface (Waikar and Nilawar 2014). High drainage density areas produce lower infiltration causes poor ground water recharge as compared to low drainage density areas (Murasingh 2014). River or water bodies are commonly considered as the principal sources of groundwater recharge. But, if large numbers of rivers flow in an area escalating the drainage density, implies high runoff and eventually creates less infiltration and declined ground water storage (Dinesh Kumar et al. 2007; Magesh et al. 2012). Therefore, higher drainage density area is given lower rank and low density area is favorable for high ground water potential and is consigned high rank. The higher drainage density was located in the central part, whereas, the lower drainage density appears in the eastern and southern part of the Purulia (Fig. 8.3).

8.4.5 *Land use/Land cover*

Land use/land cover of an area is mostly dominated by the ground water sources and at the same time performs a vital role in regulatory the resources. It effects several hydrogeological processes in the water cycle such as evapotranspiration, infiltration, runoff, etc. (Kaliraj et al. 2014). The vegetation and agricultural land is promot more infiltration whereas, upland and settlement areas decreases the infiltration rate. Thereby agricultural land (46%), vegetation cover area (15%) were consigned high rank and pediment (15%) and settlement (2%) consigned low rank (Fig 8.3).

8.4.6 *Fractional Impervious Surface (FIS)*

Impervious surface is mainly rock-hard surface which inhibit the filtration of rain water and ground water storage. Therefore, evaluation of impervious surface has significant influence to detection of GWPZ. Various researchers (Fohrer et al. 2001; Lee et al. 2003; Zhou et al. 2010; Weng 2012) have considered the control of the impervious surface on hydrology and environment. Impervious surfaces prevent infiltration, percolation, subsurface water recharge and stimulate high quantities of run-off, overland flow and lesser period of absorption (Brun and Band 2012). Thus higher extent of impervious surface confines ground water potentiality in an area. Thereby high FIS area is considered as low ground water potentialility. In Purulia, the coverage of impervious surface is around 46% representing low ground water possibility (Fig. 8.3).

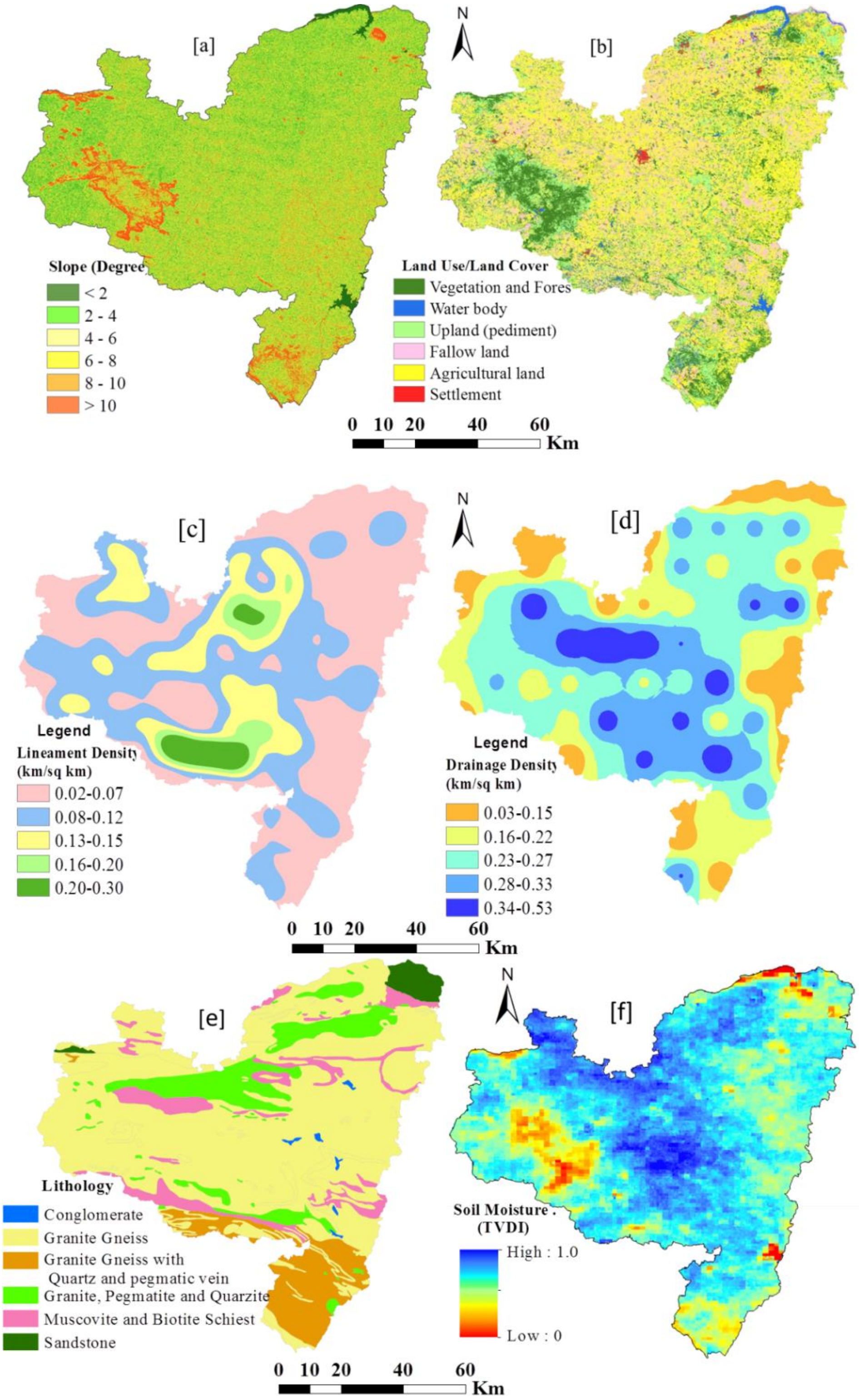

Fig 8.3 Thematic layer displaying slope (a), land use/land cover (b), geology (c), soil texture (d), distance from stream (e), and soil moisture (f).

8.4.7 *Ground Water Potential Zones*

The total six parameters (lithology, slope, lineament and drainage density, land use/land cover and FIS) were intrigrated by weighted overlay technique and prepared groundwater potential map which showing the suitable groundwater zones (Fig. 8.4). Four different categories, specifically, 'Poor', 'Fair', 'Good' and 'Excellent' GWPZs were classified on a 1 to 4 scale (Table 8.4).

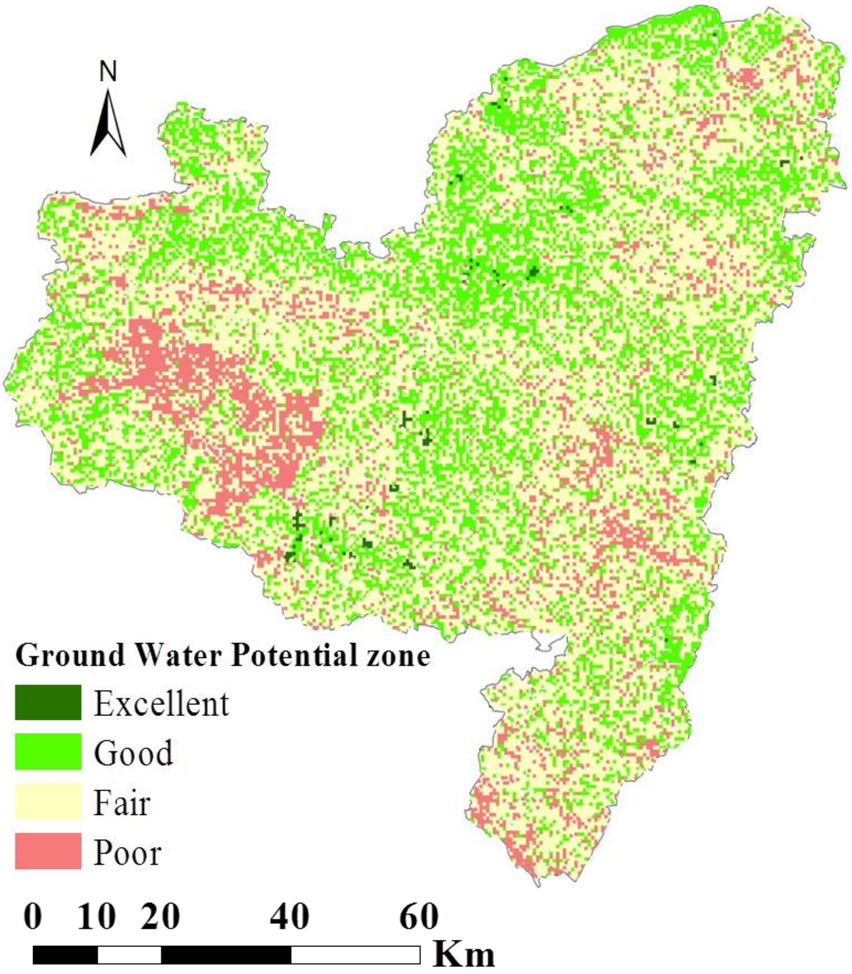

Fig 8.4 Ground Water Potential Zone of Purulia

The 'Fair' groundwater potential zones are obtained to be randomly allocated over the study area. It comprises an area of 3053 km^2, which is about 49% of the total area of the district. The north and central portions of the Purulia come under the group of 'good' GWPZ of about 2190 km^2 (35%). 'Good' GWPZ is distinguished by a gentle slope, high lineament density, low drainage density and favorable lithological condition. 'Poor' GWPZ has less recharge ability and steeper slope as compared to good and fair GWPZ (Patra et al. 2018).

The southern and western part of the district covers an area of about 905.83 (15%) km^2 'poor' GWPZ zone due to undulating hard rock terrain and unfavorable lithological form.

Table 8.4 Spatial extent of different groundwater potential zones of the Purulia

Sr. No	Potential zones	area (sq km)	(%)
1	Poor	905.83	14.7
2	Fair	3053.069	49.4
3	Good	2190.774	35.5
4	Excellent	26.0688	0.4

Ground water potential zones have been detected with the multi citeria decision making process-based on AHP in worldwide (Sener Et al. 2004; Gumma and Pavelic 2013; Rahmati et al. 2015; Ferozur et al. 2019). Outcomes of these studies revealed that out of the total study area, 35 - 45% have fair to good groundwater potentiality, as in Bangladesh (Ferozur et al. 2019), in Iran (Rahmati et al. 2015) or Egypt (Abdalla 2012). A similar analysis in Ghana (Gumma and Pavelic 2013) could recognize 50 % of the total area to be of fair to good potentiality of groundwater.

8.4.8 *Validation*

To validate the groundwater potentiality, the present-day status of numerous dug wells was considered as a proxy of groundwater obtainability. It was assumed that zones having good to fair GWPZ must be complemented by perennial dugwells and the dugwells of poor GWPZ should non- perennial (drying up in summer). Rigorous field surveys were performed and the maximum numbers of dugwells in good/fair GWPZs were obtained to be perennial signifying the presence of permeable reservoir with considerable water storage at subsurface. Inversely, the most of the wells in the poor zone were observed to dry during the summer season. Out of the total 330 perennial wells in the RLZ, 84% were constitute in good GWPZ and 16% in fair GWPZ approving the first part of the hypothesis. Conversely, among the 90 non-perennial wells, 78% fall in the poor zone. The consequences prove the high accuracy of the measurement.

8.4.9 *Conclusion*

Sustainable usage of groundwater is essential to endorse long-term agricultural sustainability as well as for socio-economic improvement in drought-prone areas. As the onset and quantum of monsoon rainfall have become inconsistent in recent times, the pressure on groundwater is rising to fulfil the water shortage not only in the winter season but also during the monsoon season. Thus the GWPZs were delineated by the integrated RS and GIS-based AHP methodology in Purulia as an adaptation measure for drought. The findings presented that poor, fair, good and excellent potential zone comprised 15% (905sq km), 49% (3053sq km), 35% (2190sq km) and 0.4% (26 sq km) of the Purulia respectively. Results revealed that a good groundwater storage area is situated only in the peneplain regions of the Purulia with favourable lithology, slope, lineament, drainage and land use/land cover setup. Rainwater is the main source of ground water recharge. Good GWPZs is suitable for locating dug well for efficient recharge and sustainable use of ground water. However, moderate slope region is determined as fair zones for groundwater recharge procedures. These areas can be chosen for the invention of recharge structures like checkdams, farm ponds etc. to store the rainwater and to prevent intense runoff. The consequences is envisaged to be applicable for locating appropriate sites for dugwell, sustainable groundwater usage and recharge, advance land and water resource management in Purulia. The present study confirms the effectiveness of the combination of multi-citeria dicission process with AHP in term of being a cost-savings approach that required less laborforce and time, which are the limitations of conventional techniques for the prospecting of groundwater. Ground water potential zone supports sustainable recharge and utilization of groundwater water which is required to mitigate the drought impacts.

8.5 IDENTIFYING POTENTIAL RAINWATER HARVESTING STRUCTURE SITE TO EXPANDING THE INTERMEDIATE RAINFED–IRRIGATED SYSTEMS

Droughts are one of the severe disasters that lead to acute water scarcity. The drought-induced water scarcity has significantly increased in recent decades owing to augmented climate change, population explosion, rigorous farming, and enhanced levels of contaminants in inland water bodies (Ward et al. 2010; Jha et al. 2014). Although sub-humid countries receive adequate rainfall, these regions are likely to get affected by this scarcity and its implications. So globally, the management of freshwater resources is a serious concern at present. Rainwater Harvesting structure (RWHS) is an effective tool to generate water resources and optimum water supply in sub-humid regions, where water supply is barely sufficient (Buraihi and Shariff 2015; Mugo and Odera 2019). Implementation of RWH structures throughout the globe fetched fruitful outcomes for drought adaptation and the welfare of marginalized farmers (Bitterman et al. 2016; Ammar et al. 2016).

Indian economy depends profoundly on the yields from the agriculture segment, which has witnessed negative impacts from the recurrent climate-change-induced droughts (Jayaraman and Murari 2014). The recurrence and intensity of droughts would probably escalate in the coming days (IPCC 2012) and reduce agricultural production and freshwater availability. Thus, optimal and efficient water management strategies have become the needs of the hour (Tiwari et al. 2018; Balkhair and Rahman 2021). Warming induces droughts in sub-humid red and laterite zones (RLZs), causing agrarian unproductivity and, ultimately rural poverty (Nath et al. 2017). The drought-induced water scarcity in rural India resulted in a paucity in water supply in the agrarian segment, which needs it the most. Therefore, research on optimum water provisioning tactics and the use of alternative options gained impetus (Pandey et al. 2003; Terencio et al. 2018).

Agriculture predominantly depends on the monsoon rain in the RLZs, where this livelihood option engages 75% of the total workforce (as of Census 2011), comprising the impoverished (<1 ha) and small-scale farmers (1–2 ha). Voluminous studies assert that the sub-humid RLZs have been experiencing frequent drought in the recent decade due to climate change (Masroor et al. 2020). Such recurrent droughts significantly affected the agricultural production and well-being of the marginal and small farmers and their households (Kumar et al. 2011; Pattanayak and Kumar 2014). In RLZ, unpredictability in monsoon-induced rain, increasing temperature, and improper utilization of runoffs principally result in the enhanced recurrences and intensity of drought and the subsequent water scarcity. There is a dire need to store the surplus rainwater during the rainy season by evolving RWHSs to overcome such challenging situations. RWHSs would provide a secured irrigation system and stabilize the yield from rain-fed farming in the RLZs. Therefore, identifying optimal sites for RWHSs is extremely necessary for farming households as their livelihood is highly susceptible to drought.

Storage of rainwater gives rise to cheap and eco-friendly alternative water sources because it is an assemblage of versatile, resourceful, and environmentally friendly techniques to screen, accommodate, and dispense rainwater for multiple purposes, and local communities have total control of these water resources (Akter and Ahmed 2015; Musayev et al. 2018; Toosi et al. 2020). RWHSs such as percolation tanks, dams, ponds, and subsurface dikes also sustain and enhance the groundwater recharge and minimize the uncertainty in water supplies due to drought (Glendenning et al. 2012; Jha et al. 2014). These structures act as efficient tools for tackling water insufficiency and ensure sustainable use of water under the present climate change scenario.

RWH is the easiest and feasible alternative to water conservation and management in sub-humid areas (Gavit et al. 2018; Mahmood et al. 2020). The efficiency of RWHS depends on the identification of potential sites (Adham et al. 2017; Wu et al. 2018). Multi-criteria decision analysis (MCDA) and Analytical Hierarchy Process (AHP) with GIS emerged as an efficient method for delineation of proper areas for RWH (Singh et al. 2017; Adham et al. 2018). The integration of GIS and MCDA approaches finds fruitful application in developing a framework for identifying RWH potential zones (Singhai et al. 2019; Toosiet al. 2020; Rana and Suryanarayana 2020). AHP is a widely used technique that assigns precise weightage to different factors that essentially govern selection criteria for rainwater harvesting sites (Singhai et al. 2019). AHP-based-MCDA approach using a GIS domain finds extensive application in RWH site allocation and storage in various regions of the world such as Pakisthan (Mahmood et al. 2020), China (Matomela et al. 2020), Ethiopia (Mekonnen et al. 2016), Eswatini (Sacolo and Mkhandi 2020), Bangladesh (Akterand Ahmed 2015), Iran (Toosi et al. 2020) and Iraq (Adham et al. 2018).

Singhai et al. (2019) conducted a study taking into account soil, slope, LULC (LULC), runoff, lineament, and drainage layers to select suitable runoff storing sites in a sub-catchment in the Bundelkhand region of India. Rana and Suryanarayana (2020) have utilized slope, LULC, soil texture, stream order, runoff, and distance from drainage criteria to characterize RWHS in Gujarat, India. Kumar and Jhariya (2017) considered slope, soil texture, LU, lineament, and runoff potential to examine potential RWH zones using the GIS-MCDA approach in the Bindra watershed situated in Chhattisgarh (India). LULC, soil, slope, lineament density, and depth of groundwater, and stream order factors enabled the selection of rainwater harvesting sites for the Varada River basin in hard-rock terrain of South India (FAO 2003; Bhagwat et al. 2018).The literature review (Rejani et al. 2017; Gavit et al. 2018; Wu et al. 2018; Ahmad and Verma 2018; Rajasekhar et al. 2020) on the characterization of potential rainwater harvesting sites in sub-humid regions of India using MCDM indicated that slope, LULC, soil texture, geology, drainage, runoff, and lineament were the most popular and frequently used criteria. Singh et al. (2017, 2020) examined the promising runoff accumulation zones using the MCDM approach that integrated components, i.e., soil, slope, runoff coefficient, LULC, drainage network, surface water supply, groundwater potential, and lineament in the upper reaches of Damodar River, West Bengal, India.

Mitra (2018) used a GIS-based approach to classify the likely sites for RWHS in the Kasai basin, Purulia, based on runoff and land use. Kar et al. (2020) used soil, land use, slope, and drainage layers to propose potential rainwater harvesting sites for the Arsa and Balarampur blocks of the Purulia district. Kolekar et al. (2021) identified potential water conservation zone by runoff and slope criteria using a hydrologic index with the GIS approach. Most of the related studies concluded that the AHP based MCDA is a robust approach for identifying RWHS. The selection of appropriate criteria is critical in determining the reliability of MCDA methods in plotting suitable RWHS sites (Jha et al. 2014; Singh et al. 2017; 2020). Various researchers have applied lineament, slope, and geology to map the most suitable sites for RWH in undulating rocky regions (Jha et al. 2014; Bitterman et al. 2016; Omolabi and Fagbohun 2019). Slope, soil texture, land use, land cover, drainage, lineament, groundwater level depth, and runoff coefficient parameters are essential for identifying RWHS sites (Mugo and Odera 2019; Toosi et al. 2020). RWH mapping should also consider the socio-economic impacts (FAO 2003; Jha et al. 2014). Thus there is a scope of improvement in the AHP based analysis in the region by selecting a more exhaustive set of criteria instead of a few as done earlier. Studies regarding the impact of RWH on the well-being of the farmers would enable us to illustrate the holistic scenario.

The present study, therefore, aims to improve the methodology by analyzing all the significant layers (runoff coefficient, land cover/land use, slope, soil, lineament, drainage density, stream order, geology, and groundwater level) with AHP based MCDA techniques to identify the optimum sites for RWHSs in the drought-prone RLZs of West Bengal. Field observations in a small micro-watershed within the study area helped us to validate the model-derived results. Additionally, this study introduced a novel approach from an econometric perspective to examine the effectiveness of RWHS site selection as an adaptation option by investigating the socio-economic impacts of previous and current drought adaptation actions. This study also discussed the future management strategies, which are essential to tackle the future climate scenario.

8.5.1 *Land Use/Land Cover*

Agricultural land (2898 km^2; 46%) encompasses almost half of the entire study area (Fig 8.5a). Subsequent noticeable land cover classes were fallow land, vegetation, forest, upland, water body, and settlement with areal percentages of 18, 16, 14.5, 4, and 1.3, respectively. The classification accuracy displayed 86%, 89%, and 84% accuracy for the producer accuracy, user accuracy, and kappa coefficients, respectively.

8.5.2 *Slope*

The map (Fig. 8.5b) illustrating the slope of the point of interest broadly demarcates six categories, such as nearly flat (0–2%), gentle (2–4%), marginal (4–6%), moderate(6–8%), steep (8–10%), and very steep (>10%). The study area comprises 45% under the nearly flat and gentle slope category and 30% area under a moderately steep slope.

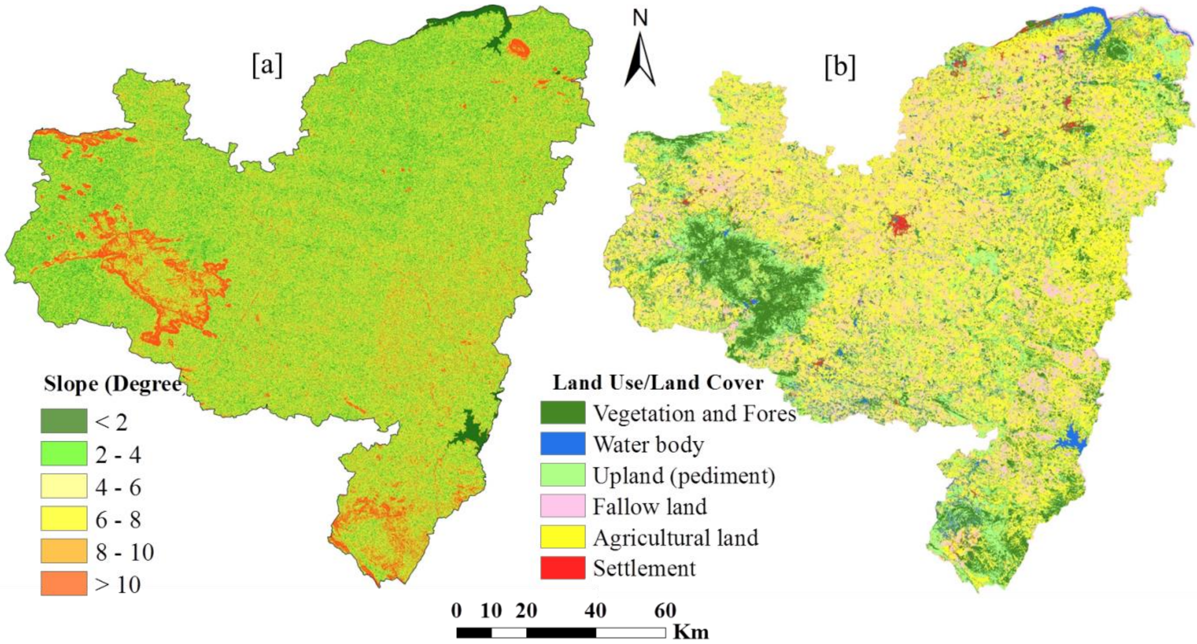

Fig 8.5 (a) Slope (b) LULC map of the study area

8.5.3 *Soil texture*

The dominant soil texture in Purulia is sandy loam to loam (Fig. 8.6a),which occupies 30.7 % in the northern, southwestern, and southern regions. Gravelly loam soils cover a substantial part of the study area with an area extent of 28.6%. Loamy sand to sandy loam, coarse loam, and gravelly loam soil textural occupy 19, 12, and 8%, respectively. HSG classification indicates that most of the area comprises HFG B-type soils (Subramanya 2013).

8.5.4 *Lineament density*

The lineament density in Puruliaranges from 0.025 to 0.30 km/km2 (Fig.8.6b). The low lineament density class occupies the highest area with an area cover of 43%.The low, moderate, high, and very high categories cover 35%, 14%, 4, and 3% area, respectively.

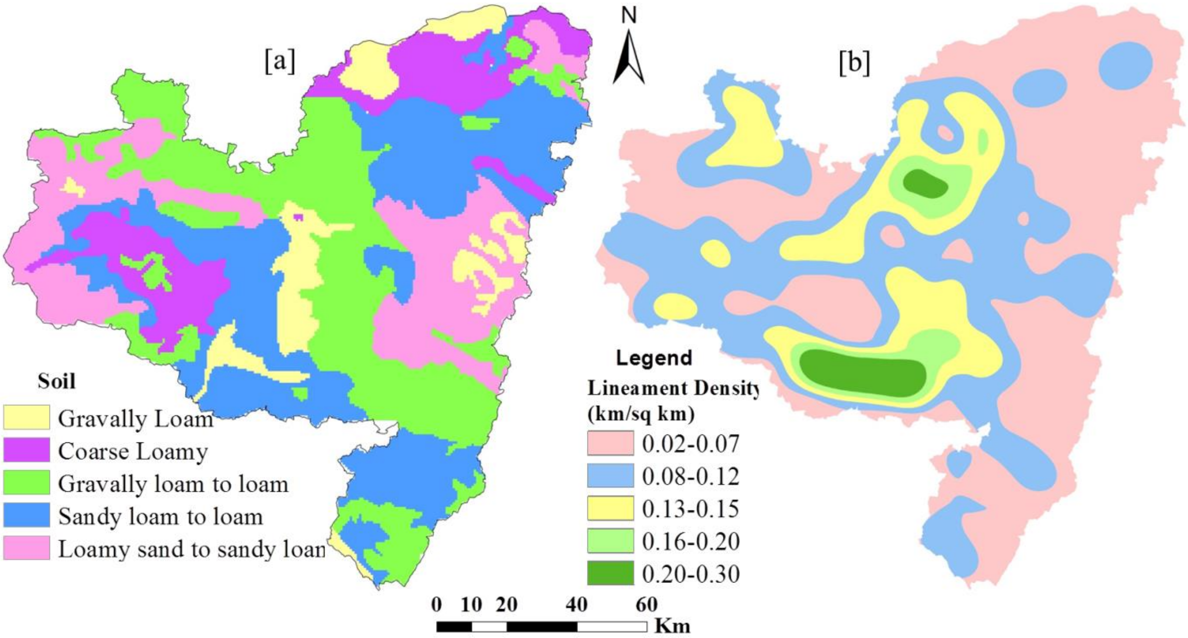

Fig 8.6 (a) Soil Texture (b) Lineament Density

8.5.5 *Drainage density*

The study considered five categories of drainage density (Fig 8.7b). About 33% of the study area has moderate drainage density, followed by high and low drainage density with a spatial coverage of 24% and 23%, respectively.

8.5.6 *Stream order*

The study area has the highest fourth-order drainage networkwith a total drainage length of 250 km. The first-order streams covernearly 57% of the drainage network followed by the second (25%) and third-order streams (10%) (Fig 8.7a).

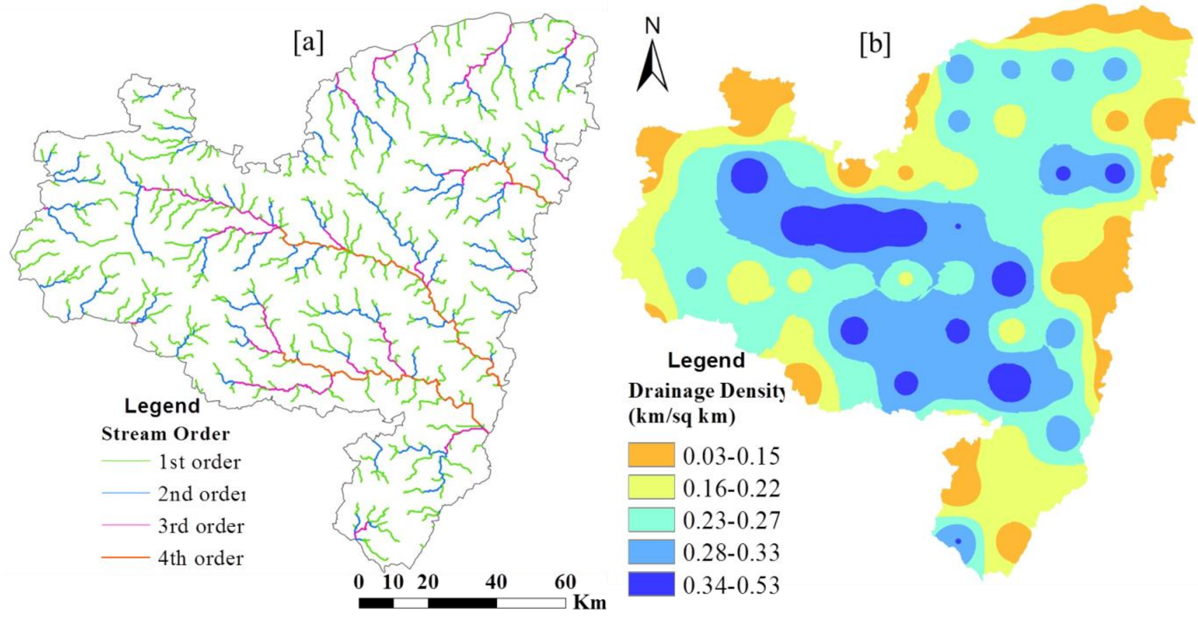

Fig 8.7 (a) Stream order (b) Drainage Density map of the study area

8.5.7 *Geology*

Geologically, the Purulia is dominated by hard rock Granite gneiss (61% of the total area). Nearly 17% of the study was covered by Mica Schist followed by granite in 10% area and metabasic Rock in 5% area (Fig 8.8a). Sedimentary soft Gondwanarocks covered only 2% area of the district.

8.5.8 *Depth of Ground Water level*

Fig. 8.8b shows the post-monsoon groundwater depth map. Approximately 28%, 23%, and 22% of Purulia have a mean groundwater depth of 4.5 to 5, 4.2 to 4.5, and 3.5 to 4.2 mbgl, respectively. Groundwater depth > 5 m prevailed in scraps in the mid-western and southern parts encompassing 20% of the entire region of interest. Subsurface depth was less than 3.5 m in isolated locations of the central part, covering 5% of the study area.

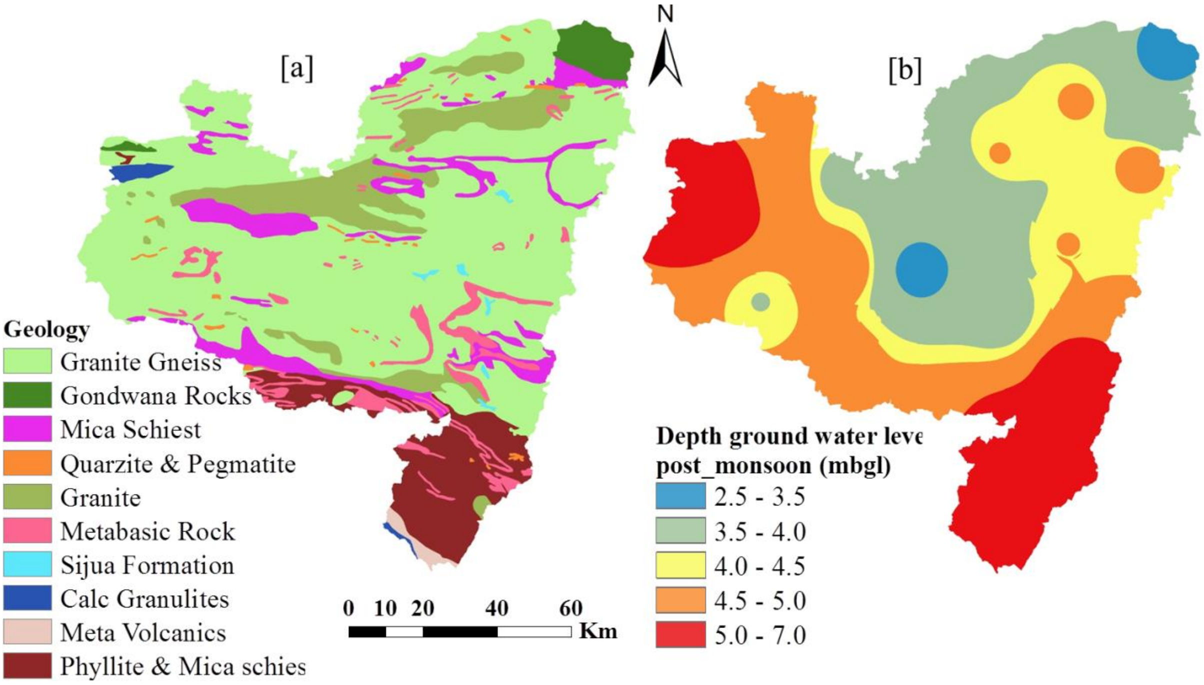

Fig 8.8 (a) Geology (b) Depth of groundwater level map of the study area

8.5.9 *Runoff Coefficient*

The runoff coefficient ranged between 0.1% and 64%. The class distribution was very high (45-64%), high (35-45%), moderate (25–35%), low (15-25%), and very low (<15%). Fig.8.9a shows that a small portion (8%) comes under the very high runoff potential category. Low and moderate runoff coefficient classes cover 21% and 48% of Purulia, respectively.

8.5.10 *RWH suitability map*

The final rainwater harvesting potential zones map (Fig.8.9b) has been generated by integrating all nine thematic layers. Results revealed that a substantial part of this district lies under high (35.7%), followed by moderate (31.3%), low (29.3%), and very high suitable (1.4%) from the perspective of harvesting rainwater. Only 2.3% of the study area has been categorized as unsuitable.

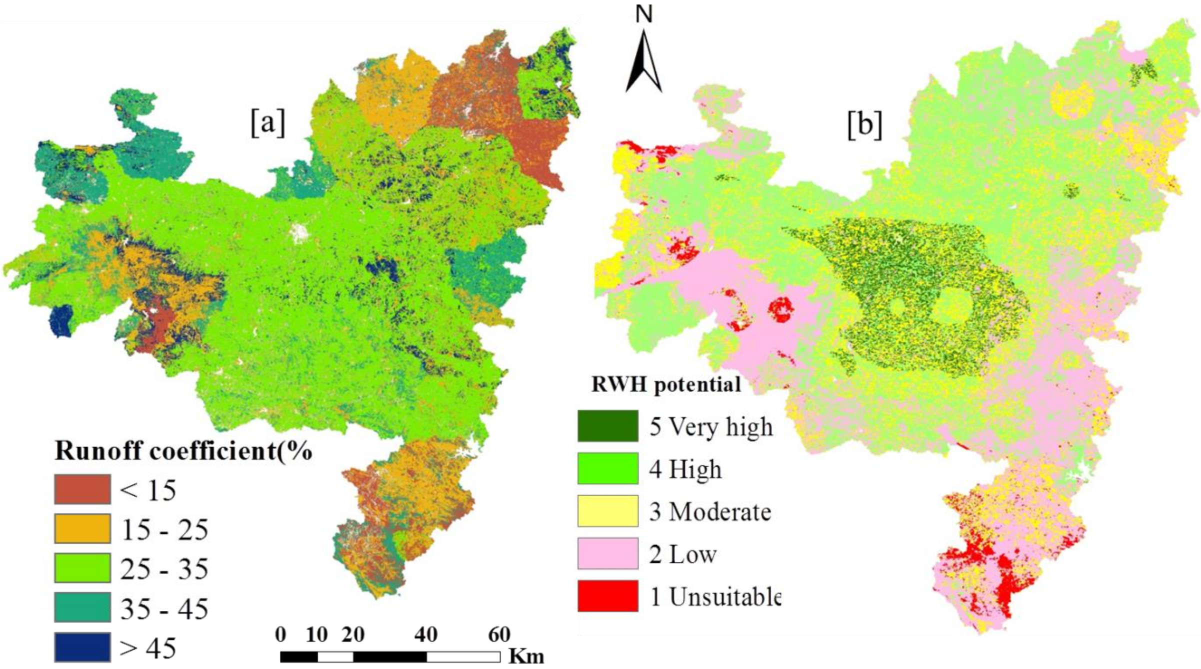

Fig 8.9 (a) Runoff coefficient map (b) Rainwater harvesting potential zone in Purulia

This study further identified the suitability of various types of rainwater harvesting structures, like nala bunds, farm ponds, percolation tanks, check dams, and sub-surface dykes. Based on the weighted overlay technique in combination with Boolean criteria, farm pond and percolation tank could cover 245 km2 and 36 km2of the RWH suitable locations, respectively. The suitable sites for the construction of check dams, plugs, and sub-surface dykes are 30 km2, 166 km2, and 21 km2, respectively.

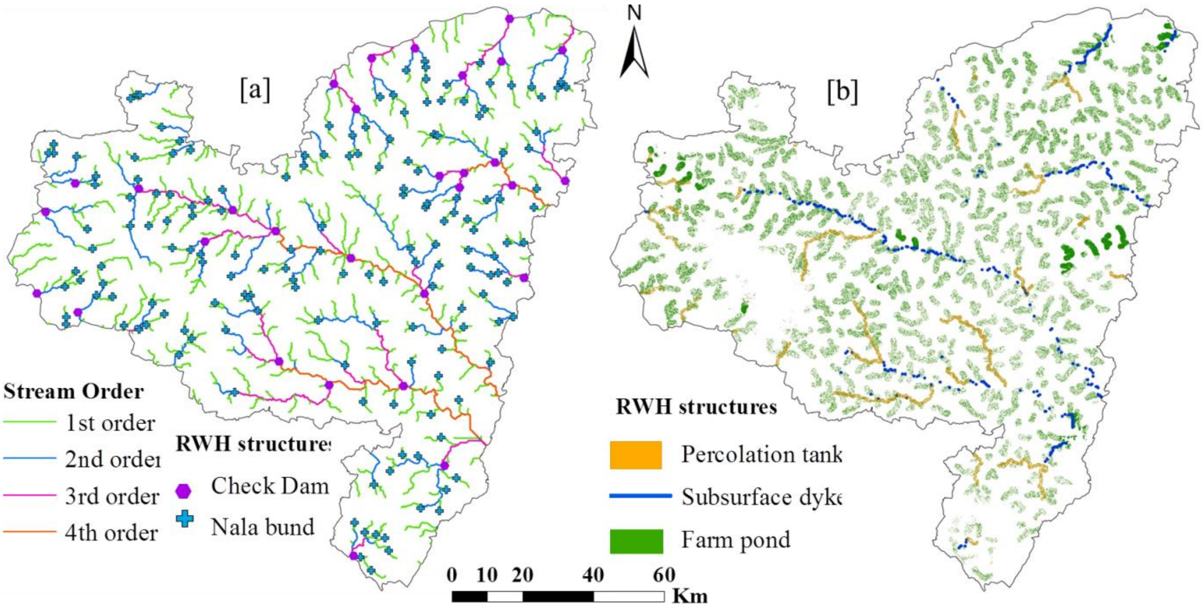

Fig 8.10 (a) The map of suitable rainwater harvesting structures sites for [a] check dam, Nala bund [b] farm Pond, percolation tank, and sub-surface dyke.

8.5.11 *Validation*

Field surveys were carried out in Kashipur village of Purulia to validate and estimate the accuracy of the potential site suitability map. This study compiled and assessed the details of existing rainwater conservation structures from105 sites (Fig. 8.11). On 90 occasions, the results obtained from this study were in parity with the particular type of RWHs existing in reality. In 15 cases there was a disagreement. Thus, the accuracy of the prediction = (90/105) × 100 = 85.71%.

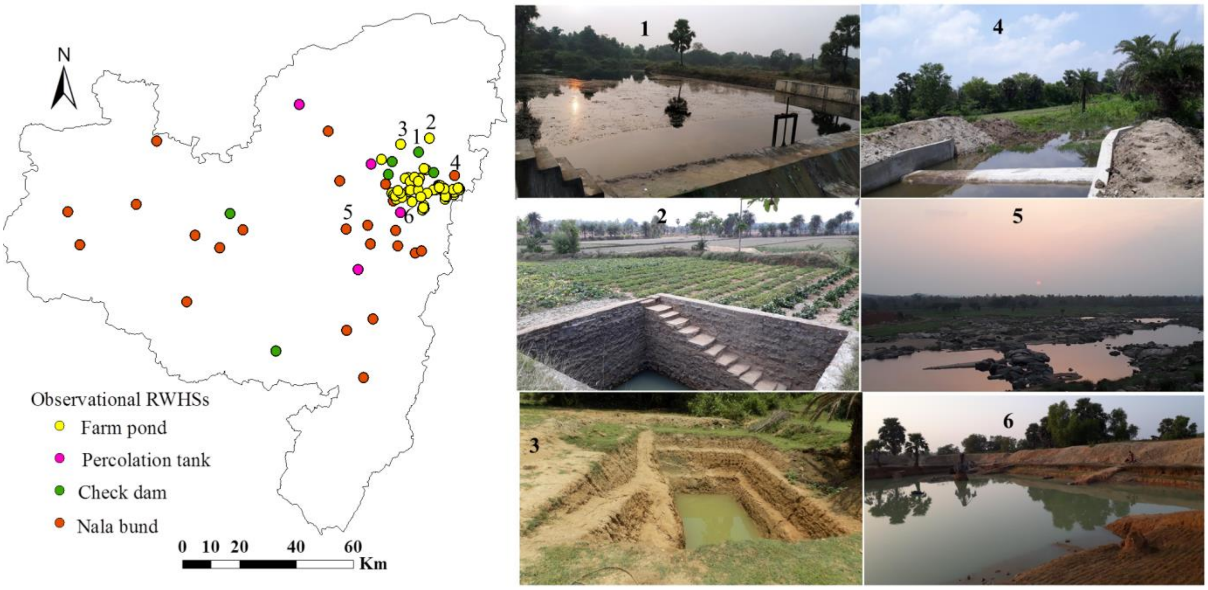

Fig 8.11 The map Showing the field validated RWHS sites like [1] check dam, [2, 3] farm pond, [4, 5] Nala bund and [6] percolation tank**.**

8.5.12 *Discussion*

The present study applied a GIS-based weighted overlay technique to produce a suitability map of potential rainwater harvesting zones in an RLZ based on the various parameters (runoff coefficient, slope, LULC, soil texture, drainage density, stream order, geology, lineament density, depth of groundwater). AHP pair-wise matrix enabled us to compute the relative importance for all these parameters. Among these factors, surface runoff plays the most crucial role in identifying effective RWH sites because around half of rainfall-runoff in RLZ can be stored to maintain optimum agricultural yield in an eco-friendly and sustainable way (Ziadat et al. 2012; Mekonnen et al. 2016; Kumar and Jhariya 2017). The slope is a significant controlling factor of surface runoff. Soil texture is another important input variable for the study as it regulates the infiltration rate (Bhagwat et al. 2018). Land use pattern influences surface runoff and evapotranspiration (Adham et al. 2018; Shadeed et al. 2019; Matomela et al. 2020). Drainage character is an effective proxy of a watershed's reaction to hydrology (Singhai et al. 2019). The drainage order regulates the obtainability of the surface water, and some specific structure signifies a particular drainage order only (Singh et al. 2017; Adham et al. 2018; Matomela et al. 2020). In hard-rocky regions, lineament intersects are the potential sites for percolation (Bhagwat et al. 2018; Singh et al. 2020). Geology influenced the permeability (Onda et al. 2006) and soil characteristics (Tetzlaff et al. 2009) and even controls water storage (Jencso and McGlynn 2011). Percolation is also a function of the depth of groundwater level (Singh et al. 2017; 2020).

Considering such an exhaustive set of parameters, the western and southern parts of Purulia are in the low suitable region, and this area mainly consists of hills, low runoff coefficient, steep slope, rocky soil, and high depth of groundwater level. The highly suitable sites are in the central and north-eastern parts of the district. These regions have a high runoff coefficient, moderate permeability, drainage density, moderate to gentle slope, agricultural and fallow land, loamy soil, and low depth of groundwater level.

Similarly, Singh et al. (2017,2020) reported that above 35- 30% of areas in the higher reaches of the Damodar River Basin falling under ‘high’ and ‘moderate’ RWH potential, respectively. In Gujarat, Karnataka, Madhya Pradesh, and Chhattisgarh, > 30% of the total area were potentially suitable for storing water and RWHs (Kumar and Jhariya 2017; Bhagwat et al. 2018; Singhai et al. 2019; Rana and Suryanarayana 2020). Toosi et al. (2020), while working in the Mashad Plain Basin, Iran, observed that moderately and significantly suitable RWH areas covered 31% and 43%, respectively.

In contrast, the surface water harvesting potential zone in 65-70% of Purulia’s total area (Mitra 2018; Kar et al. 2020; Koleker et al. 2021) falls under the poor RWH zone. Moderate RWH zone could be observed in only 20-35% area of the district. Furthermore, ground-truthing of RWHS sites in the present study has not expressed such a reassuring proposal.

The weighted overlay technique coupled with Boolean criteria is effective for examining various RWHSs (Singh et al. 2017). The fundamental features for selecting a specific structure (Farm pond, Check dam, Percolation tank, sub-surface dyke, and Nala bund) at an allotted site have been discussed below.

8.5.12a Check dam

The suitable sites for check dams (30 locations) are mostly in the eastern, northern, and western parts of Purulia (Fig 8.10a). Check dams should essentially be placed on the drainage course, and constructed at lower order streams (up to third order), having gentle to moderate slope and are practicable both in alluvial as well as hard rock. The structure of check dams should look for influent streams where the depth of the water table is moderate (4-5 mbgl). However, a catchment area of > 25 ha facilitates an economic return against such structures. A low to medium permeability lets some recharge to the downstream parts of the dam. The check dams have been detected near agricultural areas for providing supplementary irrigation. Check dams can also effectively alleviate soil erosion, which enhances its significance compared to other RWHs (Matomela et al. 2020).

8.5.12b Farm ponds

The preferable sites for farm ponds (245 km^2) were located on the flat to gentle slopes of the agricultural fields to store rainfall runoff in the RLZs (Fig. 8.10b). Farm ponds are manually dug in areas with comparatively flat topography, low soil penetrability, moderate tohigh runoff coefficient, very low depth of groundwater level, and high lineament density. Normally, farm ponds providewater storage for life-saving irrigation within individual farms. However, these ponds also facilitate recharging groundwater (Singhai et al. 2019).

8.5.12c Nala bund/ Gully Plugs

Randomly distributed 166 locations have been identified for nala bunds in this RLZ (Fig 8.10a). Nala bunds are economical, occupy a small area, and easy to construct using readily available materials near gullies which flows through the hill slopes to adjacent catchments during the monsoon season. Gully plugs hold the silt flow, which helps in reducing runoff and increasing water percolation and soil moisture levels (Kumar and Jhariya 2017). The sites for gully plugs may be either onthe first or second order of drainage,wherever there is anabrupt change in slope (1-3^o) to accumulate enough water behind the bunds. Low groundwater levels (2-2.5 mbgl) with low to medium permeability and high runoff coefficient are preferable for this type of structure.

8.5.12d Percolation tank

The southern part of Purulia (36 km2) meets the criteria for percolation tanks (Fig 8.10b). The feasible site for locating percolation tanks lies across streams and big gullies to store the runoff water. The slope for constructingpercolation tanks should ideally be < 10º. These tanks perform well if the catchment area ranges between 25 ha and 40 ha. The percolation tank should have substantial permeability so that the surface runoff may permeate and rejuvenate the groundwater stock (Mahmood et al. 2020). The groundwater depth should be high (6-7 mbgl) with a low runoff coefficient and a high storage capacity to facilitate potential groundwater recharge.

8.5.12e Sub-Surface Dyke

The sub-surface dykes (21 potential sites) concentrated mainly in the central part of the present RLZ along the streams (Fig. 8.10b). Sub-surface dyke should lie on straight and wide river course, that may be on high stream order (either 4th or grater order) of drainage. Sites with a gentle slope (0-3º), high permeability, and low to moderate runoff coefficient are preferable for this structure. Sub-surface dykes require an adequate watershed area (>50 h). The purpose of the construction of a sub-surface dyke is to reduce the base flow in the river and consequent evaporation losses (Ramakrishnan et al. 2009).

8.5.13 *Performance of RWHS in drought adaptation*

The present study investigated the socio-economic impacts of RWS structures in mitigating drought impacts. We adopted a case study approach to study the drought impacts on agriculture, past and present drought adaptation measures. This study examines ten villages of Kashipur block in Purulia (Fig 8.12). Kashipur has the most cultivated land, which witnessed an array of social and economic impacts of drought, and thus, furnishes an ideal platform for comparative case studies. The sample size for the study consists of 55 recharge structure sites, which matches the RWHS site suitability map. We prepared a questionnaire for data acquisition on the socio-economic profile from the 55 sample sites. The impacts of RWHS on agriculture were analyzed by comparing changes across the past and present drought adaptation measures for two recent drought years (2015 and 2019). We examined the changes in cropping intensification, crop yield, and income from agriculture (as stressed by Malik et al. 2014).

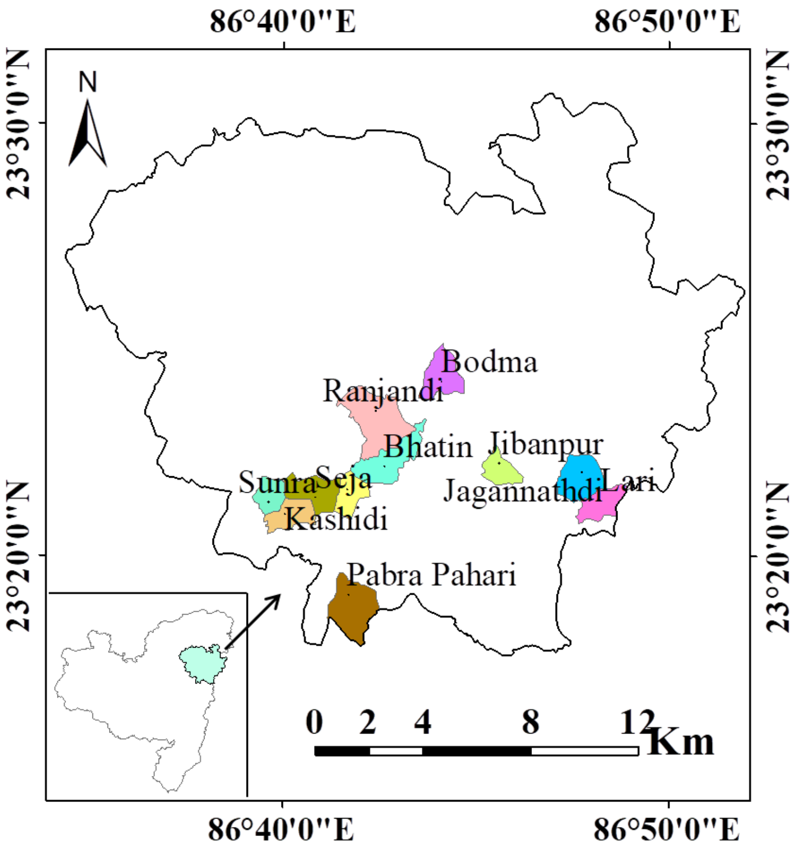

Fig 8.12 The map showing the selected villages in Kashipur for case study

8.5.13a Crop intensification

Intensification to the addition of new crops on a particular farm resulted from utilizing the additional water available through water harvesting structures (Kumar et al. 2016). The study revealed that crop intensification has significantly augmented after the RWHSs came into operation. Before RWHSs, only Kharif rice and oilseed in small proportions were cultivated in the study area. Whereas, after RWHSs excavation, Cereals, Pulses, Oilseeds, and Vegetables emerged as other farming options.

8.5.13b Increase crop production

The increase in crop production is an indicator of the impact of RWHSs (Bouma et al. 2016). Hence, the present study compared crop yields across the two drought years after (2019) and before (2015) RWHSs intervention. The average Kharif rice yield increased by 39 % (Table 5), which indicates that Kharif rice yields after RWHSs intervention have significantly increased. The increased water availability for irrigation from RWHSs assured an optimum Kharif rice yield in a drought year. Deora and Nanore (2019), Malik et al. (2014) find a similar increase in Kharif crop yield due to farm pond digging. Kumar et al. (2016)

concluded that the additional water availability in RWHSs like farm pond, Nala bund, check dam, and percolation tank provided a provision for irrigation during the dry season, which reduces the risk of Kharif crop failure.

8.5.13c Increase income from agriculture

Increased income from agriculture is an efficient drought adaptation measure. An assured amplification in the rate of crop production in drought situations can act as a proxy for the ensured water obtainability for irrigation. Thus the study finds out the change in income from agriculture after RWHSs intervention. After RWHSs, the annual income from selling of crops has increased from 12500/- to 18650/-. The average income increase between the years 2019 and 2015 drought year has been 46% (Table 8.5).

The construction of RWHS is a capacity-building component (Patnaik and Das 2017), which focuses on the empowerment of communities by implementing better agricultural practices (Patnaik et al. 2019). The RWHS provides support in terms of agricultural extension services that enhance the overall capacity of the marginal farmers (Sharma et al. 2014). Tiwari et al. (2011), Esteves et al. (2013), and Sharma et al. (2014) also found that RWHS are capable of alleviating the drought vulnerability in the water-scarce regions of India.

Table 8.5 Changes in crop production and income of the farmers due to RWHS intervention

SL NO	RWH structures	Area (Bigha)	Rice production (kg)		Change (%)	income from agriculture (Rupees)		Change (%)
			2019	2015		2019	2015	
1	Farm pond	1	300	250	20	5575	4200	33
2	Farm pond	1	300	200	50	4200	3500	20
3	Farm pond	1.5	300	220	36	5275	3780	40
4	Farm pond	1	300	200	50	6530	3880	68
5	Farm pond	1	300	250	20	7280	4580	59
6	Farm pond	40	30000	20000	50	439200	283200	55
7	Farm pond	1.5	586	400	47	10304	7700	34
8	Farm pond	2	1000	700	43	17050	12600	35
9	Farm pond	2	845	600	41	11450	8400	36
10	Farm pond	1.5	800	500	60	14000	8800	59
11	Farm pond	1	500	400	25	11325	8300	36
12	Farm pond	1	400	300	33	9114	6300	45
13	Farm pond	2.5	1200	800	50	18350	14000	31
14	Farm pond	2	900	600	50	16300	11200	46
15	nala bund	1.5	700	500	40	13800	9450	46
16	Farm pond	2	1000	850	18	18775	15300	23

17	Farm pond	1	365	300	22	11604	8050	44
18	Farm pond	1	326	250	30	8450	6300	34
19	Farm pond	1	286	200	43	11710	8050	45
20	Farm pond	2	450	300	50	10550	7000	51
21	Farm pond	2	550	400	38	11830	8400	41
22	Farm pond	2	1000	700	43	24000	15750	52
23	Farm pond	1.5	600	400	50	7000	5600	25
24	Farm pond	2.5	750	550	36	12500	7700	62
25	Farm pond	2	800	600	33	13700	8400	63
26	Farm pond	2	1000	750	33	16250	10500	55
27	Farm pond	2	800	700	14	13600	9800	39
28	Farm pond	2	1000	650	54	14750	9100	62
29	Farm pond	2	1000	700	43	15750	9800	61
30	nala bund	1.5	600	450	33	9350	6300	48
31	Farm pond	1.25	500	350	43	7475	4900	53
32	Farm pond	1	380	250	52	10400	6300	65
33	Farm pond	1	345	250	38	4900	3500	40
34	Farm pond	1	500	340	47	12350	8960	38
35	Farm pond	1	335	230	46	9265	6020	54
36	nala bund	0.5	175	125	40	2575	1750	47
37	Farm pond	2	1000	700	43	14200	9800	45
38	Farm pond	1.5	650	450	44	9120	6300	45
39	Farm pond	2	1000	850	18	15000	11900	26
40	Farm pond	1.5	500	340	47	13250	8260	60
41	Farm pond	1	400	260	54	6350	3640	74
42	Farm pond	3	1300	950	37	31575	22300	42
43	Farm pond	2	800	670	19	12950	9380	38
44	Farm pond	2	1000	760	32	15250	10640	43
45	Farm pond	1.5	700	650	8	13800	9100	52
46	Farm pond	2	650	450	44	9600	6300	52
47	Farm pond	1	300	200	50	3500	2800	25
48	Farm pond	1	300	200	50	3800	2800	36
49	Farm pond	1	350	250	40	5675	3500	62
50	Farm pond	1.5	500	400	25	8400	5600	50
51	Farm pond	1	300	200	50	3575	2800	28
52	Farm pond	1.5	500	350	43	9000	4900	84
53	Farm pond	1	300	250	20	5830	3500	67
54	Farm pond	1	350	240	46	4550	3360	35
55	Farm pond	0.5	200	150	33	2888	2100	38

It is evident from the analysis that rainwater harvesting has enabled the farmers to augment their cropping intensity, rainfed crop production, and income from agriculture through supplemental irrigation during short dry spells. Water harvesting structures are capable to furnish sustainable agricultural intensification in drought-prone sub-humid RLZs, resulting in both risk reduction and yield improvements. Perhaps, the agricultural sustainability of small-holder farmers has been achieved through rainwater harvesting implementation, which also functioned as a climate change adaptation strategy in sub-humid RLZ.

8.5.14 *Conclusions*

Sub-humid red and lateritic zones (RLZs) of West Bengalexperience recurrent drought and crop failure because of erratic rainfall and higher runoff and evapotranspiration rates. This study integrated RS-GIS and AHP and detailed a novel approach to examine the suitable sites for conserving water and for the demarcation of suitable locations for rainwater harvesting in RLZs. The present study showed how the rainwater conservation structures like check dam, farm pond, Nala bunds, percolation pond, and sub-surface dykes at suitable locations can ensure a perennial supply of water. The site selection for different water harvesting options is carried out by taking into account the factors like runoff coefficient, land cover/land use, slope, soil, lineament, drainage density, stream order, geology, and groundwater level. The present study integrated weighted overlay and Boolean logic to identify the preferable sites and correct structures for RWH. The suitability map segregated the study area into five potential zones: very high, high, moderate, low and unsuitability zones consisting of area 90 km2 (1.4 %), 2236 km2 (35.7%), 1960 km2 (31.3%), 1828 km2 (29.3%) and 145 km2 (2.3%), respectively. The suitable zones for creating farm ponds cover 245 km2 and zones for percolation tanks occupy 36 km2. This study also identified 21 sites for sub-surface dykes along the streams, 166 sites for Nala bunds, and 30 sites for check dams. A detailed field investigation aided us to determine the accuracy of selected sites for RWHS. An accuracy of 85.7% testified the applicability of this method for field implementation. The technically sound and pragmatic methodology led to such accuracy levels in site identification. This method can be replicated, especially, in other sub-humid RLZ regions to combat growing water shortages. The uniqueness of this study is that the socio-economic impacts of small rainwater harvesting structures as drought mitigation have been assessed by incremental changes across past and present drought adaptation measures. It found that RWHSs facilitated an increased cropping intensity, crop yield, and income from agriculture. Inserting to the evaluation of the effectiveness of the RWHSs as drought adaptation is an innovative and advantageous tactic for the proficient management of water resources in the RLZ. Implementing these measures would reduce runoff and restrict soil erosion. It would also augment the infiltration potential and water recharge capacity. RWHSs can play a critical role in combating the future water scarcity that may arise due to the ongoing climate change.

8.6 RURAL LAND USE MANAGEMENT FOR ENSURING FOOD SECURITY AND IMPROVING FARMERS' LIVELIHOODS

In the perspective of the warming climate, the frequency and intensity of drought have been increased in recent decade causes substantial agricultural damages, particularly in developing countries that are greatly dependent on agriculture (Lei et al. 2016, 2014). Therefore, coping with the risks of increasing frequency and intensity of drought is a noteworthy global challenge (IPCC 2012).

India is the most vulnerable drought-prone country (Gupta et al. 2020) and the agricultural segment of the country credits more than 54% and 19% of gross national employ and GDP, respectively (Nath et al. 2017). Drought occurrence is spatially extensive and intensity has been increased which affected about 68% of the Indian agricultural land and at least half can be recognized as extremely affected cause serious losses to the agriculture (Guhathakurta et al. 2017). Drought is becoming more regional and reallocates to the agricultural important Indo-Gangetic plains, rec and laterite zone and coastal south India resulting in high food security and socio-economic susceptibility (Mallya et al. 2016). Thus investigating approaches for mitigating and adapting to intensified drought become a serious issue for drought risk diminution and sustainable progress.

Sub-humid RLZ of West Bengal has been experienced extreme drought to severe drought frequently in recent decades (Bhunia et al. 2020). In recent decades, Sub-humid RLZ experienced more droughts during monsoon which are Short-term but devastating impact on agriculture around 10-15% Kharif crop failure (Mahto and Mishra 2020) which cause income deficit for farmers, raised poverty and an enhanced seasonal unemployment (Parida et al. 2018). Drought intensity and frequency trend to increase in Purulia (Ghosh 2019) and undulating topography, low water retention soil with inadequate irrigation and insufficient agricultural inputs make this region more vulnerable to drought. Therefore, exploring area-specific adaption and mitigation strategies to increase drought is essential for rural poverty decrease and sustainable improvement.

Area-specific adaptation approaches play an important role to mitigate the impacts of climatic variation and drought on agriculture has been studied (Opiyo et al. 2015). Coherent land use management (less water-intensive irrigation practices and drought-tolerant crop cultivation) can perform an effective role in declining disaster damages (Tang et al. 2008; Fu et al. 2013; Tang and Hailu 2020; Tahmasebi et al. 2020). Some studies (Lei et al. 2016, 2014) revealed that appropriate land use practice has been alleviated the drought impact on local agriculture (UN/ISDR, 2011; Hussain et al. 2020). The land use management in drought risk reduction is serving as an active adaptation method in the agricultural segment in various regions of the world (Lei et al. 2016). In Malaysia and Thailand, paddy farmers adjusted their land use patterns to handle climate change, containing the use of various crop types, changing sowing time, and plantation (Alam et al. 2012; Polthanee et al. 2014). In the well-adapted crop varieties, changed planting dates and farming process have been incorporated in adaptation strategies to drought in South African (Bryan et al. 2009; Deressa et al. 2009). In China (Zhou et al., 2014) over the past decade, the government has been by implemented nationwide reforestation to mitigate drought, which has provided clear environmental advantages. Changing agricultural production inputs and adjusted harvesting or seeding time are taken as an adaptive measure to protect crop production against drought in China (Chen et al. 2014). Lei et al. (2016) concluded that less water-intensive crop cultivation reduced the vulnerability of local agriculture to drought and improve their income. In Bangladesh, sustainable irrigation practices are adopted to cope with drought (Alam 2015; Alam et al. 2017).

The farming practices in rural Maharashtra, India have transformed from flood irrigation to drip irrigation and conventional tillage to ridge farming tillage, stubble mulch farming tillage which improved and stabilized crop production and conserved soil moisture (Udmale et al. 2014). Farmers in south India have been changed farming practices by cultivating short-duration and drought-tolerant crops to cope with drought (Dhanya and Ramachandra 2016; Dhanya et al. 2021). Rural farmers in Karnataka adopted rational land use management to cope with drought risk which includes mixed cropping, agroforestry, shifting cropping patterns and irrigation provision (Kattumuri et al. 2017).

However, previous studies have been based on theoretical or qualitative perspective. The case studies with quantitative analyses on the efficiency of land use patterns to cope with drought risk are inadequate. On the other hand, is changing land use patterns can effectively reduce regional drought vulnerability and improve local resilience and adaptive capability to possible drought risk needs to examine? To answer these questions, experimental studies in sub-humid RLZ are necessitated at the rural community level. Therefore, the current analysis attempts to evaluate the efficiency of land use adjustments in mitigating drought risk and expediting farmers' livelihood. Primary data has been collected through detailed interviews with local supervisors, household surveys and land use surveys at the farm level.

8.6.1 *Conversions in micro-level land use patterns*

After 2015, the local government and NGO encouraged farmers to prevent the pracctice of planting on sloping land and convert the low- producing upland with reforests. The proportion of artificial forests reached an average of 20% of tarn land of the villages. On the relatively moderate to gentle slope lands, farmers continuously decreased the cultivated areas of Amana and Boro and enhanced the quantity of drought-tolerant crops (Casava, Roselle, Arhar, Pearl Millets etc) cultivation which diversifies their incomes. The number of former potato and grain corn fields was replaced by drought-tolerant crops, which comprised 15-30% of the low-yield monocroped area. Furthermore, Village introduced low-cost drip irrigation for nutrition gardening. Thus, averages of 3 to 6% dry fallow lands of villages were transformed into nutrition gardens which raise food security.

8.6.2 *The usefulness of land use management in drought risk alleviation*

This segment emphases on the comparative evaluation of the drought mitigation ability through land use adjustments on the crop intensification, crop yield and income. Also, the impacts of nutrition gardens on food supply have been discussed during drought conditions.

8.6.2a Crop intensification

General agriculture practice in the study area is of cultivating single crops in a year, during the monsoon (Kharif) season which is predominantly rainfed. After 2015, in the study area

15-30% of low-yield agricultural land is cultivating more than three crops as mixed cropping instead of rice in a year. After cultivating drought tolerate crops, average cropping intensity has increased from 130% to 135%. Mix cropping of drought-tolerant crops has facilitated crop intensification and reduced the risk of crop failure, which has supported local farmers' income and livelihood during the dry period.

8.6.2b Increase in crop yield

Increasing crop production is one of the most frequently pertained indicators of drought adaptation through drought-tolerant crop cultivation (Pushpalatha et al. 2020; Adjebeng-Danquah et al. 2020; Mishra et al. 2019). Therefore, the present study compares the crop yield across the two drought years – one before the adoption of drought mitigation measures (2015) and other after the drought mitigation measures implementation (2019). Responses to the questionnaire indicate that before the adoption of drought mitigation measures all respondent farmers mainly cultivate rice during the monsoon season over a year but the drought mitigation measures implementation farmers cultivated three to five drought tolerate crops. Four crops are occupying more than 10% of low-yield agricultural land in sample villages. The principal drought-tolerant crops in this area are Cassava, Roselle, Sorghum, green gram, maize, pigeon pea and Vegetables like Yardlong beans (Barbati), Lady's finger/ okra, Ridge Gourd (Jhinga). After the drought tolerates crop cultivation instead of rice, crops production exhibit a relatively higher percentage increase in yield for agricultural fields in drought condition. Crop yields after drought tolerate crop cultivation is significantly increased (89%) in recent drought year 2019 as compared to past drought year 2015.

8.6.2c **Increase in income**

The primary goal of adopting drought mitigation measures is to ensure farmers' income from agriculture. (Singh et al. 2019; Goel et al. 2018); therefore, it becomes crucial to study the impacts of rural land use management on the farmers' income. In this study, income growth has been calculated by comparing the income from agriculture before and after drought adaptation. After rural land use management, the number of farmers' income from agriculture has been increased from 70 to 90%, and farmers have also reported reducing crop failure risk. With the introduction of drought-tolerant crops cultivation instead of rice, the annual income from selling crops and vegetables has increased by 35000 rupees per hectare in sample villages. This income increment has been seen in recent drought years (2019) compared to the previous drought year (2015).

8.6.2d **Impact on food supply**

A nutrition garden is beneficial to ensure food supply during drought conditions (Suri 2020; Rammohan et al. 2019; Bhaskar et al. 2017). Similar findings were found in the present study also. Respondents reported the nutrition gardening using traditional drip irrigation has been significantly increased the food supply of every household in the study area during dry spells. At all study villages, respondents reported nutrition gardening provides food security to household with direct access to food that is often harvested, prepared and fed on daily basis. Gardening provides a variety of fresh vegetables that enhance the amount of nutrients obtainable to the family. The gardens become the major source of food for household during drought condition, e.g. the pre-harvest lean season, crop failure. Households with gardens usually acquire more than 95% of their vegetables supply from gardens. Very small mixed vegetable gardens have also been provided a significant percentage of the recommended dietary allowance throughout the drought year with varying Seasonal vegetable availability – 25%, 27%, 30% and 20% in post-monsoon-rabi, pre-monsoon, monsoon and post-monsoon Kharif season respectively. This household food security directly relates to additional vegetable consumption and expenses savings on purchased vegetables for the families.

8.6.2e Changes in vegetable consumption

The nutrition gardening has multiple benefits, of which the most significant is improved access to nutritious vegetables (Suri 2020; Rammohan et al. 2019; Hudson et al. 2016). Even very poor, landless or near landless people have been practicing gardening on small patches of homestead land, vacant lots, roadsides or edges of a field that improve the fresh vegetables available to the family. The obtainability of year-round vegetable for household to consumption is one of the certain results of nutrition garden, as drought adaptation. Average monthly per capita vegetable consumption for households having nutrition gardens increased from 53 to 106 kg. This is nearly equivalents to about 200 g per person per day, the FAO suggested a minimum consumption of vegetables. Intra-household intake of vegetables information also signifies a progressive trend on vegetable intake by infants and very young children.

8.6.2f Changes in expenses used for purchasing vegetable

Garden production is also provied additional earning for poor rural families in the study villages (Diehl et al. 2019; Singh et al. 2019; Jindal et al. 2017). The integrated benefit of garden products, containing the sale of residue vegetables and savings in food expenses, differs seasonally but makes a considerable percentage of total income (upwards of 15%) for many families. Average monthly food expenses for households having nutrition gardens reduced from 90 to 35 rupees. The income value increased 35% when savings on purchased vegetables were considered. Among the households saving expenses used for purchasing vegetables, the average monthly saving from nutrition garden was 55 rupees, which increased 6% of the total average monthly revenue, which is used mainly on agricultural activates.

8.6.3 *Discussion*

In the present micro-level study, rural land use adjustments has performed encouraging roles in drought mitigation and developing farmers' resilience. Since 1990s, in the aspect of growing water shortages caused by frequently severe drought, farmers modified their land use models according to the local settings. The farmers gradually abandoned the water-intensive rice cultivation and planted more drought-tolerant crops like potatoes and millet etc. Numerous researches (Montiel et al. 2021; Cowan et al. 2020; Karimi et al. 2019; Wossen et al. 2017; Renwick et al. 2020) indicated that maize, potato, pulse and millet require less water and have greater drought resistance than Kharif-rice, thus appreciably diminishing the impacts of erratic rainfall on the agriculture. The farmers cultivated multiple crops by mixed cropping practices instead of a single rice crop in relatively flat arable lands. This adjustment has helped to decrease the impacts of frequent drought on crop failure, and it has enabled the farmers to ensure their income sources. The farmers have been planted trees rather than crops on sloping drylands. These activities have not only prominently mitigated the risk of crop production, but have also improved the eco-environment.

Additionally, on the small patches of homestead land, the poor families actively implemented nutrition garden using traditional drip irrigation and transformed their fallow into cultivated lands. These nutrition gardening activities involve the food supply, nutrition and income in an integrated approach. Nutrition gardening is a sustainable intervention for enhancing food security during drought situations in the context of food availability, access, consumption and nutrition which help to resolve the food crisis at the local scale. The nutrition garden saves about two-thirds of the food expenses, which helps to increase the income. Various studies also revealed that nutrition garden can successfully reduce the food scarcity (Suri 2020; Rammohan et al. 2019) and increase nutrition and income (Diehl et al. 2019; Singh et al. 2019). This drought resilience and adaptability of farmers could be reduced drought-induced losses and risks.

This micro-level study indicates that, in the face of erratic rainfall, rising temperature and recurring drought, the term adaptation technique in the agriculture should try to decrease the susceptibility of the local agronomy to drought risk which helps farmers to achieve socio-economic sustainability. In the study villages of Kashipur block, Purulia, the water-intensive rice-dominant farming model was not suited to the regional climate, topography and soil, which caused higher vulnerability of the local agronomy to droughts. In recent years, the farmers have mitigated the drought impacts through the rural land use adjustments which also produced their livelihoods more resilient and modifiable to probable drought risks. Based on the in-depth field survey and empirical analysis, this study indicates that farmers are economically wealthier after the conversion of land use designs. Although our data indicate, that land use management has been reduced the vulnerability of agriculture to drought risk, however their adaptive competences are not adequate to face of extreme droughts. The government and NGOs should encourage farmers' to obtain weather info, markets, social capital and technology, which would allow farmers to formulate proactive adjustments instead of reactive alterations in their farming systems.

8.6.4 *Conclusions*

In the current period, rising temperature, irregular rainfall during the crop growing monsoon season has repeatedly disrupted yield; this creates a great threat to the occupations of farmers in Purulia. By executing a case study, this is reveals that rural land use alterations can perform a significant role in assisting micro-level adaptation to drought. Based on primary data assembled through the field survey and interviews, this study assessed farmers' adaptation activities to droughts and evaluated their success in terms of economic and social advantages. Outcomes indicate that a series of rural land use management can perform effectively to reduce farm-level drought impact. The methodology that has been used in the study, containing the comprehensive field analysis and quantitative evaluation, can be suitably covered to further adaptation-related study on disaster risks. First, local farmers cultivated more drought tolerate crops, instead of water-intensive rice crops, which greatly increase cropping intensity, crop yields and expanded their earnings sources that lessened the drought risk to agriculture. Second, the development of nutrition gardens in the small patches of homestead land using water- conserving drip irrigation has alleviated the drought impact on agriculture, and it has significantly enhanced food supply, nutrition and farmers' revenues. Third, plantation on low-yield upland increased the eco-environment and diminished the risk. This study delivers an achievable method to identify farm-level adaptation techniques and gives multiple ways to improve farmers' adaptability; still, limitations exist. Some results were acquired by qualitative study due to the difficulty of amassing the observed data. In the long term, more emperical analyses should be conducted by considering areas with different socio-economic backgrounds, such as developing and wealthy villages. Preliminary findings of this study may provide information about suitable farm-level adaptation strategies to policymakers. Additionally, this research may give insights into efficiently developing farmers' adaptability to climatic extremes within the extended RLZ of India.

8.7 CONCLUSION

Recurrent Drought in the recent period is one of the major restraints influencing crop production and occupations of more than two million people in Purulia and the trends analysis indicated an increasing tendency in drought frequency and intensity in this area. The increasing temperature and low precipitation in the growing months of rice in Purulia raise the regional vulnerability to drought in RLZ, thus adaptation and preparedness strategies are extremely needed. In the present study, adaptation and Preparedness strategies to drought include (a) suitable agricultural land use for sustainable agricultural (b) assessment potential groundwater zone making irrigated systems more efficient; (c) identified optimum sites for Rainwater Harvesting Structure to expand the intermediate rainfed–irrigated systems; (d) rural land use management including reforestation, using the traditional drip irrigation in nutrition garden, less water-intensive crops cultivation for ensuring food security and improving farmers' livelihoods. The chapter presents valuable research consequences and case studies using these innovative practices where obvious impact is revealed to manage drought and food security in sub-humid RLZ areas. Water supply management and efficient use of water are the main measures to adapt to droughts by reducing the drought disaster risk. According to the various physical, hydrological and topography characteristics in the study area, optimum agricultural land, groundwater potential zone and rain-water harvesting structure locations have been identified, such as which area is the best to adapt to the droughts. Suitable agricultural land is an optimized land use structure used to implement sustainable cultivation which could reduce the exposure to drought risks; and also accumulate the efficient use of water. The rainwater harvesting structurals can be an effective approach to adapt to the frequent droughts as well as to focus sustainable water management in sub-humid RLZ. Assessment of potential groundwater zone making irrigated systems more efficient by supplying groundwater through dug wells. Irrigation water supply through rainwater harvesting structure and dug well are greatly increased cropping intensity, crop yields and multiplied their earnings sources that diminished the drought risk. Based on the detailed field survey and empirical analysis signifies that irrigation water supply has been increased by conserving rainwater and supplying groundwater which makes local farmers economically better-off. The analysis indicates that the demand-based water management like drought tolerate crops cultivation instead of water-intensive crops, intensifying efficacy in water usage and regulate total water pressure has magnificently stabilized. The development of nutrition gardens in the small patches of homestead land using water- conserving drip irrigation has diminished the drought effect on farming systems, and it has significantly enriched food supply, nutrition and farmers' profits. These adaptation strategies help to manage drought and water shortage to increase crop production and food security in the sub-humid RLZ of India through an integrated agroecosystem approach. The science-based solutions delivered from the adaptation strategies that have been adopted in regions will be influenced in the small to long term. This study delivers an achievable method to identify micro-level adaptation techniques and offers various paths to develop farmers' adaptability. But constraints exist, such as; some results were taken from qualitative assessment due to the hindrance of assembling the primary data. Further empirical studies should be executed by considering different socio-economic regions. The government and NGOs should support farmers' to access weather forecast, markets, argo-advisury and knowledge which would help farmers to prepare preemptive alterations in their farming systems.

CHAPTER IX

GENERAL DISCUSSION AND CONCLUSION

[This chapter synthesizes all the principal observations from the present thesis which justifies the initial research hypothesis. A general discussion about the results obtained from the study of different objectives is included in this chapter.]

The present thesis on the '**Assessment of Drought Dynamics in Purulia Districts, West Bengal for appropriate adaptation to climate change impacts**' conducted a comprehensive analysis of the three kinds of droughts, the meteorological, agricultural and hydrological one using incidence , intensity, duration, and spatial-temporal variability in the sub-humid RLZ of Purulia district of West Bengal. Specific focus was delivered to the monthly drought assessment during the crop growing monsoon season (June -September) and its influences on agricultural production and socio-economic condition. The study also identified the suitable water management strategies to address the spatially differentiated drought risk of the area and suggested suitable micro irrigation and cropping strategies at a regional level to reduce drought risk through enhancing crop yield and livelihood diversification. Such strategies have been validated in the field at farm level though a pilot research with the help of a reputed NGO, which could prove their efficacies identifying areas of land and water use interventions and socioeconomic upliftment and wellbeing of the dominant tribal communities in villages.

In this section, I have tried to incorporate the principal findings to resolve the study's research queries and to prove the research hypothesis set at the initial stage of the thesis. To evaluate the first two questions on changing characteristics of droughts in Purulia and exploring the most appropriate indices for drought assessment the changing characteristics of meteorological drought in terms of its duration, intensity, frequency, and spatial-temporal variability using rainfall-temperature based (SPI and SPEI) indices during 1901- 2019 have been accomplished. The monthly variability of monsoon season agricultural droughts at a sub-district level have been studied using satellite derived multi indices (NDVI anomaly, VCI, TCI, TVDI, and ZPET) during 2005-2019. The spatial-temporal variability of hydrological droughts have been evaluated at seasonal (pre-monsoon, monsoon, post-monsoon kharif and rabi) time frame using groundwater level data (of 1265 wells) from the Central Ground Water Board for the period 1996 to 2019. Mann–Kendall (M–K) test was performed to identify the trend of meteorological and hydrological droughts for several time steps (monthly, seasonal, and annual). The multi indices used are found to be appropriate for the assessment of different types of drought in Purulia.

The RLZ of the Purulia district of West Bengal mainly consists of the Chhotonagpur Granite Gneiss complexes and their weathered variants. Due to the compact nature of the Granite Gneiss, deep aquifer is hardly developed and the shallow aquifers are mainly found at the joints, fissures, fractures, cracks, and in some part of the weathered/lateritic zones.

Consequently, agriculture predominately depends on rainfall and mono-cropping is the predominant practice. All the 20 blocks of Purulia, are recorded under Drought Prone Areas Programme (DPAP) by the Department of Land Reforms, Ministry of Rural Development (GoI). The area is characterizes by a sub-tropical monsoon climate, with an annual average rainfall of 1300 mm (according to 120 (1901-2019) years record) of which 80% rainfall occurring during the monsoon season from June to September. However, these four months do not receive the same intensity of rains throughout the period, rather, an intermittent high nature is noticed over the last few decades. According to IMD, the region receives 80% of monsoon rainfall in just less than 100 h. Greater slope, rocky regolith and impervious layers, poorly weathered and shallow topsoil with poor water holding capacity are incapable to permit subsurface storage in shallow aquifers; therefore this area is highly susceptible to drought occurrence.

A minor change in the long-term droughts (12-monthly) while a major change in short-term (1, 3-monthly) droughts have been observed in Purulia. On a monthly time scale, extreme droughts were found from June to October, while severe droughts were found in the lean periods of February to April. Mild droughts could be found in the months of November and December. Among the cases of drought incidences in the region, 50% were found to be of extreme to severe (-2 to -1.5) nature which occurred from June to October during the recent period (1990-2019). A majority (53%) of the mild droughts could be identified to have occurred before the 1960s. The long-duration drought of 8 to 10 months prevailed during the period 1930-1960, appeared to have been replaced by frequent short-duration droughts in the region. Drought occurrences and intensity appeared to have increased in the recent decades. On a seasonal scale, extreme to severe droughts is observed to be more prevalent in the monsoon season during the post-1990 period.

From the monthly agricultural drought analysis, inconsistent temporal trends were observed in drought variability over the wet monsoon seasons in the Purulia. In 2015, the wet condition in June was quickly followed up by extreme drought during July and August which affected 65% of agricultural land, though, in that year, the area received a fair amount of monsoon rainfall (1000 mm). On the other hand, in 2005, 2009 and 2010 and monsoon rainfall was less (100, 300 and 81 mm) than the long term monsoon mean (1050 mm) and moderate to extreme drought conditions prevailed in June and August which affected 20%, 35% and 45% agricultural land respectively. The analysis brings out the fact that it is not the total rainfall deficit in a year but the monthly deficit of rain in the wet months of crop growing season that perpetuates droughts in RLZ and loss of Kharif crop production. In Purulia, a good temporal similarity has been perceived among meteorological, agricultural, and hydrological droughts as brought out by drought indices. Since 2000, the years when three types of droughts occurred during the monsoon season are 2000, 2001, 2002, 2005, 2009, 2010 and 2015. The intensity of meteorological drought events was higher than the agricultural and hydrological droughts. It was also found from the analysis that among the three types of droughts that the sub-humid RLZ has been experienced, short duration droughts occurred more frequently in recent years and extreme droughts were mainly concentrated in the monsoon months. The correlation coefficient analysis (R-values) between meteorological and agricultural drought indices and in-situ drought indices were used to assess the accuracy. Result revealed that SPEI (meteorological) and ZPET (agricultural) performed as better indices compared to others, especially in recent years, when the temperature is significantly higher promoting more evapotranspiration and dryness. Trend analysis of monthly meteorological and seasonal hydrological drought revealed a significant increasing trend in July, August months. An increasing propensity has been observed in drought frequency and intensity during the recent years. Overall, the spatial distribution of the three indices indicated that the drought impacted area progress from west to east in the Purulia with different severity deciphered from different indices. Long-term (seasonal or annual) decrease rainfall decrease in soil moisture and increase in temperature are important factors for agricultural and hydrological droughts.

The third question that was raised in this thesis is *“which areas are highly risk-prone to drought?”* To find the answer to these question a total of 33 different bio-physical and socio-economic components based on IPCC AR4 and AR5 frameworks have been assimilated for drought vulnerability and risk assessment in 20 administrative blocks of Purulia district The Non-Linear Principal Component Analysis was performed to process the data with mixed scaling and prioritize the indicators. Principal components explaining the largest variance in the data set, such as access to employment opportunities, access to land, irrigation, access to food, occupational diversity, access to resources, crop-livestock integration and access to water. Finally, indicators of exposure, sensitivity and adaptive capacity were standardized for easy comparison and drought vulnerability and risk indices were computed based on AR4 and AR5 approaches.

Results obtained revealed that the northern blocks of Raghunathpur-I, II, Nathuria and Santuri were relatively less vulnerable to drought stressors. The higher vulnerability was observed in the majority of the eastern blocks Kashipur, Puncha, Hura, Manbazar-I, Purulia-II and the few western blocks Jaipur, Jhalda-I, Bugmundi have the highest percentage of tribal households and marginal farmers. A majority of households in Bandoyan, Manbazar-II, Barabazar, Balarampur, Arsa and Jhalda-II were moderately vulnerable. Inherent vulnerability and risk assessment has the potential to predict the future harm a household might suffer due to drought events.

The last two questions were "*will the present surface water resource, be able to meet the agricultural water requirement? If not, what are the appropriate spatial planning and adaptation options that may be undertaken for drought risk reduction?*" To address the question on water availability and water demand for agriculture, the impacts of agricultural droughts on agricultural area sown and productions at the block level have been assessed first. The block-wise drought-affected agricultural lands with different intensities have been evaluated by compiling monthly agricultural drought indices (NDVI anomaly, TVDI and SPEI) and frequency of drought for 2005- 2019 period. Drought impact on crops production indicated failure of Aman rice, Maize, Green Gram cereals, pulses and oilseeds crops production during the dry spells in different drought years. The long (5 monsoon months) extreme drought in 2010 and moderate drought in 2005 decreased the Kharif rice productions (Aman) around by 43%) and 20%) respectively. Kharif rice production was declined by 14% by the short-term monsoon drought of 2015. The investigation reveals that the inadequate irrigation facility, infiltration potential, sloping nature of agricultural land, gravelly loamy soil and high soil erosion can be attributed as major drivers of crop failure in the district. The most drought-affected southern block (Bundwan), western blocks (Jhalda-I, Bagmundi, Balarampur, Purulia-I,II, Jaipur and Arsa) and eastern blocks of Purulia (Manbazar, Kashipur and Hura) recorded a decrease in main workers and also increase of marginal and non-workers during 2001 to 2011 period . The field study based on qualitative data derived from a questionnaire survey in selected villages of Kashipur block revealed that farmers have experienced more frequent and intense drought in the Purulia during the recent years and severe reduction in crop production. Poor marginal farmers are more affected by drought. Recurrent crop failures have lead to unemployment.

To address the situation the gap between agricultural water demand availability and demand need to be quantified. The crop and irrigation water requirement has been estimated by CROPWAT (8.0) and water availability has been estimated from different source of irrigation (ponds/tanks, open dug wells and river lift irrigation and others). Results revealed that the water availability for a different source of irrigation is 172 mcm which does not meet the irrigation requirement of 267 mcm and 449 mcm in normal and drought years respectively. The maximum irrigation deficit has been found in Kashipur block (15.72 mcm) and the lowest deficit has been seen in Santuri block (0.25 mam). From the block-level assessment of irrigation deficiency, it is observed that the frequent drought-affected blocks have experienced high irrigation deficiency (have less than 30% cultivated area under irrigation) which makes them more vulnerable to drought.

Whenever there is a water scarcity issue, the resolution largely depends on the supply system (i.e. an innovative water usage and distribution network) to fulfill the irrigation water demand. The supply-driven approach such as building more water harvesting structures of various proportions for different land settings can be a suitable option to meet their water requirement. Therefore, surface runoff from rainfall was estimated in the Purulia using the NRCSS-CN model. Assessment of surface water potential shows that 31% of the annual rainfall is discharged as runoff and 89.9% of the runoff occurred during the monsoon (July and October) in Purulia. Results indicated that if 50% monsoon runoff can be efficiently harvested and 25% of available water resources are used for irrigation, there are 280 mcm and 168 mcm water available for irrigation in normal and drought years respectively. The irrigation water availability from surface runoff is sufficient for normal years but in the drought years, only 40% of irrigation requirements meet by surface runoff.

The key issues emerging from the present analysis is that structural supply-based management alone will not be sufficient to deal with the drought risk inspite of substantial rainfall. Demand-based management can improve water consumption efficacy and reduce the water deficiency. To address the final question on appropriate spatial planning and adaption strategies present study attempted to detect the optimum locations for rainwater harvesting structures, dug wells and farm-level land use management and also quantitatively investigate how these strategies perform in drought risk reduction and socio-economic benefits through a pilot study in the drought-prone Purulia.

Adaptation strategies for drought risk reduction in the sub-humid Purulia district were identified as (a) suitable agricultural land use for sustainable agricultural, (b) assessment potential groundwater zone making micro-irrigation systems more efficient, (c) identification of the optimum sites for Rainwater Harvesting Structure to expand the rainfed–irrigated systems, (d) rural land use management including reforestation, using the traditional drip irrigation in nutrition garden, cultivation of less water-intensive crops for ensuring food security and improving farmers' livelihoods.

The present study emphasizes a pragmatic methodology for evaluating suitable sites for RWH structures, groundwater potential zone and sustainable agriculture using GIS-based multi-criteria decision making process in the drought-prone district of Purulia. The accuracy of the geo-informatics appraisal was assessed by comparing with ground data and the validation has been found above 85%. This reaffirms that the effectiveness of combination of remote sensing with AHP being a cost-effective with superior potential to identify the optimum sites for RWHSs and groundwater potential and also eliminating the time constraints of conventional methods. To assess the performance of the RWHSs and rural land use management on farmers' well-being frequent surveys with semi-structured questionnaires, field observation and assessment were conducted in few villages of drought affected Kashipur block of Purulia with the help of a reputed NGO in the region. Primary data on farmers' agricultural production and the effectiveness of adaptation actions to droughts were collected. Impacts on drought adaptation measures have been established through comparison of changes in crop production, cropping intensity and income in the two drought years- before (2015) and after (2019) implementation of the adaptation options by the NGO. The study also reaffirmed the advantages of cost-effective drip irrigation used for nutrition gardening in the drought years. The ground level impacts of the suggested adaptation strategies can be summarized as follows: First, farm-level adaptations through RWHSs and dug wells lead to significant gains in crop yield and income of the marginal farmers which proved the efficiency of RWHSs as drought adaptation in RLZ. Second, local farmers cultivated more drought tolerant crops, instead of water-intensive rice crops, and also changed to multiple crops by mixed cropping practices, which significantly increased cropping intensity, crop yields and diversified their income sources that minimized the drought risk to their livelihood. Third, the development of nutrition gardens in the small patches of homestead land using traditional drip irrigation could reduce the drought impact on food and nutrition deficiency, and it has considerably improved food supply, nutrition and farmers' revenues.

This study presents a feasible methodology for suitable farm-level adaptation measures and delivers multiple pathways to reduce drought risk to the farmers' livelihood. Suitable agricultural land practice, rain water harvesting, land use management and reforestation would help to mitigate the risk to recurrent agricultural droughts and also to improve the eco-environment. Drought tolerant crop cultivation, water harvesting and multi cropping, mixed cropping, nutrition gardening using drip irrigation could help the framers to improve their food and nutrition security. Rainwater harvesting and ground water have significantly improved micro-irrigation supply, crop yields and farmers' incomes. Such adaptation strategies for the agricultural sector of the RLZs have capacity to address equally the ecological prosperity, economic advantages, and social benefits for agricultural sustainability even in the face of climate change.

Synthesizing all the results obtained from the present study, it can be concluded that although sub-humid RLZ of the Purulia receives a considerable amount of annual rainfall, this region experienced frequent short-term drought in the monsoon season during recent periods due to the erratic nature of monthly rainfall and rising temperature. An increasing tendency has been also observed in drought frequency and intensity during the monsoon season, especially July and August month. This short-term drought has lead to significant crop failure and unemployment. The gap between crop water requirement and irrigation water availability revealed that the area has substantial irrigation deficiency which makes this region more vulnerable to drought. The effective harvest of surface runoff from rainfall can reduced irrigation deficiency but is not enough to meet the water demand in drought conditions. The action research with an NGO on implementing Rainwater harvesting structures and groundwater potential zone identified through high resolution geoinformatic analysis of the present research has proved to have made micro-irrigation systems more efficient while agricultural land suitability and rural land use management improved water consumption efficiency and food security in the study area. All together, these adaptation strategies could reduce the vulnerability of few villages under study within a short time span of 5 years. The interdisciplinary insights gained from the present research process could therefore prove the initial hypothesis that high resolution spatiotemporal assessment of drought incidences in the sub humid red and laterite zones using geospatial technology and field investigations of agriculture and water use practices can aid in drought risk reduction through appropriate micro level adaptation to climate change.

LIMITATIONS OF THE PRESENT WORK

Although our data indicate, that RWHSs and land use management have been reduced the vulnerability of agriculture to drought risk, their adaptive capacities are inadequate when confronted with extreme droughts. However, limitations exist. For example, some findings were obtained by qualitative analysis due to the difficulty of collecting the observed data. In the long-term, more case studies should be performed by considering regions with various socio-economic backgrounds, such as developed regions and wealthy villages. In the long-term, the government and NGOs should promote farmers' access to climate information, markets, social capital and technology, which would allow farmers to make proactive adaptations rather than reactive changes in their farming practices.

FUTURE RECOMMENDATIONS OF WORK

Recommendations for the future direction of work may be as follows:

(i) Drought forecasting by using appropriate technology may be attempted to the proposed drought assessment procedure for early warning in the study region.

(ii) Using the proposed drought assessment procedure, attempts can be extended for RLZ of India to effectively manage drought by appropriate preparedness planning.

(iii) An attempt can be made to use SAR remote sensing data for monsoon drought assessment in sub-humid RLZ of India which would serve as an efficient tool for wet season drought assessment, monitoring and management.

(iv) The groundwater potential zone, potential location for RWHSs and agricultural land suitability as outcomes of the present study is envisaged to be useful for detecting suitable locations for harvest of rainwater, sustainable groundwater uses, further land-use and water resource management in this region and can be replicated in the wider RLZ or several other drought-prone states with comparable physiographic characteristics in India and other subtropical areas.

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