Chapter – I

PROBLEM AND PROCEDURE

1.1. Introduction

Rainfed agriculture plays an important role in Indian economy. In India, 68% net sown area (136.8 m ha) comes under rainfed agriculture. In India, some 48% area is under food crops and 68% area under non-food crops. According to the National Rainfed Area Authority (NRAA) almost 50% rural work force and 60% livestock depend on rainfed agriculture More than 177 districts of India are dominantly rainfed districts. Arguably, a significant increase in the form of groundwater irrigation is reported from some of these areas in the last few decades. Rainfed areas also match closely with the areas characterized by human poverty. Under various programs, the Government has invested almost thrice the amount in irrigation projects as compared to investments in rainfed areas. Subsidies continue to flow to farmers with irrigation facilities, in the form of drips, sprinklers or fertilizers. A major challenge for rainfed areas is that of protecting, conserving and intelligently using water resources especially considering two factors. Firstly, given the overarching impacts from Climate Change, rainfall vagaries will bear a profound impact on water resources from such areas, especially in scenarios that require 'buffers' during the prolonged dry spells of the monsoon. Secondly, a water management strategy in rainfed areas also holds the key to water management solutions in areas where large - scale groundwater overexploitation has occurred and both Kharif and Rabi cropping has become vulnerable to water shortages.

Groundwater is water located beneath the ground surface in soil pore spaces in the fractures of rock formations. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water. When water can flow directly between the surface and the saturated zone of an aquifer, the aquifer is unconfined. The deeper parts of unconfined aquifers are usually more saturated since gravity causes water to flow downward.

The upper level of this saturated layer of an unconfined aquifer is called the water table. Below the water table, where generally all pore spaces are saturated with water is the phreatic zone. Substrate with low porosity that permits limited transmission of groundwater is known as an aquitard. An aquiclude is a substrate with porosity that is so low it is virtually impermeable to groundwater. A confined aquifer is an aquifer that is overlain by a relatively impermeable layer of rock or substrate such as an aquiclude or aquitard. Groundwater recharge is a hydrologic process where water moves downward from surface water to groundwater. This process usually occurs in the vadose zone below plant roots and is often expressed as a flux to the water table surface. Recharge occurs both naturally by rain and snow melt and to a smaller extent by surface water. Use of ground waters, especially for irrigation, may also lower the water tables. Groundwater recharge is an important process for sustainable groundwater management, since the volume-rate abstracted from an aquifer in the long term should be less than or equal to the volume-rate that is recharged. The most important factors affecting diffuse groundwater recharge are the intensity, timing and duration of discrete rainfall particularly over arid and semi arid region. The water table may rise or fall depending on several factors. Heavy rains increase recharge and cause the water table to rise. An extended period of dry spell may decrease recharge and cause the water table to fall.

Geospatial Information is spatial data concerning a place or, in space, collected in real time. Geospatial techniques together with remote sensing, geographic information science, Global Positioning System (GPS), and spatial statistics are being used to capture, store, manipulate and analyze to understand complex situations to solve mysteries of the study. These techniques have been effectively applied in various fields such as meteorology, agriculture, hydrology etc. In the present study with the aid of geospatial techniques, spatial analysis of groundwater level, its rational utilization in relation to rainfall reliability for agricultural activities have been carried for Tiruchirappalli district being the semi arid area of Tamil Nadu State.

1.2. Rainfed and Dry land Agriculture

1.2.1. Rainfed Agriculture

The term Rainfed agriculture is used to describe farming practices that rely on rainfall for water. It provides much of the food consumed by poor communities in developing countries. For example, rainfed agriculture accounts for more than 95% of farmed land in sub-Saharan Africa, 90% in Latin America, 75% in the Near East and North Africa; 65% in East Asia and 60% in South Asia. Levels of productivity, particularly in parts of sub-Saharan Africa and South Asia, are low due to degraded soils, high levels of evaporation, droughts, floods and a general lack of effective water management. A major study into water used by agriculture, known as the Comprehensive Assessment of Water Management in Agriculture, coordinated by the International Water Management Institute, noted a close correlation between hunger, poverty and water. However, it concluded that there was much opportunity to raise productivity from rainfed farming.

The importance of rainfed agriculture varies regionally but produces most food for poor communities in developing countries. In sub - Saharan Africa more than 95% of the farmed land is rainfed, while the corresponding figure for Latin America is almost 90%, for South Asia about 60%, for East Asia 65% and for the Near East and North Africa 75% (FAOSTAT, 2005). Most countries in the world depend primarily on rainfed agriculture for their grain food. Despite large strides made in improving productivity and environmental conditions in many developing countries, a great number of poor families in Africa and Asia still face poverty, hunger, food insecurity and malnutrition where rainfed agriculture is the main agricultural activity. These problems are exacerbated by adverse biophysical growing conditions and the poor socioeconomic infrastructure in many areas in the semi-arid tropics (SAT). The SAT is the home to 38% of the developing countries' poor, 75% of whom live in rural areas. Over 45% of the world's hungry and more than 70% of its malnourished children live in the SAT

There is a correlation between poverty, hunger and water stress (Falkenmark, 1986). The UN Millennium Development Project has identified the 'hot spot' countries in the world suffering from the largest prevalence of malnourishment. These countries coincide closely with those located in the semi-arid and dry subhumid hydroclimates in the world (Fig. 1.1), i.e. savannahs and steppe ecosystems, where rainfed agriculture is the dominating source of food and where water constitutes a key limiting factor to crop growth (SEI, 2005). Of the 850 million undernourished people in the world, essentially all live in poor, developing countries, which predominantly are located in tropical regions (UNSTAT, 2005).

Since the late 1960s, agricultural land use has expanded by 20–25%, which has contributed to approximately 30% of the overall grain production growth during the period (FAO, 2002; Ramankutty et al., 2002). The remaining yield outputs originated from intensification through yield increases per unit land area. However, the regional variation is large, as is the difference between irrigated and rainfed agriculture. In developing countries rainfed grain yields are on average 1.5 t/ha, compared with 3.1 t/ha for irrigated yields (Rosegrant et al., 2002), and increase in production from rainfed agriculture has mainly originated from land expansion. Trends are clearly different for different regions. With 99% rainfed production of main cereals such as maize, millet and sorghum, the cultivated cereal area in sub-Saharan Africa has doubled since 1960 while the yield per unit of land has been nearly stagnant for these staple crops (FAOSTAT, 2005). In South Asia, there has been a major shift away from more drought-tolerant, low-yielding crops such as sorghum and millet, while wheat and maize has approximately doubled in area since 1961 (FAOSTAT, 2005).

Rural development through sustainable management of land and water resources gives a plausible solution for alleviating rural poverty and improving the livelihoods of the rural poor. In an effective convergence mode for improving the rural livelihoods in the target districts, with watersheds as the operational units, a holistic integrated systems approach by drawing attention to the past experiences, existing opportunities and skills, and supported partnerships can enable change and improve the livelihoods of the rural poor. The well-being of the rural poor depends on fostering their fair and equitable access to productive resources.

The rationale behind convergence through watersheds has been that these watersheds help in ‘cross-learning’ and drawing on a wide range of experiences from different sectors. A significant conclusion is that there should be a balance between attending to needs and priorities of rural livelihoods and enhancing positive directions of change by building effective and sustainable partnerships. Based on the experience and performance of the existing integrated community watersheds in different socioeconomic environments, appropriate exit strategies, which include proper sequencing of interventions, building up of financial, technical and organizational capacity of local communities to internalize and sustain interventions, and the requirement for any minimal external technical and organizational support need to be identified.

Worldwide, rainfed agriculture is practised in almost all hydro climatic zones. In temperate regions with relatively reliable rainfall and productive soils, and in the sub humid and humid zones of tropical regions, rainfed agriculture can have some of the highest yields.

In contrast, in dry sub humid regions, as well as in temperate and tropical arid and semiarid regions, yields are often relatively low. Owing to highly variable rainfall, long dry seasons, and recurrent droughts, dry spells and floods, water management is a key determinant for agricultural production in these regions and will become even more important during climate change. Yields can be significantly enhanced by improved water management, in particular by increasing water availability and the water uptake capacity of crops. Furthermore, investments in improved agricultural water management are in many circumstances catalytic—reducing the barriers to adoption of otherwise costly soil and crop management practices by increasing the returns to such investments. Rainfed agriculture is most significant in Sub-Saharan Africa where it accounts for about 96% of the cropland. World Bank lending commitments to water management in rainfed agriculture amounts to about 10 percent to that for irrigated agriculture, with about half of commitments for the Africa Region.

Project activities focus on promoting soil and water management techniques, and more recently also on providing better hydro climatic information and climate risk management.

Rain-fed agriculture will play a major role in India’s food security and sustainable economic growth, and there are large opportunities for gains from adaptation and new investments in water management for meeting the targets under the proposed National Food Security Act.

1.2.2. Characteristics of Rainfed Agriculture

Rainfed areas in India are highly diverse, ranging from resource rich areas with good agricultural potential to resource-constrained areas with much more restricted potential. Some resource rich areas (normally under temperate climate) are highly productive and already have experienced widespread adoption of modern technology. On the other hand traditional farming systems in drier and less favored areas is more of a survival mechanism rather than a growth oriented activity. Earlier, the rainfed farming systems, because of its risky nature was dependent upon locally available inputs (seeds, manures, animal draft) and used to grow a number of crops, which were able to withstand drought-like situation. But over time, the cropping systems have changed and presently farmers in these rainfed areas have limited options and have stated cultivating high value crops which require intensive use of costly inputs (chemical fertilizers/ pesticides, hybrid seeds, life saving irrigation, farm energy etc.) and find it difficult to manage the resources on their own.

1.2.3. Dry land Agriculture

Indian agriculture is predominantly a rainfed agriculture under which both dry farming and dry land agriculture are included. Out of the 143 million ha of total cultivated area in the country, 101 million ha (i.e. nearly 70 percent) area are rainfed. In dry land areas, variation in amount and distribution of rainfall influence the crop production as well as socio-economic conditions of farmers. The dry land areas of the country contribute about 42 percent of the total food grain production.

Most of the coarse grains like sorghum, pearl millet, finger millet and other millets are grown in dry lands only. Dry land Agriculture refers to growing of crops entirely under rainfed conditions. Based on the amount of rainfall received, dry land agriculture can be grouped into three categories:

1. **Dry Farming**: Cultivation of crops in areas where rainfall is less than 750 mm per annum.
2. **Dry land Farming**: Cultivation of crops in areas receiving rainfall above 750 mm.
3. **Rainfed Farming**: Cultivation of crops in regions receiving more than 1, 150 mm.

1.2.1. Soil moisture dynamics in Dry land

During rainy period, a portion of the rain received goes as runoff and remaining part enters the soil. It generally percolates to the lower layers and sometimes, goes beyond the root zone of crops. After the rain, the surface soil gradually dries out either due to evaporation or transpiration or due to both.

1.3. Role of Rainfall in Indian Agriculture

India is home to an extraordinary variety of climatic regions, ranging from tropical in the south to temperate and alpine in the Himalayan north, where elevated regions receive sustained winter snowfall. The nation's climate is strongly influenced by the Himalayas and the Thar Desert. The Himalayas act as a barrier to the frigid katabatic winds flowing down from Central Asia keeping the bulk of the Indian subcontinent warmer than most locations at similar latitudes. As such, land areas in the north of the country have a continental climate with severe summer conditions that alternates with cold winters when temperatures plunge to freezing point. In contrast are the coastal regions of the country, where the warmth is unvarying and the rains are frequent.

The country is influenced by two seasons of rains, accompanied by seasonal reversal of winds from January to July. During the winters, dry and cold air blowing from the northerly latitudes from a north-easterly direction prevails over the Indian region. Consequent to the intense heat of the summer months, the northern Indian landmass becomes hot and draws moist winds over the oceans causing a reversal of the winds over the region which is called the summer or the south-west monsoon This is most important feature controlling the Indian climate because about 75% of the annual rainfall is received during a short span of four months (June to September). Variability in the onset, withdrawal and quantum of rainfall during the monsoon season has profound impacts on water resources, power generation, agriculture, economics and ecosystems in the country.

The variation in climate is perhaps greater than any other area of similar size in the world. There is a large variation in the amounts of rainfall received at different locations. The average annual rainfall is less than 13 cm over the western Rajasthan, while at Mausiram in the Meghalaya has as much as 1141 cm. The rainfall pattern roughly reflects the different climate regimes of the country, which vary from humid in the northeast (about 180 days rainfall in a year), to arid in Rajasthan (20 days rainfall in a year). So significant is the monsoon season to the Indian climate, that the remaining seasons are often referred relative to the monsoon.

For the country as whole, mean monthly rainfall during July (286.5 mm) is the highest and contributes about 24.2% of annual rainfall (1182.8 mm). The mean rainfall during August is slightly lower and contributes about 21.2% of annual rainfall. June and September rainfall is almost similar and contributes 13.8% and 14.2% of annual rainfall, respectively. The mean south-west monsoon (June, July, August & September) rainfall (877.2 mm) contributes 74.2% of annual rainfall (1182.8 mm). Contribution of pre-monsoon (March, April & May) rainfall and post-monsoon (October, November & December) rainfall in annual rainfall is mostly the same (11%). Coefficient of variation is higher during the months of November, December, January and February.

Analyzed according to the Koppen system, the **climate of India** resolves into six major climatic subtypes; their influences give rise to desert in the west, alpine tundra and glaciers in the north, humid tropical regions supporting rain forests in the southwest, and Indian Ocean island territories that flank the Indian subcontinent. Regions have starkly different yet tightly clustered microclimates. The nation is largely subject to four seasons: winter (January and February), summer (March to May), a monsoon (rainy) season (June to September), and a post-monsoon period (October to December).Though the Tropic of Cancer the boundary between the tropics and subtropics passes through the middle of India, the bulk of the country can be regarded as climatically tropical. As in much of the tropics, monsoonal and other weather patterns in India can be wildly unstable: epochal droughts, floods,

Cyclones and other natural disasters are sporadic, but have displaced or ended millions of human lives. There is widespread scientific consensus that South Asia is likely to see such climatic events, along with their aleatory unpredictability, to change in frequency and are likely to increase in severity. Ongoing and future vegetative changes and current sea level rises and the attendant inundation of India's low-lying coastal areas are other impacts, current or predicted, that are attributable to global warming.

July and August rainfall, which contributes major portion of monsoon seasonal rainfall. We find in July, six subdivisions have shown decreasing trends and eight subdivisions have increasing trends. In August, four (ten) subdivisions have decreasing (increasing) trends for August rainfall.

July rainfall has decreased for most parts of the central and peninsular India but increased significantly in the northeastern parts of the country.

Table 1.1. Rainfall by District

	District	South west Monsoon ((June '10 to September'10)		North east Monsoon (October' 10 to December 10)		Winter season (January'11 and Feburary'11)		Hot weather season (march' 11 to May'11)		Annual total (June' 10 to May ' 11)	
		Actual	Normal	Actual	Normal	Actual	Normal	Actual	Normal	Actual	Normal
SI. No	1	2	3	4	5	6	7	8	9	10	11
1	Chennai	568.8	443.5	62.5	753.1	53.6	36.7	29.4	58.5	1304.3	1291.8
2	Kanchipuram	526.7	462.7	744.8	697.2	41.7	29.1	85.7	66.0	1398.9	1255.0
3	Thiruvallur	817.2	449.5	518.2	604.1	45.9	31.5	69.6	67.2	1450.0	1152.3
4	Cuddalore	362.9	373.6	1043.7	716.	70.0	44.1	120.6	81.7	1597.2	1215.9
5	Villupuram	521.1	433.0	755.0	484.8	23.9	28.2	104.4	76.0	1404.4	1022.0
6	Vellore	456.8	442.0	410.7	353.0	34.4	14.9	110.0	106.5	1011.9	916.4
7	Tiruvannamalai	511.3	465.8	64.6	439.8	45.2	26.5	106.0	98.9	1317.1	1031.0
8	Salem	545.8	380.0	64.2	347.0	8.7	16.0	211.4	170.8	1330.1	913.8
9	Namakkal	303.6	317.0	429.0	291.0	10.7	13.9	237.5	148.6	980.8	770.5
10	Dharmapuri	424.9	361.0	43.7	316.7	34.5	18.2	300.9	160.4	1196.0	856.3
11	Krishnagiri	367.9	403.6	405.2	290.9	37.1	10.7	190.6	151.6	1000.8	856.8
12	Tiruppur	163.6	135.1	524.7	304.3	1.0	14.0	138.2	135.1	827.5	588.5
13	Coimbatore	188.0	233.1	437.0	341.9	82.9	20.3	194.6	150.3	902.5	745.6
14	Erode	305.3	250.6	495.4	331.8	9.9	16.1	227.2	142.4	1037.8	740.9
15	**Tiruchirappalli**	**313.8**	**295.1**	**508.2**	**385.6**	**5.1**	**22.7**	**97.7**	**109.9**	**924.8**	**813.3**
16	Karur	230.9	223.4	479.6	310.5	3.0	17.5	140.2	109.2	853.7	660.6
17	Perambalur	326.6	301.7	498.8	383.4	1..3	21.4	192.7	108.9	1019.4	815.4
18	Pudukkottai	367.3	350.7	494.5	418.0	18.0	33.1	121.7	97.5	1001.5	899.3
19	Thanjavur	391.0	342.0	837.1	545.5	34.6	42.3	95.3	102.1	1358.0	1032.1
20	Thiruvarur	532.5	301.8	1118.8	665.4	55.5	60.1	83.5	97.7	1790.3	1125.0
21	Nagapattinam	386.2	305.4	1041.6	886.4	45.3	85.7	78.9	80.5	1552.0	1326.7
22	Madurai	301.6	157.5	756.0	373.0	38.8	28.1	151.7	144.8	1248.1	851.3
23	Theni	341.1	251.4	512.4	377.5	55.1	35.4	171.5	168.0	1080.1	738.7
24	Dindigul	286.0	136.1	768.4	399.2	37.4	30.9	170.7	168.0	1262.5	849.5
25	Ramanathapuram	274.1	181.1	736.7	507.4	32.0	51.3	72.2	115.5	1115.0	810.3
26	Virudhunagar	207.3	289.6	555.8	431.2	48.4	42.8	104.7	161.5	916.2	817.3
27	Sivagangai	496.0	92.6	538.6	415.5	17.7	27.9	106.4	121.2	1158.7	854.2
28	Tirunelveli	189.6	86.8	555.8	429.8	74.5	69.3	127.7	166.2	947.6	757.9
29	Thoothukkudi	109.5	1060.0	523.5	410.1	13.7	42.8	46.0	111.6	692.7	651.3
30	The Nilgiris	1211.7	393.3	609.9	367.7	67.0	49.3	228.0	235.3	2116.6	1712.3
31	Ariyalur	329.4	327.8	759.1	514.4	29.3	32.5	93.0	101.8	1629.9	1083.9
32	Kanniyakumari	384.3	327.8	973.1	427.4	88.8	40.4	180.7	288.3	1626.9	1083.6
	State Average	**383.3**	**319.2**	**605.2**	**430.3**	36.3	31.3	140.0	127.8	1165.5	908.6

Source: Indian Meteorological Department, Chennai

1.4. Groundwater Resource and Irrigation Agriculture

Groundwater – containing by far the largest volume of unfrozen fresh water on Earth – is a hugely important natural resource. However, what the general public and most decision-makers know and understand about groundwater is usually very little. Today, knowledge of groundwater around the world, its functions and its use is increasing rapidly – and views about the many ways in which groundwater systems are linked with other systems are changing accordingly. All around the world, groundwater is a resource in transition: its exploitation started booming only during the twentieth century. This boom has resulted in much greater benefits from groundwater than were ever enjoyed before, but it also triggered unprecedented changes in the state of groundwater systems.

On a global level, the key issues that need to be addressed to ensure the sustainability of groundwater resources are the depletion of stored groundwater (dropping water levels) and groundwater pollution. Climate change will affect groundwater, but because of its characteristic buffer capacity, groundwater is more resilient to the effects of climate change than surface water. Therefore, in areas where climate change is expected to cause water resources to become scarcer than they are at present, the role of groundwater in water supplies is likely to become more dominant. Their buffer capacity is one of the major strengths of groundwater systems. It allows long dry periods to be bridged (creating conditions for survival in semi-arid and arid regions) and generally reduces the risk of temporary water shortages. It also smooths out variations in water quality and causes a portion of the stored water (medium-deep to deep groundwater) to be relatively insusceptible to sudden disasters, thus making this portion suitable as an emergency water source. In terms of making a contribution to securing water availability and groundwater-related environmental values, managing groundwater resources sustainably is of vital importance to society and the environment.

The groundwater regimes in humid and arid regions differ fundamentally from each other. In humid climates, with their high rainfall, large volumes of water seep into the groundwater, which contributes actively to the water cycle feeding streams, springs and wetlands during periods when the rainfall is lower.

In semi-arid and arid climates, there is by contrast practically no exchange between the surface water and groundwater regimes because the small volume of seepage from the occasional rainfall only rarely penetrates the thick and dry (unsaturated) soils. In these areas groundwater resources are only minimally recharged. These differences must be considered in any concept of regionally integrated water resource management. Scientists' attempts to achieve robust numerical characterisations of the groundwater component of the water cycle require adequate measurements and observations over decades. Furthermore, exchange between slowly moving groundwater and the faster water cycle operating in the atmosphere and on the Earth's surface must be adequately quantified.

1.4.1. Groundwater Resources and Irrigated Agriculture

Globally, irrigated agriculture is the largest abstractor and predominant consumer of groundwater resources, with important groundwater-dependent agro - economies having widely evolved. But in many arid and drought prone areas, unconstrained use is causing serious aquifer depletion and environmental degradation, and cropping practices also exert a major influence on groundwater recharge and quality. The interactions between agricultural irrigation, surface water and groundwater resources are often very close –such that active cross-sector dialogue and integrated vision are also needed to promote sustainable land and water management. Clear policy guidance and focused local action are required to make better use of groundwater reserves for drought mitigation and climate change adaptation.

1.4.2. Groundwater condition in Indian and Tamil Nadu

Groundwater has rapidly emerged to occupy a dominant place in India's agriculture and food security in the recent years. It has become the main source of growth in irrigated area over the past 3 decades, and it now accounts for over 60 percent of the irrigated area in the country.

It is estimated that now over 70 percent of India's food grain production comes from irrigated agriculture, in which groundwater plays a major role. The number of blocks in which, officially, the creation of wells must completely stop is scaling new heights every year. Yet, the sinking of wells continues rapidly at enormous private, public and environmental cost. The way India will manage its groundwater resource in the future will clearly have very serious implications for the future growth and development of the agriculture sector in India, as well as the alleviation of poverty in India.

1.4.3. Ground Water Resource Potentials in Tamil Nadu

The total annual replenishable ground water resource is about 43 million hectare metres (Mham). After making a provision of 7 Mham for domestic, industrial and other uses, the available ground water resource for irrigation is 36 Mham, of which the utilisable quantity is 32.5 Mham. The utilisable irrigation potential has been estimated as 64 million hectares (Mha) based on crop water requirement and availability of cultivable land. Out of this, the potential from natural rainfall recharge is 50.8 Mha and augmentation from irrigation canal systems is 13.2 Mha. The irrigation potential created from ground water in the country till 1993 is estimated as 35.4 Mha.

In spite of the national scenario on the availability of ground water being favourable, there are pockets in certain areas in the country that face scarcity of water. This is because the ground water development over different parts of the country is not uniform, being quite intensive in some areas resulting in over-exploitation leading to fall in water levels and even salinity ingress in coastal areas. The declining water levels have resulted in failure of wells or deepening of extraction structures leading to additional burden on the farmers.

Out of 4272 blocks in the country (except Andhra Pradesh, Gujarat and Maharashtra where ground water resource assessment has been carried out on the basis of mandals, taluk as and watersheds respectively), 231 blocks have been categorised as "Over-exploited" where the stage of ground water development exceeds the annual replenishable limit and 107 blocks are "Dark" where the stage of ground water development is more than 85%.

Besides, 6 mandals have been categorised as “Over-exploited” and 24 as ‘Dark’ out of 1104 mandals in Andhra Pradesh. Similarly out of 184 taluk as in Gujarat, 12 are “Over-exploited” and 14 are ‘Dark’ and out of 1503 watersheds in Maharashtra, 34 are ‘Dark’.

1.5. Soil Resources

Soil is a natural body consisting of layers (soil horizons) that are primarily composed of minerals which differ from their parent materials in their texture, structure, consistency, color, chemical, biological and other characteristics. It is the unconsolidated or loose covering of fine rock particles that covers the surface of the earth. Soil is the end product of the influence of the climate (temperature, precipitation), relief (slope), organisms (flora and fauna), parent materials (original minerals), and time. In engineering terms, soil is referred to as regolith, or loose rock material that lies above the 'solid geology'. In horticulture, the terms 'soil' is defined as the layer that contains organic material that influences and has been influenced by plant roots and may range in depth from centimetres to many metres. Soil is composed of particles of broken rock (parent materials) which have been altered by physical, chemical and biological processes that include weathering (disintegration) with associated erosion (movement). Soil is altered from its parent material by the interactions between the lithosphere, hydrosphere, atmosphere, and biosphere. It is a mixture of mineral and organic materials in the form of solids, gases and liquids. Soil is commonly referred to as "earth" or "dirt"; technically, the term "dirt" should be restricted to displaced soil.

Soil forms a structure filled with pore spaces and can be thought of as a mixture of solids, water, and gases. Accordingly, soils are often treated as a three-state system. Most soils have a density between 1 and 2 g/cm^3. Little of the soil of planet Earth is older than the Pleistocene and none is older than the Cenozoic, although fossilised soils are preserved from as far back as the Archean.

On a volume basis a good quality soil is one that is 45% minerals (sand, silt, clay), 25% water, 25% air, and 5% organic material, both live and dead. The mineral and organic components are considered a constant while the percentages of water and air are variable where the increase in one is balanced by the reduction in the other.

Given time, the simple mixture of sand, silt, and clay will evolve into a soil profile which consists of two or more layers called horizons that differ in one or more properties such as texture, structure, colour, porosity, consistency, and reaction. The horizons differ greatly in thickness and generally lack sharp boundaries. Mature soil profiles in temperate regions may include three master horizons A, B and C. The A and B horizons are called the solum or "true soil" as most of the chemical and biological activity that has formed soil takes place in those two profiles.

The pore space of soil is shared by gases as well as water. The aeration of the soil influences the health of the soil's flora and fauna and the movement of gases into and out of the soil.

Of all the factors influencing the evolution of soil, water is the most powerful due to its involvement in the solution, erosion, transportation, and deposition of the materials of which a soil is composed. The mixture of water and dissolved and suspended materials is called the soil solution. Water is central to the solution, precipitation and leaching of minerals from the soil profile. Finally, water affects the type of vegetation that grows in a soil, which in turn affects the development of the soil profile.

The most influential factor in stabilizing soil fertility are the soil colloidal particles, clay and humus, which behave as repositories of nutrients and moisture and act to buffer the variations of soil solution ions and moisture. Their contributions to soil nutrition are out of proportion to their part of the soil. Colloids act to store nutrients that might otherwise be leached from the soil or to release those ions in response changes to soil pH.

The greatest influence on plant nutrition is soil pH, which is a measure of the hydrogen ion (acid-forming) soil reactivity, and is in turn a function of the soil materials, precipitation level, and plant root behavior. Soil pH strongly affects the availability of nutrients.

Most nutrients, with the exception of nitrogen, originate from minerals and are stored in organic materials both live and dead and on colloidal particles. Some nitrogen originates from rain, but most of the nitrogen available in soils is the result of nitrogen fixation by bacteria. The action of microbes on organic matter and minerals may be to free nutrients for use, sequester them, or cause their loss from the soil by their volatilisation to gases or their leaching from the soil. The nutrients may be stored on soil colloids, and live or dead organic matter, but may not be accessible to plants due to extremes of pH.

The organic material of the soil has a powerful effect on its development, fertility, and available moisture. Following water and soil colloids, organic material is next in importance to soil's formation and fertility.

1.5.1. World Reference Base for Soil Resources

The World Reference Base for Soil Resources (WRB) is the international standard taxonomic soil classification system endorsed by the International Union of Soil Sciences (IUSS). It was developed by an international collaboration coordinated by the International Soil Reference and Information Centre (ISRIC) and sponsored by the IUSS and the FAO via its Land & Water Development division. It replaces the previous FAO soil classification.

The WRB borrows heavily from modern soil classification concepts, including USDA soil taxonomy, the legend for the FAO Soil Map of the World 1988, the Référentiel Pédologique and Russian concepts.The classification is based mainly on soil morphology as an expression pedogenesis. A major difference with USDA soil taxonomy is that soil climate is not part of the system, except insofar as climate influences soil profile characteristics. As far as possible, diagnostic criteria match those of existing systems, so that correlation with national and previous international systems is as straightforward as possible.

The WRB is meant for correlation of national and local systems. The level of detail corresponds to USDA soil taxonomy subgroups, without the soil climate information. It is not detailed enough for mapping at scales larger than about 1:200k, although proposal has been made to couple WRB with substrate information to map at 1:50k in regional studies.

Key to the WRB reference soil groups (2006)

Table. 1.2. Identification key for the 32 reference soil groups:

1.	Soils with thick organic layers:	Histosols (HS)
2.	Soils with strong human influence Soils with long and intensive agricultural use: Soils containing many artefacts:	 Anthrosols (AT) Technosols (TC)
3.	Soils with limited rooting due to shallow permafrost or stoniness Ice-affected soils: Shallow or extremely gravelly soils:	 Cryosols (CR) Leptosols (LP)
4.	Soils influenced by water Alternating wet-dry conditions, rich in swelling clays: Floodplains, tidal marshes: Alkaline soils: Salt enrichment upon evaporation: Groundwater affected soils:	 Vertisols (VR) Fluvisols (FL) Solonetz (SN) Solonchaks (SC) Gleysols (GL)
5.	Soils set by Fe/Al chemistry Allophanes or Al-humus complexes: Cheluviation and chilluviation: Accumulation of Fe under hydromorphic conditions: Low-activity clay, P fixation, strongly structured: Dominance of kaolinite and sesquioxides:	 Andosols (AN) Podzols (PZ) Plinthosols (PT) Nitisols (NT) Ferralsols (FR)
6.	Soils with stagnating water Abrupt textural discontinuity: Structural or moderate textural discontinuity:	 Planosols (PL) Stagnosols (ST)
7.	Accumulation of organic matter, high base status Typically mollic: Transition to drier climate: Transition to more humid climate:	 Chernozems (CH) Kastanozems (KS) Phaeozems (PH)

8.	Accumulation of less soluble salts or non-saline substances Gypsum: Silica: Calcium carbonate:	 Gypsisols (GY) Durisols (DU) Calcisols (CL)
9.	Soils with a clay-enriched subsoil Albeluvic tonguing: Low base status, high-activity clay: Low base status, low-activity clay: High base status, high-activity clay: High base status, low-activity clay:	 Albeluvisols (AB) Alisols (AL) Acrisols (AC) Luvisols (LV) Lixisols (LX)
10.	Relatively young soils or soils with little or no profile development With an acidic dark topsoil: Sandy soils: Moderately developed soils: Soils with no significant profile development:	 Umbrisols (UM) Arenosols (AR) Cambisols (CM) Regosols (RG)

Table 1.3 WRB 98 Soil groups

Code	Soil type	Br ief description
AC	Acrisol	Red, brown or yellow coloured soil, develops in areas of intense weathering, has a clay rich B horizon
AB	Albeluvisol	
AL	Alisol	
AN	Andosol	Soil developed from volcanic material, are young immature soils, characteristics depend on type of volcanic material
AT	Anthrosol	
AR	Arenosol	Sandy soil with no more profile development than a A horizon
CL	Calcisol	Soil with a substantial secondary accumulation of lime
CM	Cambisol	Transformation of soil matter (Fe particularly) in situ without moving in profile. Mostly brownish color.
CH	Chernozem	Fertile black-coloured soil containing a high percentage of humus, phosphoric acids, phosphorus and ammonia
CR	Cryosol	Soil in permafrost areas, exhibits cryoturbation and is usually rich in organic matter

DU	Durisol	Soil of some arid and semi-arid environments, contains cemented secondary silica
FR	Ferralsol	Red to yellow soil rich in iron and aluminium, common in temperate to tropical humid areas
FL	Fluvisol	Soil developed above flood plain sediments, A horizon is commonly directly above C horizon
GL	Gleysol	
GY	Gypsisol	
HS	Histosol	Soil consisting primarily of organic materials, common in wetlands
KS	Kastanozem	
LP	Leptosol	Shallow soil over bedrock, calcareous material or a deeper soil that is gravelly or stony, common in mountains
LX	Lixisol	
LV	Luvisol	
NT	Nitisol	
PH	Phaeozem	Sod organic-accumulative
PL	Planosol	
PT	Plinthosol	
PZ	Podzol	Soil that presents significant podzolization, common in coniferous forests
RG	Regosol	
SC	Solonchak	
SN	Solonetz	
UM	Umbrisol	Soil with a dark topsoil and in which organic matter has accumulated significantly within the mineral surface soil
VR	Vertisol	Shows significant and recurrent swelling with water, high content of expansive clay

1.6. Need for Integrated Analysis

Remote-sensing represents a technology for synoptic acquisition of spatial data and the extraction of scene-specific information. Demand for remote-sensing as a data input source for spatial database development has increased tremendously during the last few years.

Products derived from remote-sensing are particularly attractive for GIS database development because they can provide cost-effective, wide-area coverage in a digital format that can be directly entered into a GIS. Because remote-sensing data are typically collected in a raster data format, the data can be cost-effectively rectified or converted to a vector format for subsequent spatial data analysis or modelling applications.

A leading agro - meteorological weather service, using advanced data collection and analysis tools like remote-sensing and GIS, must be equipped with sophisticated devices, but above all must have efficient and trained staff. In developing countries, there remains a risk that using limited resources (high-level agro - meteorological personnel and funding) on the development of highly specialized and complex products will not serve the needs of agricultural decision-makers. The problems and priorities of agro - meteorological services need to be defined first. Methodologies come second, but will be essential if they are made available and applied properly.

Our understanding of associated data-processing errors, especially for integrating multiple spatial datasets, lags far behind. It is necessary to identify clearly the types of error that may enter into the process and understand how the error propagates throughout the processing flow. Procedures need to be developed to better quantify and report errors using standardized techniques. Performing spatial data analysis operations with data of unknown accuracy, or with incompatible error types, will produce an output product of low confidence and limited use in the decision-making process.

In agro - meteorology, to describe a specific situation, all the relevant information available about a given territory may be used, including: water availability, soil types, land cover, climatic data, geology, population, land use, administrative boundaries and infrastructure (highways, railroads, power grids and communications systems). Each layer of information provides the operator with the possibility of considering its influence on the final result.

More than just the overlapping of different themes, however, the relationship of the various layers is reproduced with models (ranging from simple "indicator formulae", such as the Universal Soil Loss Equation (USLE), to physical process-based models).

The final information is extracted using graphical representation or precise descriptive indices. Developed countries use agricultural and environmental GISs to plan the times and types of agricultural practices, territorial management activities, and population security, and to monitor devastating events and evaluate damages.

1.7. Application of Geospatial Techniques

Geospatial Information is spatial data concerning a place or, in space, collected in real time. Geospatial techniques together with remote sensing, geographic information science, Global Positioning System (GPS), and spatial statistics are being used to capture, store, manipulate and analyze to understand complex situations to solve mysteries of the study. These techniques have been effectively applied in various fields such as meteorology, agriculture, hydrology etc. In the present study with the aid of geospatial techniques, spatial analysis of groundwater level, its rational utilization in relation to rainfall reliability for agricultural activities have been carried for Tiruchirappalli district being the semi arid area of Tamil Nadu State.

Remote-sensing is the science and art of obtaining information about an object through the analysis of data acquired by a device that is not in contact with the object (Lillesand and Keifer, 1994). Remotely sensed data can take many forms, including variations in force distribution, acoustic wave distribution or electromagnetic energy distributions, and can be obtained from a variety of platforms, including satellites, airplanes, remotely piloted vehicles, hand-held radiometers or even bucket trucks. They may be gathered by different devices, including sensors, film cameras, digital cameras and video recorders. Instruments capable of measuring electromagnetic radiation are called sensors.

1.7.1. Geographic Information System

A Geographical Information System (GIS) can be defined in a broad sense as a collection of hardware, software, data, organizations and professionals for the purpose of representing and analysing geographic data. A GIS references real-world spatial data elements (also known as graphic or feature data elements) to a coordinate system. These features can usually be separated into different thematic types (for example, soils and meteorological data). A GIS can also store attribute data, which contain descriptive information pertaining to the map features. This attribute information is placed in a database that is separated from the graphics data, but linked to them. A GIS allows the examination of both spatial and attribute data at the same time. Also, a GIS lets users search the attribute data and relate them to the spatial data, and vice versa. Therefore, a GIS can combine geographic and other types of data to generate maps and reports, enabling users to collect, manage and interpret location-based information in a planned and systematic way. In short, a GIS can be defined as a computer system capable of assembling, storing, manipulating and displaying geographically referenced data.

1.8. Review of Literature

1.8.1. Rainfall

Throughout the history, climatic impact on agriculture is a great puzzle to farmers, researchers and scientists. Only during the past one decade, agro - climatic studies for agricultural development constitute as the central components of Green Revolution. Many attempts had been made on the systematic analysis of this impact – resulting mainly crop production systems and delineating agro - climatic zones. There are number of studies available regarding climatic variables and crop system/pattern.

Climatic impacts on various activities are carried out on macro levels. Many attempts have been made on systematic analysis of rainfall and its reliability. There are number of studies available regarding rainfall distribution, periodicity and rainfall variability.

Amani K. Z, (1966) analyzed variability of rainfall and its relation to agriculture. Balasubramaniyam. C, (1954, 1959) studied rainfall pattern in central zone of Chennai State and in Nagarcoil and Nanjanad and its significance in agriculture.

Ahmed Rasheed, (2010) discussed the two distinct seasons in the Maldives, namely Northeast monsoon and Southwest monsoon. However the duration of these two seasons differ from north to south. The above graphs show that the Northeast monsoon (dry season) over northern atolls extend from January to April for a period of about 4 months, but as we move from north towards southern atolls, the length of this dry period reduces for about 2 months from February to March. Normally southwest monsoon (wet season) onset to southern atolls by 1st week of May and gradually progress to north and gets fully established over the country by the last week of May.

Bishnoi . O.P, (1975 and 1977) studied reliability of rainfall and its deficiency and excess in Hariyana State and by analyzing rainfall and its utility in crop planning, the author highlighted the importance of rainfall.

Khambate .M (1979) analyzed characteristics of short period of rainfall and its importance in Gujarat. Malik .A.K. (1972) studied rainfall deficiency and its hazard in crop plannings. Parthasarathy. P. (1976) studied the trend and periodicity in the seasonal and annual rainfall. A studies on the of 50 years of rainfall of Madras city, by Ramakrishnan (1953) and rainfall regions of Vellore by Ramamurthy K. (1950) have highlighted the rainfall distribution pattern and its reliability.

Several similar studies have been carried out in India by Subrahanyam (1956, 1958, 1964, 1968, 1980), Malik (1961), Krishnan (1966), Raj (1973) and Subramaniam (1964, 1971) and others. Raman and Venkataraman (1970), Bishnoi (1975, 1978), George and Ramasashi (1975) have analysed the rainfall reliability and their probabilities and moisture storage in different cropping seasons. These studies gave a proper assessment of moisture storage and rainfall reliabilities for better agricultural management and cropping pattern.

Amalkumar Sen (1976), Rakhecha (1974), Mallik (1972), Subrahmanyam and Subramaniam (1964), Subramaniam and Ramasamy (1972), Rammohan (1978), and Padmanabha Murthy (1972) have studied the application of Thornthwaite and Mather's (1955) water balance concept for the climatic study of drought and its impact on crops and their yields. They have used Palmer's aridity index, climatic index and Thornthwaite's moisture indiex and brought out different climatic zones and analysed the drought severity of different seasons.

Studies by Stenhill (1961), Parthasarathy and Rakhecha (1972), Atar Singh (1979), Bishnoi (1977), Ratnam (1975) also assessed the water availablility – water surplus or water deficit during different crop growing seasons, by using monthly and weekly water balance techniques of Thornthwaite and Mather (1955) and Penman.

Studies on optimum rainfall for sowing by Ramana Rao (1978), the effective rainfall by Bishnoi (1975), weekly water availability to crops by Srinivasamurthy (1973), Murthy (1982) and Malik (1972) explain the need for better analysis of climate in relation to crop production in India.

Among the climatic elements the amount of rainfall received has always been considered to be one of the most important factors of the climate of an area, particularly in a country which dependent on agriculture and with rainfall as precarious as that of India (Walher, 1972).

Ramamurthy (1943) and Balasubramaniam (1958) ascertain that the calendar months are the unit of interval of time for rainfall studies. However, the calendar months are altogether discarded and the unit of interval of 5, 7 or 25 days have been substituted.

Panabokke (1979) delineated agro - ecological zones of the south and South East Asia. He has considered rainfall and soil grouping as factors for the classification.

A modified method with due consideration for the physical cultural and water availability characters is suggested by Murthy and Pandey (1978) to delineate agro-ecological zones. They have incorporated the regional imbalances also.

Kusre. B.C, Singh Kh.S, (2012) have attempted analyzes the spatial and temporal variation of rainfall in Nagaland state of India. The state is mainly dependent on agrarian economy and thus knowledge of rainfall distribution in space and time is of significance for agricultural planning. The analysis of rainfall showed that there exists a wide variation in the rainfall amounts with variation from 859 mm to 2123 mm. Annual rainfall pattern indicates that northern part receives higher rainfall as compared to eastern and western side of the state. Similarly for July and monsoon season northern side receives higher rainfall.

Rama Rao (1978) estimated the optimum rains for sowing and their occurances. Rama Rao, in his study considered a period with one week on either side of the sowing week as the optimum sowing period and the amount of at least 20mm rain is desired.

Amani (1966) studied the variability of rainfall and its relation to agricultural activities.

Bishnoi (1975 and 1977) analyzed the reliability of rainfall and its excess and deficiency periods in Haryana state and stressed the importance of rainfall for crop planning.

Parthasarathy (1976) studied the seasonal, annual, periodicity and trend of rainfall in India and explained the importance of seasonal and annual rainfall. Rajendra (1974) Ramakrishnan (1953), Ramamoorthi (1950), were attempted to study the rainfall and its periodicity, distribution and reliability in Maharastra, and Chennai areas respectively.

Ishappa Muniyappa Rathod and Aruchamy .S (2010) have revealed that the windward of the western ghat region has high intensity in rainfall during monsoon season.

These places Valparai, Upper Niradam, Aliyar Nagar, Attakatti, and Nallar colony exhibit very high intensity in rainfall during Northwest monsoon season and Upper Niradam may be treated as the wettest point in the region and it is located in the tip of the Anaimalai hill of western ghat and the Palaghat gap and eastern region experiences the highly deficits in the rainfall intensity. The northeast monsoon gives complete stabilized rainfall for the entire region which helps the agricultural activities in the region.

Ishappa Muniyappa Rathod, Aruchamy .S, (2010) concluded that the analysis of region heavy rainfall experiences towards the south and southwestern part and north western part in summer, Southwest monsoon and northeast monsoon season and huge amount of deficit in the east, north east and gradually in southeast part and central part of the district. The southwest monsoon contributes the highest percentage of rainfall, which is 46.13% (573.2048 mm), north east monsoon 36.82% (457.4909 mm), summer 14.97% (186.0131 mm) and winter season contributes the lowest of which is 2.07 % (25.7851 mm),

Alaguraja .P, Manivel .M, Nagarathinam .S .R, Sakthivel. R and Yuvaraj .D (2010) conclude that the rainfall is low during January and February months. July, August and October months receive maximum rainfall. The rainfall is comparatively low during December. The analysis of rainfall variability also reveals that the variability is maximum during winter season followed by hot weather.

Sadhuram .Y. Ramana Murthy, T. V. (2008) reveal that the rainfall during 2002 and 2004 could be predicted accurately from the present model. It is a well known fact that most of the dynamical and statistical methods failed to predict the rainfall in 2002. However, as for associations between SST and ISMR, the index is quite susceptible to inter decadal fluctuations and markedly reduced skill is found in the decades preceding 1983. The RMS error for 24 years is 5.56 (% of long period average, LPA) and the correlation between the predicted and observed rainfall is 0.79.

Genesis Tambang Yengoh, Frederick Ato Armah, Edward Ebo Onumah and Justice O. Odoi (2010) have conclude that the uncertainty in measurement and estimation affects the quality of decision making in agricultural and climate policy framing. Thus, the long-term climate policy framework should necessarily address the spatial variability of rainfall.

Guhathakurta .P and Rajeevan .M (2006) have reported that the newly constructed rainfall series is uniformly distributed throughout the country and the represents all the existing districts. Though Indian monsoon rainfall as a whole does not show any significant trend, significant rainfall trends are observed over some specific areas. Present study brings out some of the astonishing significant changes in the rainfall pattern of the country. The alternating sequence of multi-decadal periods of thirty years having frequent droughts and flood years are observed in the all India monsoon rainfall data.

Pai Jyoti Bhate, D. S. Sreejith. O. P. and Hatwar. H.R. (2009) conclude that the summer monsoon rainfall over India exhibits strong intraseasonal variability. Earlier studies have identified Madden Julian Oscillation (MJO) as one of the most influencing factors of the intraseasonal variability of the monsoon rainfall. In this study, using IMD high resolution daily gridded rainfall data and Wheeler – Hendon MJO indices the composite rainfall anomaly analysis associated with the various Phases of MJO revealed the strong intraseasonal variation in the spatial rainfall anomaly distribution over India. During MJO Phases of 1 and 2, break monsoon type rainfall distribution was observed over India.

Rajeevan .M and Jyoti Bhate (2008) discussed the development of a very high resolution daily gridded (0.5 X 0.5 degree resolution) rainfall data for the Indian region for the period 1971-2005. The data set has been developed using daily rainfall data from more than 6000 stations from the country. During the monsoon season, there are significant intra-seasonal rainfall associations over the plains of India, known as active and break periods.

Rajeevan et. al., (2008) have proposed criteria of identifying the active and break periods based on the standardized daily rainfall anomaly averaged over the monsoon zone. It is well known that during the break periods, rainfall activity is significantly reduced over the country except over SE and NE India. The temperatures all over the country rise due to reduced rainfall and cloud uses. In order to examine the temperature anomalies associated with the monsoon breaks, average temperature anomalies associated with 9 break events in July and 14 break events in August have been calculated.

Pai Jyoti Bhate .D. S. Sreejith O. P. and Hatwar H.R. (2009) studied the impact of MJO on the Intraseasonal Variation of Summer Monsoon Rainfall over India. The composite rainfall anomaly analysis associated the various Phases of MJO and revealed strong intraseasonal variation in the spatial rainfall anomaly distribution over India. During MJO Phases of 1 & 2, break monsoon type rainfall distribution was observed all over India. Subsequently, as the MJO propagated eastwards, a gradual northward shift of the above normal rainfall band from south Peninsula to north India was observed.

Pai .D. S. Latha Sridhar, Pulak Guhathakurta and Hatwar .H. R. (2010) perceived that the drought climatology over India was examined both district-wise and all India wise using two drought indices, namely, Percent of Normal (PN) of rainfall and Standardized Precipitation Index (SPI). As the all India rainfall is significantly normally distributed, the years of all India drought (moderate and above) identified by both PN and SPI were almost the same.

Pattanaik D. R, (2012) revealed that the diurnal variations in rainfall over the Indo China region had three distinct peaks. An early afternoon maximum of rainfall occurred along the mountain ranges and on coastal land. Evening rainfall was observed near the foot of mountain ranges, in a valley, and in a basin-shaped plain; this rainfall weakened before the middle of the night.

Heavy rainfall in the early morning was found around the coasts over the eastern Gulf of Thailand and the Bay of Bengal, as well as over the eastern Khorat Plateau. It is seen that nearly half of the total rainfall occurred in the early morning over these regions, which indicated that early morning rainfall significantly contributes to the climatological rainfall pattern.

Guhathakurta . P. Preetha Menon, A. B. Mazumdar and Sreejith. O. P, (2010) revealed that the decreases in the number of rainy days over major parts of the country are also being observed in this study. However in the present case for the first time the analysis of frequency of wet days and the intensity of extreme rainfall was done by using maximum network of observing stations. This helps to bring out the smaller scales observed changes in frequency and intensity of rainfall.

Rajeevan .M and Pai D. S. (2006) studied the El Nino-Indian Monsoon Predictive Relationships. Their recent studies have suggested that the equatorial Indian Ocean Oscillation may be as important as ENSO in the interannual variation of the Indian monsoon (Gadgil et al 2004). El Nino and Asian monsoon are part of a complex coupled and mutually selective climate system (Webster and Yang 1992). It is clear that the Asian monsoon and the equatorial Indian Ocean Oscillation are not slaves to the forcing over the equatorial Pacific. They are mutually interactive systems.

Pai .D.S and Rajeevan .M (2007) have concluded their study states that the arrival of the monsoon over the region is noticed by wide spread persistent and heavy rainfall replacing the occasional pre-monsoon rains. In some years the MOK occurs in the middle of the month may itself.

Rajeevan, Sulochana Gadgil and Jyoti Bhate (2008) reveal a criteria to identify and monitor the active and break events during the Indian summer monsoon season on the basis of operationally derived rainfall data, which are available on real time basis. The identification of active and break events is based on the daily rainfall data averaged over the monsoon core zone which is coherent with respect to intraseasonal variation and over which large fluctuations of rainfall occur on this scale.

The interannual variation of the all-India summer monsoon rainfall (ISMR) is highly correlated with that of the summer monsoon rainfall over the core monsoon zone suggesting that it is a critical region for interannual variation as well as intraseasonal variation of the monsoon.

Ajit Tyagi, H. R. Hatwar and D. S. Pai (2009) have investigated the large rainfall deficiency during June and this is caused by the intrusion of cold and dry mid latitude westerlies into the regions which weakened the monsoon circulation and restricted the northward advance of the monsoon in June. The monsoon also took time to strengthen and advance over northern India as it was weakened by the Severe Cyclonic Storm "Aila" formed over Bay of Bengal just after the monsoon onset over Kerala. Moderate El Nino conditions prevailed over east Pacific from middle of the monsoon season resulting in large rainfall deficiency during the second half of the season. The absence of the northward propagation of monsoon trough over north Indian region caused reduced rainfall over entire north India.

Richard M. Cowling, Fernando Ojeda, Byron B. Lamont, Phillip W. Rundel and Richard Lechmere-Oertel (2005) studied the systems that accommodate for phylogenetic constraints, namely invasive species derived from mediterranean-climate ecosystems, as well as shared lineages, provide good opportunities to develop and test hypotheses on the implication of different rainfall reliability regimes. One of the novel implications of this study is that the distinctive trait of assemblages in the southern hemisphere regions may be a consequence not so much of their shared nutrient-poor soils as of their similarly reliable rainfall regimes .

Garavaglia. F, Lang .M, Paquet .E. Gailhard .J, Garc¸on. R and Renard. B, (2010) have assessed the reliability (in addition to the robustness) of estimated uncertainties. Such developments are currently investigated within the French National research project named Extraflo 2009–2012 (Extreme Rainfall and Flood estimation: design values for extreme rainfall and floods).

Jegankumar .R, Nagarathinam .S .R and Kannadasan .K (2012) have concluded their study states that the average mean rainfall of the study area is 844.49mm. The variability indicates the higher variability in winter compared other seasons. Similarly precipitation ratio is carried out to bring out the anomalies in the distribution, and the rainfall frequency is calculated to understand the occurrences. GIS is effectively used in this attempt to compute and produce maps.

Senthilvelan .A, Ganesh .A and Banukumar .K (2012) emphasized that the probability analysis is a very useful tool for making important decisions in agricultural operation. In this study, Markov Chain Model has been extensively used to study spell distribution. For this purpose a week period was considered as the optimum length of time. The present study has been carried out to find the probabilities of occurrence of wet week (W), wet week and the is proceeded by wet week (W/W) at different threshold limits of 10 and 20 mm. On the basis of the analysis the following conclusions are made: (a) the 3 and 31/2month varieties are best suited for Vettikkadu region; (b) 31/2 and 4 months paddy varieties can be successfully grown in Neivasal Thenpathi area and (c) 4 and 41/2 months paddy varieties are favourably grown in Orathanadu region.

Umamathi. S and Aruchamy. S, (2011) have discussed the mean annual rainfall variability of the watershed and estimated as 28.3%. The area in and around Suruli river watershed experiences high abnormality as the precipitation ratio is 185% whereas the lowest is about 44.4% at Sothuparai. The entire watershed is subjected to larger temporal fluctuations rather than the spatial distribution of rainfall.

Bimal Kumar Bhattacharya et.al (2011) have observed that a strong inverse exponential relation (correlation coefficient r 0.95, n=100) is found between annual rainfall and annual albedo over seven rainfall zones. The decreasing trend in snow-albedo of accumulation period (September to March) follows the declining trend in measured south-west monsoon rainfall between 1988 (980 mm) to 1998 (880 mm) over India. This finding perhaps suggests the possible reversal of reported coupling of increased snowfall followed by lower monsoon rainfall.

All the studies are carried out on macro levels and the various elements of rainfall are discussed thoroughly. An attempt is made have to bring out the existing condition of rainfall distribution & its variability in Tiruchirappalli district.

1.8.2. Groundwater

Several studies on groundwater analysis are carried out. Narayanaswami and Narashimhan (1987) carried out geological mapping of Noyyal basin. Nair (1965) Benget Tharangar (1969) carried out groundwater studies in Coimbatore district.

Cochine and Franquin's (WMO, Technical Report No.86) Method is the basis over which Krishnan (1986) has brought modifications. In Cochine and Franquin's method the precipitation and PE values are the components to estimate the water availability period.

Sathyaji Rao (2000) has studied groundwater table and hydrogeochemistry in and around Kakinada in 1996.

Ramalingam (2001) carried out the groundwater modeling in Kallar, Coimbatore district.

Usha Bhuvaneswari.N (2002) carried out a study on evaluation of groundwater suitability for irrigated agriculture in Noyal river basin

Selvam .G, Banukumar .K, Srinivasan .D, Selvakumar .R, and Alaguraja .P (2012) have concluded their study states that the movement and storage of groundwater is controlled by various terrain parameters. Hence geoscientists are employing various techniques to explore the potential zone of which Multi-Criteria Evaluation (MCE) technique seems to be more precise in demarcating the potential zone. Remote sensing and Geographic Information System (GIS) has proven as effective tools in mapping and modeling terrain features. The study area chiefly comprises of crystalline gneissic rock of Archaean age. Thematic layers are generated on geomorphology, landuse/land cover, lineament density etc.

Based on the potentiality to groundwater, weights were assigned to individual themes and ranks to features in each theme and by multiplying both, feature Scores are derived. The final integrated map is regrouped into five classes of groundwater potential zones as very good, good, moderate, moderately poor and poor.

Goyal .S .K, Chaudhary .B .S, Singh .O, Sethi .G .K, and Thakur .P .K, (2010) observed the variability in depth to water level below ground level. Groundwater development and rainfall from 1987 to 2007 in agriculture dominated Kaithal district of Haryana state in India. Spatial distribution of groundwater depth was mapped and classified into different zones using ILWIS 3.6 GIS tools. Change detection maps were prepared for 1987-1997 and 1997- 2007. Groundwater depletion rates during successive decades were compared and critical areas with substantial fall in groundwater levels were identified. Further, block wise trends of change in groundwater levels were also analyzed. The water table in fresh belt areas of the district (Gulha, Pundri and Kaithal blocks) was observed to decline by a magnitude ranging from 10 m to 23 m. In Kalayat and Rajaund blocks, the levels were found fluctuating in a relatively narrow range of 4-9 m. During 1997-2007, the depletion has been faster compared to the preceding decade. Excessive groundwater depletion in major part of the district may be attributed to indiscriminate abstraction for irrigation and decrease in rainfall experienced since 1998. Changes in cropping pattern and irrigation methods are needed in the study area for sustainable management of the resource.

1.8.3. Agro - climatology

Ramakrishnan (1930) and Misra (1963) are the well known persons in India those who studied the importance of the principal crops and physical environment on agricultural practices.

A few persons like Ayyar (1965) assess that many people in India contributed their valuable works in this aspect to the nation similarly, way in the field of cropping pattern, crop concentration and crop diversification of various parts of India, Ayyar (1965), Bhatia (1965), Singh (1967), Ahmed and Siddique (1967), Roy (1967), B.N. Sinha (1968), Mohammed and Amani (1970), Singh and singh (1970), S.C.Sharma (1971), T.C.Sharma (1972), Nityanand (1972), Musjid Hussain (1972), K.R. Dikshit

(1973), K.Bagchi and M.M.Tena (1974) and Sharma (1975) have contributed valuable articles.

Similarly in the western countries, Weaver J.C. (1974) and Coppock J.T. (1964) have contributed articles in the field of crop combination and cropping pattern.

Williams (1972), Smith (1972) and Nield and Greig (1972) had studied geographical variation in crops and climatic relationship and farming. Intheir study which they had analyzed the inter-relationship between crops and weather components in general by analyzing existing cropping pattern.

Amani (1966), Das (1972), Bishnoi (1978), Khambete and Venkataraman (1979) and National Planning Commission Report of India (1979) have thrown light on the importance and effect of weather factors on crop system/pattern in various regions in general by analyzing the cropping pattern in relation with single or multiple climatic variables. These studies have clearly indicated the variation in the natural elements control on cropping pattern in any specific area.

Another type of study relating climatic variables and soil characteristics with cropping pattern had been done by Muckhtar Singh (1972), Drishnan and Singh (1968, 1972) Jethmalani and Choubey (1972) and Saharabudhe (1972). They have analysed the cropping pattern with the climatic regions. Of the above authors Mukhtar Singh and Kanwar delineated different agro - climatic zones using the climatic index and moisture index of Thornthwaite and Mather and Palmer's aridity index. All these three indices were utilized to explain individual climatic elements along with this soil and crops were also considered for delineating the agro - climatic zones.

Krishnan and Tiwari (1977) have studied the weekly and annual adequacy of rainfall for crop growth in different areas. In this, they have analysed the probabilities of occurrence of optimum moisture to take up sowing for different crops by using Penman's weekly water balance method.

Many attempts were made to analyse the impact of climatic variables on individual crop yields. Moolani (1963), Shaha and Banerjee (1975) and Raheja (1961) have studied the rainfall as the factor controlling the crop yhield. Srinivasan and Banerjee (1974), Sreenivasan (1973) and Huda (1975) have analysed the influence of climatic elements on the yield of different crops like rice, sorghum, wheat, milltes, cotton etc. They have discussed the impact of intensity and distribution of various weather elements at different stages of crop growth.

Chatterjee (1972), Das (1972), Sen, (1966) and Sahu (1972) have studied the influence of climate on cropping pattern. In this, they have analysed climatic conditions and suggested suitable crop combination for their study area.

Studies on influence of weather on crops by Khambete and Venkataraman (1979) and assessment of crop drought by Venkataraman (1979) clearly proved that the variation in climatic elements definitely control the cropping pattern in any specific area.

Ramasundaram .M, Banukumar .K, Alaguraja .P, Yuvaraj .D and Nagarathinam .S.R. (2012) assessed that the principal crops and ranking of crops in Tamil Nadu to find out the crop combination regions in Tamil Nadu. The data collected processing and analzing by using simple statistics the results are cartographically represented. Weavers (1954) crop combinational analysis and Rafiullah's (1956) maximum deviation method of crop combination analysis, were applied finally the and crop combination regions of Tamil Nadu is brought out through using MapInfo, GIS software modules. The analysis shows that there is no diversification of cropping pattern in most of the districts of Tamil Nadu except the centre and eastern part of the state. The crop like paddy and pulses constituted as two crop region in Tamil Nadu.

Rimjhim Bhatnagar Singh et.al., (2012) made an investigation on ground based hyper spectral data collected for wheat crop residue and analyzed using Stepwise Discriminant Analysis (SDA) technique to select significant bands for discrimination.

Out of the seven best bands selected to discriminate between matured crop, straw heap, combine-harvested field LCA and CAI showed to be the best (F>115) In discriminating above classes, LCA and SINDRI were best (F> 100) among all indices in discriminating crop residue under different harvesting methods. Comparison of different spectral resolution (from1 nm to 150 nm) showed that for crop residue discrimination a resolution of 100 nm at 2100–2300 nm region would be sufficient to discriminate crop residue from other co-existing classes.

Choudhury .B .U, Anil Sood .S. Ray S, Sharma .P .K and Panigrahy .S (2012) have analysed the cropping system indices (area diversity, multiple cropping and cultivated land utilization) from remote sensing data. Analysis of remote sensing data, (2004– 05) revealed that rice and wheat individually remained the dominant crops and they occupy 57.8% and 64.9% of total agricultural area (TAA), respectively. Therefore, in the diversified plan, it is suggested that at least 39% of the current 40% TAA under rice–wheat rotation should be replaced by other low water requiring, high value and soil enriching crops, particularly in coarse textured alluvial plain having good quality ground water zones with low annual rainfall(<700 mm). This will reduce water requirement to the tune of 15, 660 cm depth while stabilizing the production and profitability by crop area diversification without further degradation of natural resources.

Rabindra K, Panigrahy S. Ray. S. and Panigrahy .S, (2009) have studied the discrimination of different Rabi season crops (rabi rice, groundnut and vegetables) and other vegetations of the undivided Cuttack district of Orissa state. Four dates multispectral AWiFS data during the period from 10 December 2003 to 2 May 2004 were used. The analysis was carried out using various multivariate statistics and classification approaches. Principal Component Analysis (PCA) and separability measures were used for selection of best bands for crop discrimination. The analysis showed the discrimination of the crops in the study area.

1.8.4. Agro-Ecological analysis

Jain (1972) and Saharabudhe (1972) have demarcated agro - climatic zones on the basis of distribution and amount of rainfall, temperature, soil, cropping pattern and natural vegetation.

Krishnan and Singh (1968) had divided soil climatic zones of India based on moisture regimes and major soil types of India. The above said studies clearly indicate how the climatological water balance budgeting method can be properly utilized for determining the potential and actual evapotranspiration, water deficiency and water surplus during different parts of the year/seasons/months taking into account the climatic element and soil factors.

Thornthwaite and Mather (1955) argues that moisture retention capacity vary from soil to soil. Field capacity of the different soils has been laboratorily estimated by agro - meteorologists throughout the World. For Coimbatore district the Department of Soil Survey and Land Use Organization, Government of Tamil Nadu had measured and recorded the necessary data. The climatic classifications by Koppen and Thornthwaite are mostly attempted on macro level regions. It is the most representative for zonation of large regions such as countries, states etc. For micro level area (like district units) its applicability is limited. Potential evapotranspiration has been defined as maximum quantity of water capable of being lost as water vapour in a given climate by continous stretch of vegetation covering the whole ground when the soil is saturated'

The (WMO 1966). Reported that the potential evapotranspiration is indicated by the abbreviation PE. Often it is not uncommon to use the abbreviation PET in the place of PE. The AE is the evapotranspiration as per availability of water to plants. Naturally its value in a field, where water is not freely available is depending on soil management and other agronomic practices and vegetative factors besides climate. AE is derived by the standard water balance techniques. When there is adequate moisture the actual evapotranspiration will be very high and may be even equal to potential evapotranspiration on the condition of saturation.

Field capacity for different soils has been estimated for climatic conditions of India by Subramaniam (1982) and Krishnan (1972) on the basis of Thornthwaite and Mather (1948). It may be pointed out that crop attains productivity optimum only when the soil moisture equals, the field capacity. So the soil moisture availability decides the irrigation scheduling both in quality and frequency.

Sathish .A and Niranjana .K .V (2010) carried out a study on using remote sensing data along with field survey and laboratory analysis for assessing the potentials and limitations of soil. Using the basic information on soil, climate and topography based on the matching exercise between the growth and production requirements of the crop, suitability of soils for groundnut, paddy and finger millet was assessed as per FAO land evaluation. The soil suitability maps were prepared using Arc GIS software. About 48 % of the total area was moderate to marginally suitable and 13 % of the area was not suitable for both groundnut and finger millet. A low land area covering 12 % of the area was highly suitable, 15% was moderate to marginally suitable and 20 % was not suitable for paddy cultivation.

Rasheed .S and Venugopal .K (2009) reported that the basic theory of FAO framework for Land Evaluation was adopted to define the suitability of crops. Land quality details necessary for evaluating the agro-land suitability of crops and for delineating the agro - ecological units include the terrain, soil and climatic characteristics. Agro-ecological units map was generated by overlaying the agro-edaphic and agro - climatic map layers in GIS. The agro-land suitability map was generated by matching the crop requirement details with the land qualities. The results of the suitability evaluation, when compared with the current landuse statistics of these crops show that the area cultivated is less than the area suitable for these crops.

1.8.5. Integrated Analysis

Ayansina Ayanlade (2009) revals studied and the results of the integrated analysis as show that the rainfall varies both in time and space. Rainfall variability is very high in most of Northern Guinea Savanna (e.g. Yola, Minna, and Ilorin) with values of coefficient of variation (CV) between 26 and 49 % while in Southern Guinea Savanna, the CV is very low especially, in Enugu (9%), and Shaki (8%). These anomalies (such as decline in annual rainfall, change in the peak and retreat of rainfall and false start of rainfall) are detrimental to crop germination and yield, resulting in little or no harvest at the end of the season.

Suja Rose R. S and Krishnan .N, (2009) revealed that the remotely sensed data can provide useful information in understanding the distribution of groundwater, an important source of water supply throughout the world. In their study, the modern geomatic technologies, namely remote sensing and GIS were used in the identification of groundwater potential zones in the Kanyakumari and Nambiyar basins of Tamil Nadu in India. The multivariate statistical technique was used to find out the relationship between rainfall and groundwater resource characteristics. It has been found out that the groundwater not only depends upon rainfall, but also various other factors also influence its occurrence. Eight such parameters are considered, and multi criterion analysis has been carried out in order to find out the potential zones. Accordingly, it is concluded that the Kanyakumari river basin has more ground water potential, whereas the Nambiyar basin has less potential. Thus, surface investigation of groundwater has proved to be easier, time consistent and cheaper using the geomatic technologies.

Owor .M Taylor .R .G, Tindimugaya .C and Mwesigwa .D (2009) have observed the changes in the intensity of precipitation as the global warming is expected to be especially pronounced in the tropics. The impact of changing rainfall intensities on groundwater recharge remains, however, unclear. Analysis of a recently compiled data set of coincidental, daily observations of rainfall and groundwater levels remote from abstraction for four stations in the Upper Nile Basin over the period 1999–2008 shows that the magnitude of observed recharge events is better related to the sum of heavy rainfalls, exceeding a threshold of 10 mm day^{-1}, than to that of all daily rainfall events. Consequently, projected increases in rainfall intensities as a result of global warming may promote rather than restrict groundwater recharge in similar environments of the tropics. Further monitoring and research are required to test the robustness of these findings, but the evidence presented is consistent with recent modelling highlighting the importance of explicitly considering changing rainfall intensities in the assessment of climate change impacts on groundwater recharge.

Das. D (2011) states that the drainage and lineament characteristics of a watershed provide important clues about the hydrogeology of the area. Information about the above characteristics is derived from satellite imageries (IRS-IB) aided by field verifications and subsequently analyzed in Geographical Information System (GIS) environment in fact this can provide a composite map and this can be used for adopting a suitable strategy for managing watersheds in a better way particularly in relation to the augmentation of the status of groundwater by artificial recharge methods. On the basis of the above concept, drainage, lineament and hydro - geomorphic study of the upper catchment area of Kumari basin, Purulia, eastern India have been performed for demarcating prospective sites for construction of artificial recharge structures. Granitic lithology and uneven topography indicate that the surface run-off is high and infiltration is low and therefore groundwater recharge is inadequate in the area. So, mainly to keep the irrigation practice and drinking water supply alive, groundwater condition has to be improved by artificial recharge method. Integrating different types of thematic layers like drainage density, lineament density, hydro - geomorphology in a GIS environment, it has been possible to generate a composite map showing prospective sites for construction of artificial recharge structures.

Forkuor .G, Pavelic .P, Asare .E and Obuobie.E, (2013) studied the modelling potential areas of groundwater development for agriculture in northern Ghana using GIS/RS Comparing the two main hydrogeological environments, the Precambrian Basement rocks (PCB) area was found to have a higher groundwater development potential than the Voltaian Sedimentary rocks (VSB). More detailed investigation reveals that the VSB can produce a small proportion of exceptionally high-yielding boreholes which can support large-scale irrigation. A test of the reliability of results showed that generally, the majority of high- and low-yielding boreholes fall in these areas predicted by the model as having high and low groundwater availability, respectively.

Samta Shah and H. J. Dalwadi (2011) conclude that the water supply and use data to determine crop water consumption and irrigation performance. Energy balance techniques using remote sensing data have been developed by various researchers, and can be used as a tool to directly estimate actual evapotranspiration that is, water consumption. Study demonstrates how remote sensing-based estimates of water consumption and water stress combined with secondary agricultural production data, which provide better estimates of irrigation performance, water productivity. A principle benefit of the approach is that it allows identification of areas where agricultural performance is less than potential, there by providing insights into how irrigation systems can be managed to improve overall performance and increase water productivity in a sustainable manner. to demonstrate the advantages.

1.9. Aim and Objectives

The main aim of the study is to evolve suitable crops and cropping activity based on rainfall and groundwater reliability for Tiruchirappalli district. To achieve the foresaid aim, the objectives considered are:

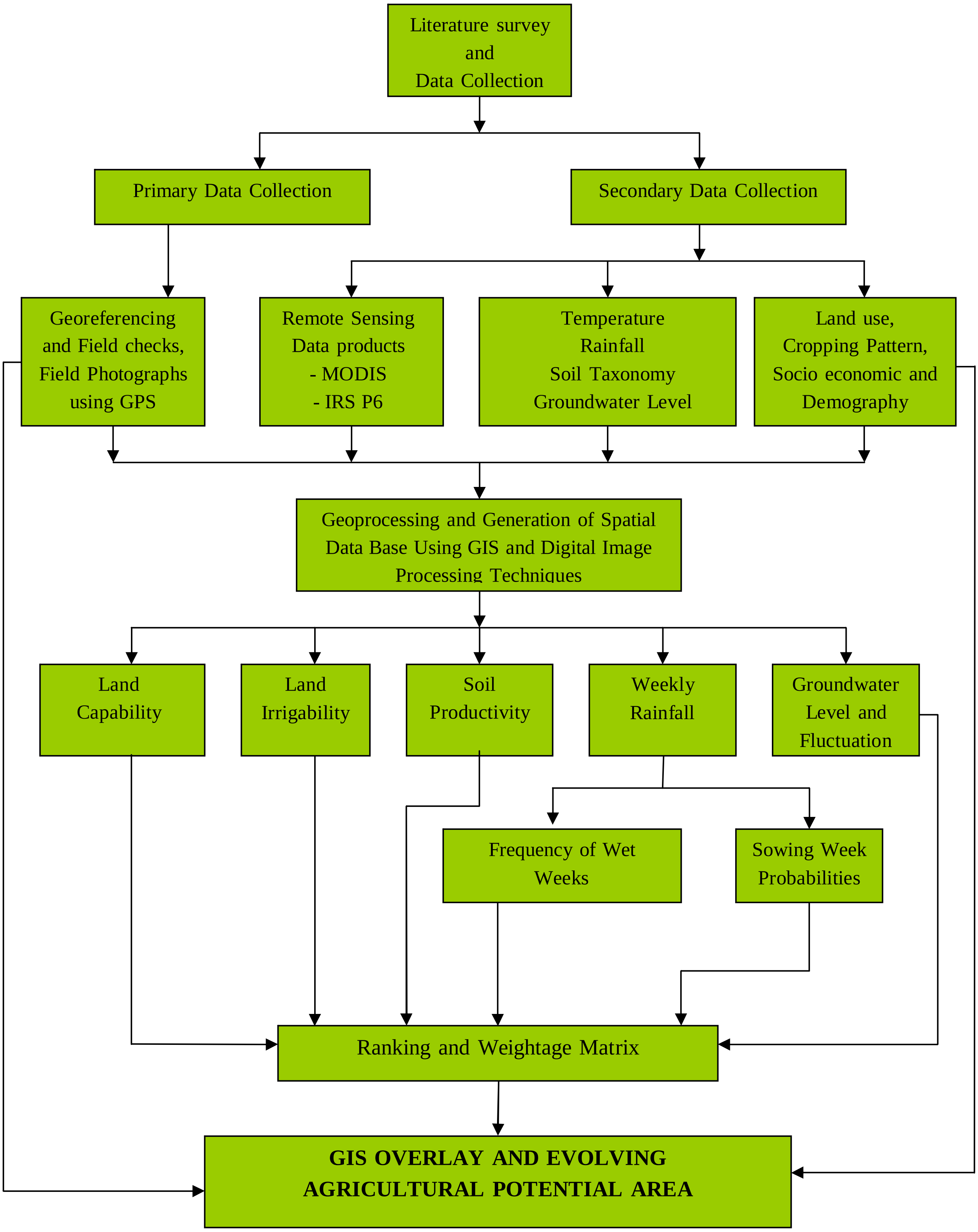
1. To analyse the spatio-temporal characteristics of rainfall.
2. To find out the groundwater level, fluctuation and recharge in association with rainfall
3. To identify the probable areas with reliable rainfall and groundwater for cropping activities of the district.
4. To evolve suitable cropping pattern and cropping activities accordingly.

1.10. Data Sources and Methodology

After having set up the objectives of the study, primary and secondary base line data have been collected from the published and unpublished reports / data of different departments and analysed in order to understand the existing condition of the study area in detail on various physical, economic and social attributes. The base map of the study area has been prepared by Survey of India topographic sheets on 1: 50, 000 scale. The sequences of techniques used to fulfill the above objectives are as follows:

- The data on mean monthly air temperature and rainfall were collected for 13 stations of Economics and Statistics Department in Chennai Indian Meteorological Department for a period of 32 years (1980 to 2011)
- Groundwater level and yield data have been collected for about controlled 60 wells of the district for the period of 22 years between 1990 and 2011from state groundwater and surface water resources data centre, Public works Department (PWD)
- Soil, productivity, capability, crops grown and data on status of irrigation are have been collected from Directorate of Agriculture, Tiruchirappalli.
- Land use maps have been prepared using IRS P6 LISS –IV satellite imagery acquired during 2013 from National Remote Sensing Center (NRSC) Maps on Geology, and these have been collected from Tamil Nadu Soil Department.
- These data are compiled, mapped and analysed. The data editing, interpolation, preparation of thematic layers and finally bring out put with proper cartographic visualization are made by using Arc GIS software and analysed using appropriate statistical techniques. Image processing tasks have been met out using Erdas Imagine 9.1. To finalize the study, limited field checks are made using GPS.

METHODOLOGICAL FLOW CHART



1.11. Organisation of the Thesis

The thesis consists of seven chapters. In the **first chapter,** is introductory which defines the problem and procedure drawn from a careful review of literature on related aspects. The relevant literatures were reviewed to identify the relative position of rainfall reliability and groundwater for crop suitability in several countries that has been implemented and also to draw lessons for present study to implement it with minimum environmental disturbance and streets. In addition, the first chapter also includes the objectives of the study, methodology, database and techniques used. The **Second chapter** portrays the study area, its location, administrative units, physiography, geology, geomorphology, soil, climate, land use and socioeconomic conditions. **Third chapter** deals the spatiotemporal distribution and reliability of rainfall of the district. **Chapter Four** focuses on the groundwater level, fluctuations and recharge and impact of rainfall on it. In the **Fifth chapter** agro-physical parameters such as soil capability, productivity, irrigability and existing landuse / cropping pattern were evaluated. In the sixth chapter the rainfall, groundwater and soil have been evolved by integrating using GIS to identify the potential areas for agriculture. **The Seventh chapter** summarises the findings and suggestions.