CHAPTER III
LITERATURE REVIEW

3 General

This chapter includes relevant review works on study area, crop selection, GIS/RS work with AHP technique for conducting soil nutrient based land suitability evaluation.

3.1 Agriculture in West Bengal

Agriculture is undoubtedly the backbone of the state of West Bengal, as the lion's share of the State's massive population depends directly or indirectly on it. West Bengal has nearly 3 % of the nation's cultivable land and about 8 % of the country's population. It produces more than 8 % of the food of the country. The importance of agriculture in the state's economy is reflected by its contribution of about 20.69% to the total Net State Domestic Product (NSDP) and 12 % share of agriculture in total Gross State Domestic Product (GSDP), (CSO, 2015). The agricultural sector is characterized by the predominance of small and marginal farmers tilling more than 68 per cent of the total operated area of the State. Cropping intensity in the state has also been upgraded from 131 % to 162 % in the last couple of decades. The State has sound food grains and cash crop production and it ranked first in production of rice (15.75 Million tonnes) and jute & mesta (7.78 million bales) in the country during 2015-16 (Directorate of Economics & Statistics, DAC&FW, 2016). There is also remarkable development during the last one decade in the production of oilseeds which increased from 0.24 to 0.55 million tonnes during the last decade. Additionally, potato production is ranked 2nd with a contribution of 28% in India. West Bengal also produces more than 60 % of the country's raw jute fibre. The State has increased rice production by 3 % per annum and oilseeds production 12 % per annum in the last decade (Calcutta yellow pages, 2017). West Bengal is one of the major agricultural states and agriculture driven economy in India (Table 3.1).

Table 3.1: Major crop production statistics in West Bengal (1980-2007).

Crops	1980-81	1990-91	2000-01	2006-07
Rice	13.9	14.1	14.6	15.9
Wheat	1.3	1.0	1.5	1.1
Pulses	2.3	1.4	2.0	1.1
Total food grains	6.4	6.4	7.0	7.4
Oilseeds	5.3	7.1	10.8	6.9
Jute & Mesta	57.6	60.1	71.2	74.7
Potato	20.4	29.5	34.7	N.A

Source: Government of West Bengal, Economic Review 2007-08.

3.1.1 Statistics of major crops in West Bengal

In West Bengal, yield growth in agriculture, particularly in food grain production, contributed significantly to overall economic growth of the state since the early 1980s. Agricultural growth has a significant impact on poverty reduction (Ravallion and Datt, 1996). The growth rates of rice production is highest as compared to the major rice producing states in India. West Bengal has been the leading jute and potato producing state in India for last decade. There is significant growth in area, production and yield of major crops in West Bengal during 2009-2016 (Tables 3.2) and there is change in level significant during 1981-2006 (Table 3.3).

Table 3.2: Production, area and yield of major crops in West Bengal (2013-2016)

Crops	State	Area (Million ha)			Production(Million Tons)			Yield (kg/ha)		
		2013-2014	2014-1015	2015-2016	2013-2014	2014-1015	2015-2016	2013-2014	2014-1015	2015-2016
Rice	West Bengal	5.51	5.39	5.46	15.37	14.71	15.75	2788	2731	2883
	India	44.14	43.86	43.39	106.65	104.80	104.32	2416	2390	2404
Potato	West Bengal	412.25	412.20	427.00	9030.00	12027.00	8427.00	21904	29178	19735
	India	1973.19	2068.95	2133.58	41555.38	45950.85	43769.56	21060	22210	20515
Jute & Mesta	West Bengal	0.57	0.58	0.55	8.88	8.92	7.78	2785	2788	2526
	India	.084	0.81	0.78	11.69	11.45	10.47	2514	2551	2416

Source: Directorate of economics and Statistics, DAC & FW, Agriculture Statistics at a glance 2016.

Table 3.3: Major food crops growth trend in West Bengal (1981-2006).

Crops	Area (Million ha)			Production(Million Tons)			Yield(kg/ha)		
	1981-2006	1981-1990	1991-2006	1981-2006	1981-1990	1991-2006	1981-2006	1981-1990	1991-2006
Rice	0.5*	1.5*	0.0	3.5*	7.7*	1.8*	3.0*	6.2*	1.8*
Potato	4.5*	6.2*	3.4*	4.7*	9.0*	2.0**	0.2*	2.8*	-1.4*
Jute	1.1*	-1.9	1.1**	3.2*	1.8	2.9*	2.1*	3.7*	1.8*
Oilseeds	2.2*	5.4*	1.9*	4.3*	12.4*	3.4*	2.1*	7.0*	1.5*
Pulses	-2.6*	-3.0*	-0.6	-1.4*	-1.3	-0.5	1.2*	1.7**	1.1**

Note: * Significant at < 1% level, ** significant < 5% percent level , the rest are insignificant;

Source: Directorate of economics and Statistics, Agriculture at a Glance, GOI; Directorate of Agriculture, Evaluation Wing. Government of West Bengal. Govt West Bengal. Economic Review 2007-08.

3.1.2 Diversified crop production in West Bengal

Cropping intensity should help us to recognize this qualitative aspect of agricultural land use. The state of West Bengal is capable with an enormous range of agro-climates and soil types to support diversified agriculture vis-à-vis multidisciplinary farming systems. In this context, intensive rather multiple cropping assumed great significance. It became an effective tool in increasing total production from a single piece of land as it increases net cropped area indirectly. Cropping area and cropping intensity of West Bengal is required to analyze (Table 3.4). The cropping intensity which is the ratio of gross cropped area to net sown area along with the gross cropped area and net sown area of different district of West Bengal during 2010-2013 (Table 3.5).

Table 3.4: Agricultural productivity statistics of West Bengal (2005-13); (Base : Triennium ending crop year 1981- 82 =100)

Year	Area ('000ha)	Production (‘000ton)	Productivity (ton/ha	Cropping pattern	Cropping intensity (%)	Productivity per hectare of net area sown	Net area sown (ha)
2005-2006	114.5	232.9	203.4	130.7	120.4	244.9	95.1
2006-2007	115.3	227.0	196.9	133.8	121.2	238.7	95.1
2007-2008	115.7	251.9	217.7	134.7	121.7	264.9	95.1
2008-2009	117.4	225.8	192.3	134.1	123.4	237.4	95.1
2009-2010	113.4	267.3	235.7	134.1	120.1	283.1	94.7

2010-2011	103.5	253.9	245.3	138.7	115.4	283.1	89.7
2011-2012	110.5	252.5	228.4	131.9	118.4	270.4	93.4
2012-2013	112.2	268.1	238.9	132.5	120.0	286.7	93.5
2013-2014	114.3	265.4	232.2	136.2	121.6	282.3	94.0

Note: Net cropped area (in hectares), Cropping intensity (in percent).

Source: Evaluation Wing, Directorate of Agriculture, Govt. of West Bengal, State Statistical Handbook 2014 Compiled by : Bureau of Applied Economics & Statistics, Government of West Bengal.

Table 3.5: Cropping area and cropping intensity of Hooghly (2010-2013), ('000 ha)

Year	2010-2011			2011-2012			2012-1013		
District	GCA	NCA	CI	GCA	NCA	CI	GCA	NCA	CI
Hooghly	542.68	212.41	255	520.74	211.27	246	527.63	212.09	249
West Bengal	8832.35	4981.22	177	9352.95	5198.15	180	9458.68	5204.90	182

Note: GCA- Gross cropped area, NCA-net cropped area, and CI-cropping intensity

Source: Economic Review, Department of Agriculture Government of West Bengal (2012)

3.2 Land Requirements for Crop Growth

3.2.1 Concept of soil and land use

Soil is the basis of plant growth, also act as the basic natural resource in land use planning. It is the three dimensional body occupying the uppermost part of the earth surface. Soil is the main component of land (Vink, 1975). Land can be defined as the specific area of the earth surface, which is the assemblage of the biosphere, soil and other materials including atmosphere, Vegetation, water plant and animal population and the human activity acting upon it (Townshend, 1981).

An area of the earth's surface, including all elements of the physical and biological environment that influence land use. Land conditions necessary or desirable for the successful and sustained practice of a given land-use type. Includes crop requirements or plant growth requirements, management requirements and conservation requirements (FAO 1993). According to Vink (1975), land use is any kind of permanent or cyclic human intervention to satisfy human needs; for a complex of natural and artificial resources which together are called "Land". The activities in land evaluation that are specifically concerned with the land use comprise two: description of the kinds of land use, and assessment of the land-use requirements. Crop-land suitability estimation is required to achieve maximum utilisation of the available land and resources to ensure sustainable agricultural production. The Food and Agricultural Organisation (FAO), (1976) through its framework for land evaluation (Soils Bulletin No. 32. FAO, Rome) recommended an approach for land suitability estimation for crops in terms of suitability indicators from not suitable to highly suitable based on climatic and terrain data and soil properties varying for crop to crop.

3.2.2 Soil series in West Bengal

The soils of West Bengal belong to 3 orders, 10 suborders, 19 great groups and 36 subgroups. It is observed that the Inceptisols are dominant soils followed by alfisols and entisols, and (Table 3.6) occupy 52%, 23% and 22% of the total geographical area of the state, respectively (NBBS & LUP, 1992).

Table 3.6: Distribution of soils in West Bengal (Order, Suborder)

Soil Order & Suborder	Area		
	% of mapped area		% of TGA (8.87 M ha)
Inceptisols	53.8		52.2
	Aquepts	36.1	
	Ochrepts	17.5	
	Umbrepts	0.2	
Alfisols	23.2		22.6
	Aqualfs	6.9	
	Ustalfs	16.2	
	Udalfs	0.2	
Entisols	22.9		22.2
	Aquents	6.3	
	Psamments	0.8	
	Fluvents	9.7	
	Orthents	6.1	
Miscellaneous areas			3.0

Source: NBBS & LUP,1992.

Sohan Lal et al. (1994) have described the Gangetic alluvial soils which belong to the Kanagarh series that is member of fine silty, mixed hyperthermic family of Aeric Fluvaguent, Kanagarh series soils have been developed on old flood plains of the Hooghly (the Ganges) river in Hooghly district at 5 to 10 metres above the mean sea level. Kanagarh series soil are deep, imperfectly drained, slow tot very permeable mildly alkaline fine soils of 12 to 20 meq/100gm cation exchange capacity, medium to high available water holding capacity and medium to high productivity potential. Mostly paddy, potato, jute and pulses are grown in them.

3.2.3 Soil fertility

Indian Institute of Soil Science, Bhopal (2005) has evaluated available N, P and K status of soils of ten districts (Darjiling, Jalpaiguri, Koch Bihar, North and South 24 Parganas, Hooghly, Nadia, Purba and Paschim Medinipur and Puruliya) of this State using GIS technology. Soil fertility map of different districts is prepared after categorization of area on the basis of percent sample falling in different categories (Figure 3.1).

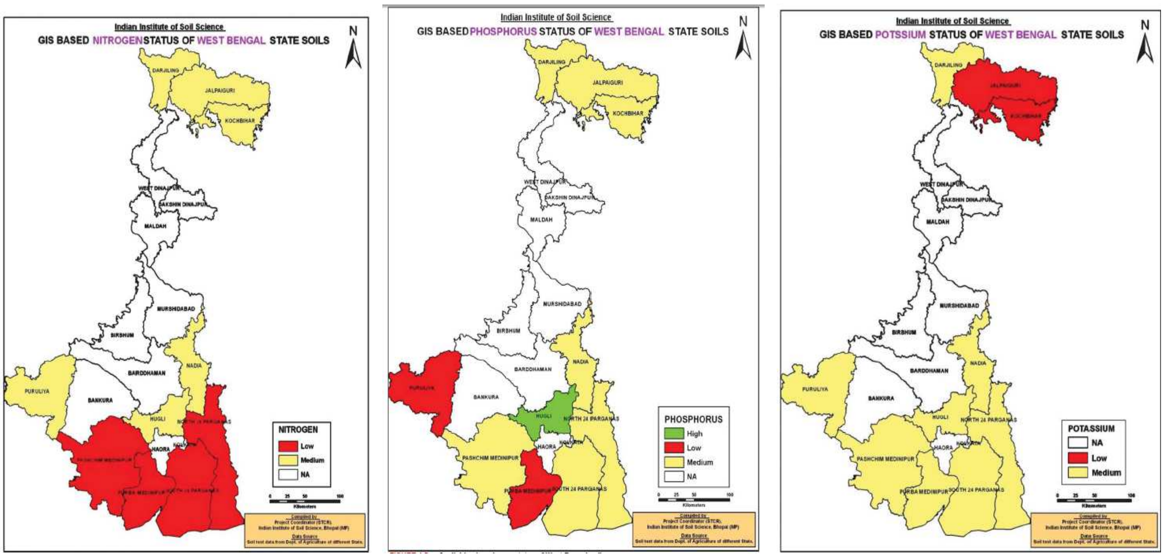

Figure 3.1: Soil fertility map of different districts in West Bengal. (Source: Indian Institute of Soil Science, Bhopal, 2005).

During triennium ending 2000-01, only Hooghly out of 4 districts in West Bengal were under high productivity group for crops **(**Anon**,** 2002).

3.3 Land Suitability Classification

3.3.1 Concept of land suitability classification

According to MacDonald (2006), the term “Land”**-** ground or soil of a specified situation, nature, or quality; “Suitability”- adapted to a use or purpose; satisfying propriety; “Analysis” **–** separation of the whole into its component parts, Based on the above term definitions, a land suitability analysis is the separation of the nature or quality of land into its component parts based on the land's capability to serve a particular use or purpose. Land suitability classification is generally refers to the fitness of a given type of land for a defined use either in present condition or after improvement. It is a process of appraisal and grouping of specific type of land in terms of their absolute suitability for a specified kind of use (FAO, 1976).

Baja et al. (2007) reported two general kinds of land suitability evaluation approaches: qualitative and quantitative. By qualitative approach, we can assess land potential in qualitative terms, such as suitable, moderately suitable, or not suitable. In the second approach, numeric indicators can be used for quantitative assessment of land suitability. Land use suitability is a generic term expressed as combination of factors and their impacts on potential land use. Land suitability assessment is therefore conventionally estimated by matching requirements of biophysical/ecological, socio-economic and environmental factors for the specific application with qualities and characteristics of land components (FAO, 1985).

Agricultural land suitability analysis is a primary requirement for achieving optimum utilization of the land resources available for inducing sustainable agricultural production system (Perveen et al., 2007). It includes the requirement of crop should be known or alternatively what type of soil and site attributes adverse impact on the crop. It also includes, identifying and delineating the land which contains the desirable attributes but with no undesirable ones. Land suitability evaluation for sustained crop production involves the interpretation of data relating to soils, vegetation, topography, climate etc., during an effort to match the land characteristics with crop requirements (Wang et al., 1990). Land suitability estimation involves evaluation of the various criteria ranging from terrain, soil to socio-economic, market and infrastructure etc. (Prakash, 2003).

Land suitability evaluation is formally defined as 'the assessment of land performance when used for a specified purpose, involving the execution and interpretation of surveys and studies of land forms, soils, climate, vegetation, and other parameters of land to identify and make a comparison of beneficial kinds of land use terms applicable to the goals of the evaluation (FAO, 1976).

Conceptually, land evaluation needs matching of the ecological and management requirements of suitability kinds of land use with land qualities, whilst taking local economic and social situations into account.

FAO (1993) proposed land evaluation in two broad classes, 'suitable' (S) and 'not suitable' (N). These two are further sub-classified into five suitability classes such as highly suitable,

suitable, marginally suitable, marginally unsuitable and permanently unsuitable etc. (Table 3.7).

Table 3.7: Land suitability classification for rain-fed agriculture (FAO, 1976;1983)

Order: Suitable				
S_1 class			High	no or non-significant limitations
S_2 class	S_2e sub-class	S_2e-1 unit	Moderate	moderately severe limitations which reduce productivity or benefits or increase required inputs
		S_2e-2 etc.		
S_3 class			Marginal	overall severe limitations; given land use is only marginally justifiable
Order: Not Suitable				
N_1 class			Currently not suitable	limitations not currently overcome with existing knowledge within acceptable cost limits
N_2 class			Permanently not suitable	limitations so severe that they preclude all possibilities of the given use

Note: Sub-class reflect different kinds of limitations. Letter symbols for some commonly encountered limitations are :Temperature regime (c), Moisture availability (m), Oxygen availability to roots (drainage), (w); Nutrient availability (n); Rooting conditions (r); Flood Hazard (f); Excess of salts (z); Toxicities (x); Potential for mechanisation (q); Erosion hazard (e). Different units of a sub-class reflect minor differences in production characteristics or management requirements.

3.3.2 Selection of parameters for land suitability

In modern agriculture use of required plant nutrients in crop production is very important to increase crop yield and maintain sustainability in the cropping system. Use of nutrients in crop production is influenced by soil, plant, climatic and social-economical situation of the farmers. The most significant technique to improve nutrient use efficiency are the use of effective source, adequate rate, timing, laboratory based soil testing methods of application. It is essential to improve the nutrient use efficiency in the farm in terms of economic and environmental point of view.

This suitability study is to estimate the overall land suitability for the crop in the study area. The major soil parameters affecting the crop growth are N, P, K, Zn, organic carbon, pH, soil texture and soil depth etc. Some factors could be neglected in the study due to their insignificant effect for the crop growth and crop cultivation has been practicing in the area for years. The merits of selection of the major parameters are as follows.

a) Available nitrogen

Plants to synthesize protein and chlorophyll, the green coloring matter of plants, which uses sunlight to create carbohydrates by the process of photosynthesis, usually use nitrogen. It increases stem and leaf area so has a direct impact on the growth and vigor of the crop. Nitrogen is the nutrient required by plants in the greatest quantity. The nitrogen concentration of plants ranges from about 0.5 to 5% on dry weight basis. Since most of the plants have comparatively higher nitrogen requirement and most soils cannot supply sufficient nitrogen to meet this demand.

b) Available phosphorous

Plants need phosphorous for strong root growth; fruit, stem and seed development; disease resistance; and general plant vigor. Phosphorous availability generally depends on warm soil temperature, range of pH and the levels of other nutrients, i.e. calcium and potassium present in the soil. Adequate P nutrition of rice is essential since it is required for energy storage and transfer within the plant. In addition to the metabolic functions, P has been observed to increase root growth and promote early maturity, straw strength, crop quality and disease resistance.

c) Available potassium

Potassium is required by plants in amounts second only to nitrogen. Unlike nitrogen and phosphorous, Potassium is not organically combines in soil organic matter. Different potassium – containing minerals, such as micas and feldspars are the principle sources of Potassium in soils. Potassium is also a major soil nutrient of plant. This nutrient plays an important role in plant growth and vigor by increasing crop resistance to disease, encouraging the growth of the root system, preventing lodging and enhancing starch formation (Swain, 2001).

d) Available Zinc

Plants require Zn in very small concentration for carrying out several important functions like photosynthesis, protein synthesis, seeding vigour, sugar formation, fight against stress and disease.

e) Soil texture

Soil texture is very important on land suitability classification because soil texture has a direct influence on the permeability and retention of moisture at various soil depths. Soil texture is important factor determining soil property which has great impact on agriculture. Soil - water and soil- air are dependent on soil texture which governs the growth of plants This is considered as a good indicator for the water holding capacity of the soil profile. The relative proportions of sand, silt and clay that determine the fineness of soil determine the parameter. The USDA recommendations on soil texture can be used for the process (USDA, 1980).

f) Soil pH

Soil acidity or alkalinity (soil pH) is important because it identifies how easily plants can take up nutrients from the soil. Brady (1974) described that the soil pH is defined as the negative logarithm of the hydrogen ion concentration. It determines the acidic and alkaline properties of the soils. The values below 7 are considered as acidic; values above 7 are counted as alkaline and 7 is neutral.

The purpose of managing soil pH is not to achieve a particular pH value, but to adjust the acidity level to the point where there are no toxic metals in solution and to maintain the availability of nutrients at its maximum. This condition is usually achieved when the soil pH is between 5.8 and 6.5; however some plants show special acidity requirements (Brady, 1974).

g) Organic carbon (OC)

Total organic carbon (TOC) is defined as the carbon (C) stored in soil organic matter (SOM). Organic carbon (OC) passes into the soil through the decomposition of plant and animal residues, root exudates, living and dead microorganisms and soil biota. Organic matter makes up only a small part of the soil. Even in small amount it is an important constituent of soil. It consists of several parts:

- The living microbes in the soil.
- Partially decade plant material and microbes.
- The stable material formed from decomposed plant and microbes.

SOC is the most important constituents of the soil due to its capacity to affect plant growth as both a source of energy and a catalyst for nutrient availability through mineralization process. SOC fractions in the active pool, previously described, are the main source of energy and nutrients for soil microorganisms. Humus participates in aggregate stability and nutrient and water holding capacity.

h) Electrical Conductivity (EC)

Soil Electrical Conductivity (EC) is the measurement, that integrates many soil properties affecting crop productivity. It influences the water content, soil texture, soil organic matter, depth to clay-pans, salinity, exchangeable calcium (Ca) and magnesium (Mg). Electrical Conductivity is a very quick, simple and inexpensive method that farmers and home gardeners can use to check the health of their soils. Whereas pH is a good indicator of the 'balance' of available nutrients in the soil, Electrical Conductivity can almost be viewed as the 'quantity' of available nutrients in the soil.

3.3.3 Soil morphological land suitability

Belder and Ali (1998) have studied land suitability of agricultural crops in central highland agricultural research station in Dhamar state in Western region of Yemen. Methodology developed was applied for studying suitability of wheat, potato, sorghum and barley. They found that very shallow (< 30 cm) layer soils are not suitable for agricultural crops and used for grazing and other applications. Shallow soils (30 - 50 cm) are found suitable for shallow rooting crops, such as, wheat, barley, and sorghum, while moderately deep (50 - 100 cm) layer soils are suitable for most of the crops including sorghum and potato.

Vasundhara et al. (2017) using cadastral mapping overlaid on Cartosat-1 (ortho corrected)+LISS IV imagery used as a base to characterize and classify land resources. Based on slope and elevation 3 physiographic units were identified, such as: i. Gently sloping lands (3-5%); ii. Very gently sloping lands (1-3%) and, iii. Nearly level lands (0-1%). Soil profile study was also undertaken to identify the potentials and problems of land resources. Based on morphological and physiochemical properties, 6 soil series were located and the study area was delineated for twenty five management units. Taxonomically, these soil series were classified under two groups; i. Alfisols (Typic Rhodoustalfs and Rhodic Paleustalfs) and, ii. Inceptisols (Typic Haplustepts). The site evaluation of the soils samples demonstrated that around 50% of the total watershed area is highly suitable for maize, onion, ragi, turmeric and banana. Also, more than 70% area found to be moderately to marginally suitable for groundnut and red gram due to texture limitation. Various land use options and suitable interventions were recommended based on the potential and limitations of the Singanallur micro-watershed area, Karnatak, India. It is also observed that soil structure and texture have an impact on crop response especially on growth of fruit tree and tuber crops are restricted due to hardening and compaction after soil drying in summer season.

Abu-Ghanem (2002) analyzed the soil in Albawn plain - western intermountain region of Yemen studying five profiles being classified into five soil subgroups and evaluated them for six irrigated crops (such as: peach, apple, barley, wheat and sorghum) on the basis of soil suitability for specific crops. The study showed that Vertic Hapluetolls and Typic Ustifluvents are very suitable for wheat, peach, sorghum and barley while Ustic torriorthents and Typic Torriorthents are moderately suitable for most of the selected crops. Chinchmalatpure et al. (1998) also evaluated soil site specific suitability of Wunna catchment area near Nagpur for predominated agricultural crops. The study identified that Entisols, the dominant soils on hill top, and erosional surfaces were unsuitable for pigeon pea and marginally suitable for sorghum crop, whereas Vertisols, the dominant soils on toe and concave slopes of the basaltic transect were highly suitable for sorghum, cotton and pigeon pea.

Geetha et al. (2017) satellite image along with toposheet was utilized for delineation of land forms and physiographic units. Soil horizon depth-wise soil samples were gathered from 19 pedons and analyzed for selective physical and chemical properties. Arecanut, mango, and sapota was suitable for nearly 69 % area and coconut were suited for 72 % area.

3.4 GIS Application in Land Suitability Evaluation (LSE)

3.4.1 Brief history

Evolution of GIS-based landuse suitability modeling and mapping is a mechanism for the progress of information technology in general and the geographic information technology in particular. The first systems we now call GIS were emerging in the 1960s, just as computers were becoming available to large Government organizations and academic institutions (Coppock and Rhind, 1991; Table 3.8). Released since early 1980s, ARC/INFO by ESRI, USA was one of the first GIS software to use the advantage of super-mini computer hardware system. The major characteristics of the system were, the successful adoption of a separate attribute and location information by combining the standard relational management system of database (INFO) in order to handle attribute tables and specific software to handle the objects stored in terms of arcs (ARC). Development of GIS applications in early 1980s has been expanded by the range of closely related available products of modern technology, including global positioning system (GPS), remote sensing, database management system (DBMS), computer aided drafting (CAD), as well as an increase of digitized data available to public and private organizations (Coppock and Rhind, 1991).

Table 3.8: Stages in GIS development and changing perspectives of planning

GIS development	Perspectives of planning	Landuse suitability analysis
Invitation (1950s–1970s)	Scientific	Computer-assisted overlay mapping
Integration (1980s)	Political	Cartographic modeling/MCDA
Proliferation (1990s)	Participatory/collective design	MCDA AI/Geocomputation Internet/Multimedia/Visualization

Aronoff (1989) stated GIS as a computer induced system which gives the units of capabilities such as data input and management (data storage, recovery and update), manipulation and spatial analysis followed by output generation to handle geo-referenced data. Rajan (1991) considered it as a system for information and storage, processing and retrieval activities that have relevant hardware and software designed specifically to be adopted with geographically referenced spatial data and corresponding attributes such as: table, charts and statistics etc. information. GIS has been defined with supply chain terminology (Schmitz, 2008) as a computer assisted system, being combined with accurate infrastructures, resources and proper management system, that acquires inputs from suppliers, checks inventory and warehousing through storage and retrieval of data, creates, adds value and delivers geographical and non-geographical data to the specified customers. GIS, which is capable in data integration and analysis and visualization, act as the main tool to support LSE approaches. The application of GIS in LSE is found well documented (Ball, 2002; Hoobler et al., 2003; Malczewski, 2004; Trung et al., 2006).

3.4.2 Components of GIS

3.4.2.1 *GIS functions*

GIS focus on 2 aspects of the system: i.e. technology and/or problem solving. GIS is conventionally accepted as a set of tools for the data input, data storage and retrieval, manipulation followed by proper analysis, and generation of required output. The technological benefits of GIS is defined as four system components: data input, data storage and management, relevant manipulation and specific analysis, followed by generation of output. Spatial data, that incorporated with the geo-referenced or features with positioning information on the earth. The data also represents the attributable data that can record representation of the features symmetrically. It may also incorporate the different stages of data verification, error measurement, editing, matching the edges, remodelling and generalization of relevant data (Burrough, 1986).

3.4.2.2 *Data models*

The relational data base management system (RDBMS) is one of the most applied approach for storing data and managing data in GIS software environment (Rigaux et al., 2002) relation called topology. One of the most common procedure for structuring the geography and geometry of the real world in the GIS software environment raster or vector data system is to utilize a layered structure (Heywood et al., 2002). The geo-spatial layers are major basis for coupling a set of maps displaying land use suitability for various land resources (McHarg, 1969). GIS system is equipped with systems for data manipulation and relevant analysis of attributed geo spatial data or tabular data. It has also the capabilities of structure conversion from grid cell to X-Y coordinate data (Burrough, 1986).

3.4.2.3 Data sources

The most common sources of spatial data in GIS-based work are comprised of one or multiples factors of the following: (a) mapsheets and plans, (b) surveys and/or (c) digital data products, (d) aerial photographs and remotely sensed images. Digitizing and scanning are the two basic techniques for integrating maps and attributes into a GIS software environment database. A field survey with questionnaire can be used as one of the alternative methods for collecting spatial data. The survey data can be in the form of a CAD drawing, consisting of thematic (layer) structure or complex block attribute structure of themselves. An important technology which simplified the surveying is the GPS receiver. Arial photography, low altitude remote sensing or satellite based remote sensing are the popular ways to gather spatial data (Treitz, 2003). Spatial data with geo-reference information are already in digital form may be acquired used from and by the private and/or public mapping outlets.

3.4.2.4 Data display

The primary function of GIS is also includes the preparation of graphs, maps, and tabular information sheets to publish in variety of output media. The output display media may include both hard copy materials (printed form) and hard ware devices (softcopy form) for output displays that include line printer, line plotter and removable hard drives, CDs etc.

3.4.3 GIS operations for land-use suitability modeling

Land-use suitability analysis based on GIS software approaches have their origins in the applications of manual overlay techniques used by American architects dealing with landscape in the later part of Nineteenth and beginning of Twentieth century. The computer-based overlay techniques and applications were introduced as a replacement to the manual method's constraints of mapping and encompassing large datasets (Steinitz et al., 1976). The integration of GIS techniques with MCDM methods has considerably advanced the conventional mapping and overlay approaches for getting better land-use suitability analysis (Banai, 1993; Eastman, 1997; Malczewski, 1999). For last two decades or so, handful types of multi-attribute (or multi-factor) estimation methods have been developed and used in the GIS software environment including Weightage Linear Combination (WLC) and the variants (Carver, 1991; Eastman, 1997), ideal vector point technique (Jankowski, 1995; Pereira and Duckstein, 1996), critical concordance analysis (Carver, 1991; Joerin et al., 2001), and analytic hierarchy process (Banai, 1993). However, multi-attribute technique, which is induced into the GIS-based land use suitability technique, is popularly known as Analytical Hierarchy Analysis (AHP) method (Saaty, 1980). This approach is more appropriate for use in the vector-based GIS and common suitability analysis (Jankowski, 1995). It is further noted that AHP is used as a consensus establishing tool in conditions involving asymmetric parameters for a committee or group making the decision (Saaty, 1980). Despite the widespread use of AHP, some planners and researchers question the theoretical applicability and scope of the method (Belton and Gear, 1983; Barzilai, 1998). However, agricultural land suitability will be beneficial with AHP based weightage assignment.

3.4.4 GIS applications

GIS is a tool for the management of information for natural resources assessment, environmental protection, agriculture, resource conservation and many other areas. GIS uses includes multi-disciplinary and multi dimensional activities including system approaches. Environmental research institute of Redlands, California, USA, used grid base GIS software environment for provincial development plan in the initial days of GIS development (Pauguet and Marble, 1990). A spatial model for LS assessment for rice (*Oryza sativa L.)* crop cultivation using GIS and supporting techniques (Dengiz, 2013), by two type of parameters such as: Nutrient Availability Index (N, P, K, Zn) and Soil Quality Index (Soil texture, soil pH, Depth, Drainage, Topography, Hydrologic conductivity, Electrical conductivity etc.). Jayasinghe and Machida (2008) designed an mutually interactive web-based GIS application for incorporating crop based land suitability analysis, that can effectively gives information on vegetables, such as: tomato and cabbage cultivation in Sri Lanka. Soil pH, average annual temperature, average annual precipitation and soil topography etc. were taken as most important criteria to evaluate crop-land suitability in Sri Lanka.

Chuong (2011) utilized GIS based technique to identify and classify the physical land suitability level for various crops to compare the ecological demands of that crop with the properties of each evaluated parcel of land. Land suitability classification generally includes the limiting factors affecting the crop growth, development and enhanced productivity of fruit crops in Central Vietnam. Biophysical variables, such as: soil texture, inherent moisture, surface drainage, depth, soil organic carbon, soil pH, land type slope, and supplementary water reserves etc. were taken into considered with the socio-economic factors in GIS environment analysing for land suitability evaluation wheat cultivation under irrigated condition in North-west Bangladesh and found that in the study area, nearly 34% of wheat fields were classified as moderately suitable areas, around 35% area was under marginally suitable areas, and nearly 31% area was under not suitable class (Perveen, 2008). The research work (Anasiru, 1999) for selecting suitable land for agricultural crop in Indonesia incorporated the GIS technique for dividing the land into 4 suitability classes, such as: highly suitable classes, moderately suitable classes, marginal suitable, and unsuitable classes.

GIS based information system for land suitability of economic crops integration at watershed level for supporting better agricultural land use planning. The land charateristics to be used in suitability analysis includes soil quality (S), water availability (W), Salt hazard situation (Sa), and terrain information (T). Each of these represents a thematic layer in GIS based database (Mongkolsawat and Paiboonsak, 2014). Land suitability assessment undertaken by the GIS tool for The Musa group (ABB Group) plantation including five environmental parameters - soil properties, supplementary water, topography, climate, marketing issues (Boonyanuphap et al., 2004). Girma et al. (2015) with help of GIS compared the land unit (LU) with relevant land characteristics (LCs) and land quality (LQ) data on soil, climate and topography with medium intensity survey methods were collected and the corresponding analysis was carried out after converting the relevant data into a usable and understandable format for the LE process to specify the physical land suitability for wheat, maize and sorghum crops in Jello watershed located under Chiro woreda following the FAO (1976) framework. The results demonstrated that out of 1650ha, around 6% area was classified as moderately suitable for wheat production, marginally suitable of 33% area and not appropriate of 61% area of the farm. Around 52% and 48% of the farm area was marginally suitable and unsuitable for maize crop, respectively. Also for sorghum crop, 33% of the total area was marginally suitable and the rest (67%) of the area was not suitable.

Thus, GIS has found wide applications and takers in land suitability evaluation studies. With the assistance of a GIS software system, Liu and Deng (2001) developed a land resources allocation system to precisely evaluate land suitability. Furthermore, using GIS, Wandahwa and van Ranst (1996) used land suitability evaluation criteria and successfully mapped altitude, climate, soil type, and ecotype etc. GIS, in combination with the mean of individual ratings from a group of experts, was also utilized to implement a land evaluation model (Kalogiroua, 2002; Liu *et al.*, 2003). In addition, GIS functions also helped to manage spatial data and to visualize evaluation results (Chen *et al.*, 2003; Wu *et al.*, 2004; Liu *et al.*, 2005) in quick time.

3.5 Remote Sensing and Applications

Remote sensing is the collecting and recording of information without any physical contact of the sensing person or equipment directly with the object. Generally remote sensing satellites are used to take the aerial photographs of the remote objects. These photographs are analyzed to produce the required results suitable for future applications. Remote sensing has been utilized to collect information about the geological features of earth, land-use and vegetation coverage, surrounding atmosphere, water bodies, and ice surfaces etc. (Lillesand and Keifer, 1987).

Images from Landsat TM and groundtruthing through extensive field visits the area were modeled for 40 land types in five zones based on altitude (foothills, valleys and gullies, hillsides and terraces, mid-mountain, and subalpine mountain). That showed the five suitability classes of agriculture, grassland, forest, scrub pasture , and farmland-woodland had altitudinal stratification total of 1151 km^2 (8.89%) of lands in the slopes of the Qinling Mountains could be reallocated (YanSui et al., 2006).

The ability to incorporate varieties of geographic technologies like GPS, GIS, Remote Sensing etc. (Krishna and Regil, 2014) took out the spatial distribution of agriculture oriented land suitability areas derived from satellite data in conjugation with estimation of different variables like soil, landuse, landform, geology and topographic information in GIS software context for Kannur district of Kerala.

AbdelRahman et al. (2016) assessed land suitability and its capability by integrating GIS and remote sensing for agricultural application in Chamarajanagar district of Karnataka, India. Using LISS III and LISS IV of IRS data with various land quality parameters, viz. slope, soil texture, depth, erosion, coarse fragments and flooding etc. under various land units were estimated for the relevant crops. Perveen et al. (2008) utilized a pixel-based measurement and a multi-scale object-based technique for agricultural land use classification with ASTER data in Sylhet district of Bangladesh. Supervised classification was performed with the Maximum Likelihood Classifier (MLC) under ERDAS Imagine software environment for land use distribution in a typical Bangladesh agricultural condition with its small-sized farm lands.

Remote sensing (RS) can provide the information of various spatial criteria and application under consideration. RS can supply us the information like land use/land cover, topography, drainage density etc. *(*Das, 2000). RS in combination with GIS software can be a powerful tool to make integration and interpretation of real world situation in realistic and transparent manner. Mashreki *et al.* (2010), carried out an assessment of land suitability evaluation for agriculture in the Republic of Yemen undertaking close examination of the parameters of land qualities and characteristics using 16 thematic maps, remote sensing satellite imagery data and GIS techniques. GIS and RS technology to arrive at land suitability distribution to support the sustainable agricultural development and planning (Nualchawee and Barcareza, 1996).

Kharif and *rabi* cropping patterns were proposed by integrating agricultural crop suitability maps for winter and summer seasons taking separately by the database on land use/land cover, soil series, precipitation, and temperature was generated from images derived from Landsat TM remote sensing satellite and soil survey series to carry out an integrated analysis in the GIS software environment. Results showed that present agricultural area of 47% could be enhanced to nearly 71% by implementing scientific land evaluation techniques for watershed development (Martin and Saha, 2009).

The ASTER sensor of NASA’s Earth observing satellite (EOS) Terra provides optical remote sensor images consisting of 14 spectral bands ranging from visible to thermal infrared region which evaluates the potential land use distribution in a typical Bangladesh agricultural environment with its small-spaced fields the different agricultural land cover types and a common problem of mixed pixels (Perveen, 2008). RS information can be incorporated and utilized in the GIS systems for better analysis purpose.

3.5.1 NDVI application in crop land suitability

The Normalized Difference Vegetation Index (NDVI) is and indicator to analyse remote sensing images for identifying vegetation level. It measures the activity of a chlorophyll, which is directly connected with growth and development and greenness of a plant, and soil site suitability. Tucker (1979) used the combinations of canopy reflectance values in different wavebands, vegetation indices (VIs), for monitoring the changes in vegetation level. The VIs used for such applications were the simple ratio (SR, Eq^n 3.1) and the Normalized Difference Vegetation Index (NDVI, Eq^n 3.2):

$$SR = \frac{\rho NIR}{\rho RED} \quad \text{... (3.1)}$$

$$NDVI = \frac{(\rho NIR - \rho RED)}{(\rho NIR + \rho RED)} \quad \text{... (3.2)}$$

Where, ρNIR and ρRED are the reflectance in the NIR and the red spectral region, respectively.

The potential of satellite based NDVI estimation for regional and global productivity estimation has been investigated by Box et al. (1989), who validated the previous findings of VIs being more closely associated with rate (productivity, FPAR) than state (LAI, biomass) variables. Tucker et al. (1985) also investigated total herbaceous biomass presence in the Sahel zone of North-Central Africa by evaluating the seasonal sum of the NDVI extracted from AVHRR data, and found to have sound correlations with biomass. Fritsch (2013) also used MODIS-based NDVI data, incorporation with adapted Light use Efficiency (LUE) modelling, for evaluating crop yield of rice and cotton crops at field (6.5 m resolution) scale and regional (250 m resolution) scale for a number of years (2003-2009), in order to assess variations in crop yield. Validation of the input data (satellite images) and the results (crop yields data) was essential for this type of approaches. The main hurdle was the vegetation-specific (LUE), which was derived for crop types on a local scale only. Ehammer et al. (2010) applied to averaged NDVI values, which produced the generation of multi-temporal and field-based fraction of photosynthetic active radiation (FPAR) based maps with correlation coefficient of 0.88 for cotton and 0.95 for rice, respectively.

Study on crop condition monitoring should be correlated with the study on crop yield. Decreasing trends of precipitation has directly affected crop areas and crop yield in the decreasing biomass (low NDVI values). People/farmers can highlight on judgments of the areas while investing agriculture for better crop yield (Lillelsand, 2004). In land evaluation prospects direct monitoring models means monitoring the crop situation by analyzing and developing the relationships between direct RS indices such as NDVI etc. (Dingshan, 1992; Groten, 1993; Hayes, 1996; Hua and Fang, 2008). Generally, green and healthy vegetation absorbs larger part of the incident visible spectrum whereas reflects a large portion of the near-infrared spectrum (Bakker et al., 2000). The unhealthy vegetation reflects more visible spectrum compare to near near-infrared spectrum (Yunhao et al., 2006). Singh (2017) identified agricultural areas in the Taba, Spain working with a GIS software and relating these delineated areas to NDVI caused by climate variations especially in precipitation.

John, (2017) used NDVI values for analysing land suitability for maize crop for 2000-2012 farming seasons in semi-arid Mberengwa Ward 36, Zimbabwe. Buhari (2014) used the NDVI analysis and ESRI ArcGIS software to investigate crop suitability geodatabase and modelling system for Sugar Cane crop in Nigeria, with both contemporary environmental data and legacy thematic information. He estimated nearly 75% of the land was classified ‘moderately suitable’ for sugar cane crop. The multi-criteria evaluation analysis with NDVI data was used to extrapolate and produce a crop suitability map displaying areas suitable for agricultural activities in Taita Hills, Kenya (Boitt et al., 2015). Landsat 8 images using NDVI estimation, derived vegetation layer of the developing suitability map for rice crop and overlaid to identify the variability between the current vegetation cover and the potential area suitable for rice crop. Relationship between suitability maps and current vegetation cover has also been computed and result predicts that there is inverse relationship between the density of vegetation growth and rice crop land suitability at Amhara Region of Ethiopia (Ayehu and Besufekad, 2015).

3.6 Multi-criteria decision making (MCDM)

MCDM procedures in GIS software incorporates the selection, combination and transformation of spatial and the spatial corrected data (input) to produce resultant decision (output) by giving relationships between inputs and outputs using decision support rules. Spatial MCDM also involves use of geographical data, decision maker's choices and required manipulation of data and preferences as per the specified decision rules. Multi-attribute techniques are the most widely followed methods as it is more straightforward as compared to multi-objective techniques which require handful effort in terms of programming algorithms and their integration with GIS software. Silva and Blanco (2003) have utilized Multi-Criteria Evaluation (MCE) approach to extract suitable areas for production of crops such as maize and potato within a GIS environment in Central Mexico. Soil databases, climate and relief were used to integrate GIS based raster coverage. A number of decision support programmes in the IDRISI GIS were applied to extract the suitability maps for all the crops. It was found that the crops, such as: maize and potato etc. production areas were situated under rain-fed agriculture, while the extent of irrigated agricultural areas were very little for maize crop and none for potato crop. They found that in valley zones very high suitability areas for maize were located, while for potato the very high suitability areas were located in the upper parts of mountain slopes having very good climate and soil properties for potato crop production. They concluded that Multi-Criteria Evaluation within a GIS (MCE-GIS) framework has the potential to extract suitable areas for crops, such as: maize and potato etc. for taking proper decisions in agricultural implementations.

Multi-attribute techniques are the most widely followed techniques as it is more straightforward than the multi-objective technique which require considerable work for programming mathematical algorithms and their integration with GIS framework. A number of multi-attribute technique have been incorporated in GIS environment with WLC and its variants applications (Carver, 1991; Eastman, 1997; Singha and Swain, 2016), ideal point technique (Jankowski, 1995; Periera and Duckstein, 1993), concordance analysis (Carver, 1991; Joerin et al., 2001) and Analytic Hierarchy Process (Banai, 1993). Among these approaches, the WLC and operations of Boolean overlay, such as: intersection (AND) and union (OR) etc. are considered the most simplified and most used techniques (Malczewski, 2004).

3.7 Analytical Hierarchy Process (AHP) and Application

Analytical hierarchy process (AHP) was first proposed by Thomas L. Saaty, University of Pittsburgh, Pennsylvania, USA in the early 1980s. It can be used as a tool for consensus building in situations involving a committee or group of decision-makers or planners (Saaty, 1980). AHP mentioned the detail procedure that seeks to incorporate the context of the spatial planning decision making by identifying and arranging the criteria into different classes (Vogel, 2008; Abdi et al., 2009). AHP mainly described by three clear-cut principles:

decomposition, comparative judgment followed by synthesis of priorities (Eldrandaly et al., 2005). It applies a hierarchy of factors, where each of the general factors is subdivided or composed of several contributing minor factors. It is based on pair-wise comparison for generation of relative matrix carrying the weightages. In this method, pair-wise comparisons are considered as input and relative weights are considered as outputs. The weightage values are also validated against its maximum ejenvector values.

By assessing the relative importance of each factors to evaluate the suitability of land for agriculture in Golestan, Iran using the AHP technique, indicated that after soil capacity parameters, slope and precipitation were second and third important factors, respectively, (Kamkar et al., 2014) for assessment of land suitability and the potential and performance of canole soybean. Joshi et al. (2011) used various soil parameters viz, soil texture, soil depth, slope, drainage, relief, erosion, soil EC, soil pH, coarse fragments etc. to derive land suitability using AHP and MCDM technology in GIS environment for the growth of selected crops namely, *rabi* sorghum and wheat crops, in Maharashtra India. They developed suitability map that allotted nearly 29% area under $S_1$for *rabi* sorghum crop, 25.6% and 16.19 % area under S_3 and N categories, respectively. For wheat crop, they allotted around 22.8% area under S_1 category and 19.4% area under N suitability categories, respectively.

Furthermore, the integrated approach of GIS and AHP methods used for identifying suitable agricultural land with the parameters, such as: great soil group (GSG), soil depth, elevation, land use capability class (LUCC), land use capability sub-class (LUCS), erosion level, and other soil properties (OSP) in Turkey (Akinci et al., 2013), and land suitability analysis for coffee in Vietnam (Duc, 2006; Jankowski, 1995).