CHAPTER 3

METHODOLOGY AND EXPPERIMENTAL INVESTIGATION

3.1 INTRODUCTION

The hyperspectral radiometric approach perhaps provides sufficient information about the characteristics and index properties of soils (chapter 2). Though it has been demonstrated about the ability of predicting certain index properties of soil through the works pertaining to study areas of different parts of the world, very little or no work related to Indian study sites has been reported in the literature. Accordingly the methodology adopted in this research involves collection of soil samples from different places of Tamilnadu, preparation of the soil samples, determination of the index properties of soil samples, spectro-radiometric measurement and analysis in the context of determining certain index properties of soils. Figure 3.1 provides an outline of the methodology adopted in this study.

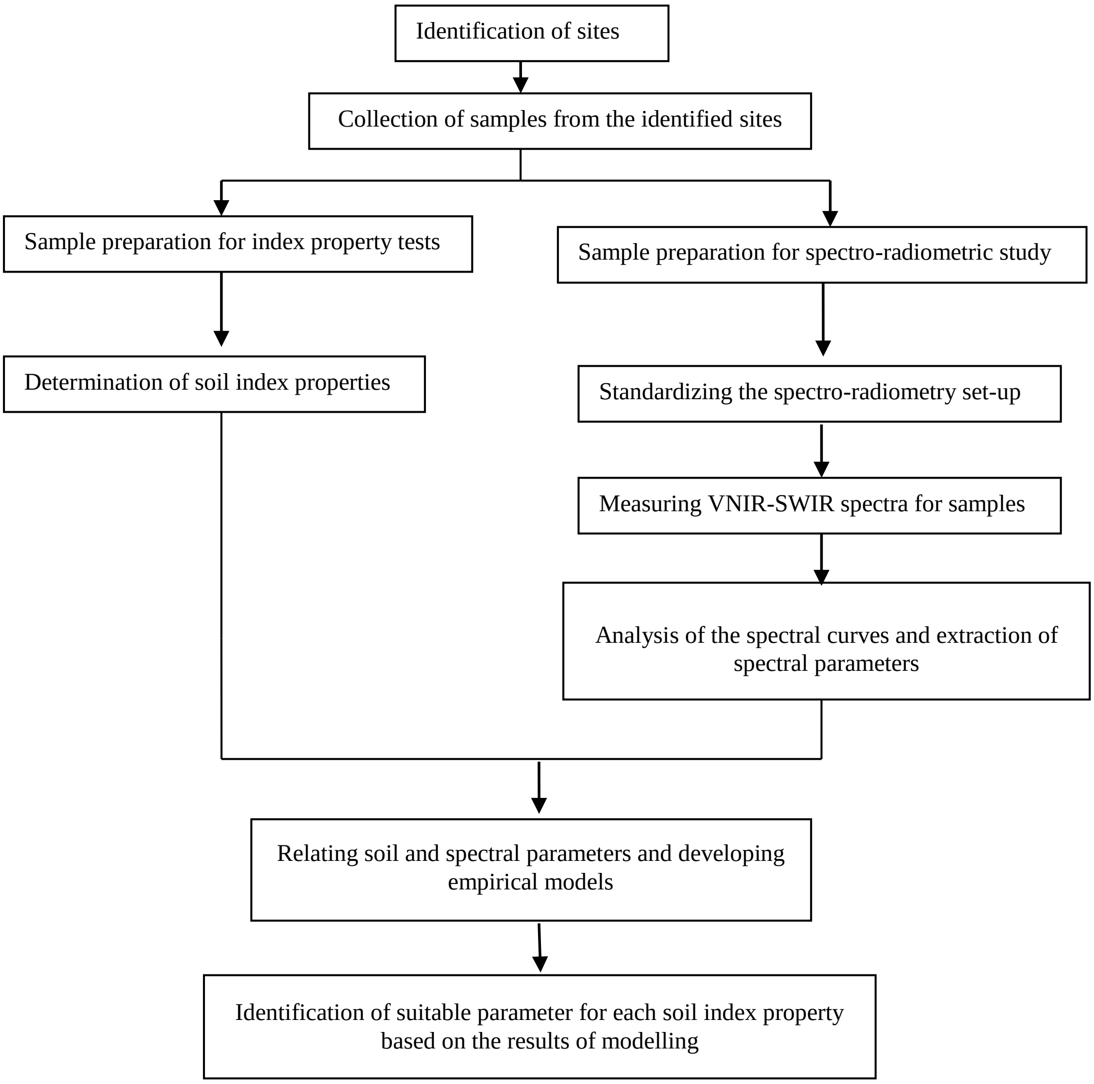

Figure 3.1 Outline of the methodology adopted in this study

3.2 SOIL SAMPLE COLLECTION

Since this research involves spectro-radiometric measurements for studying the index properties of soils, it is obvious that soils have to be collected from various locations. Soil samples were collected from a few locations within Tamilnadu, one of the southern states of India.

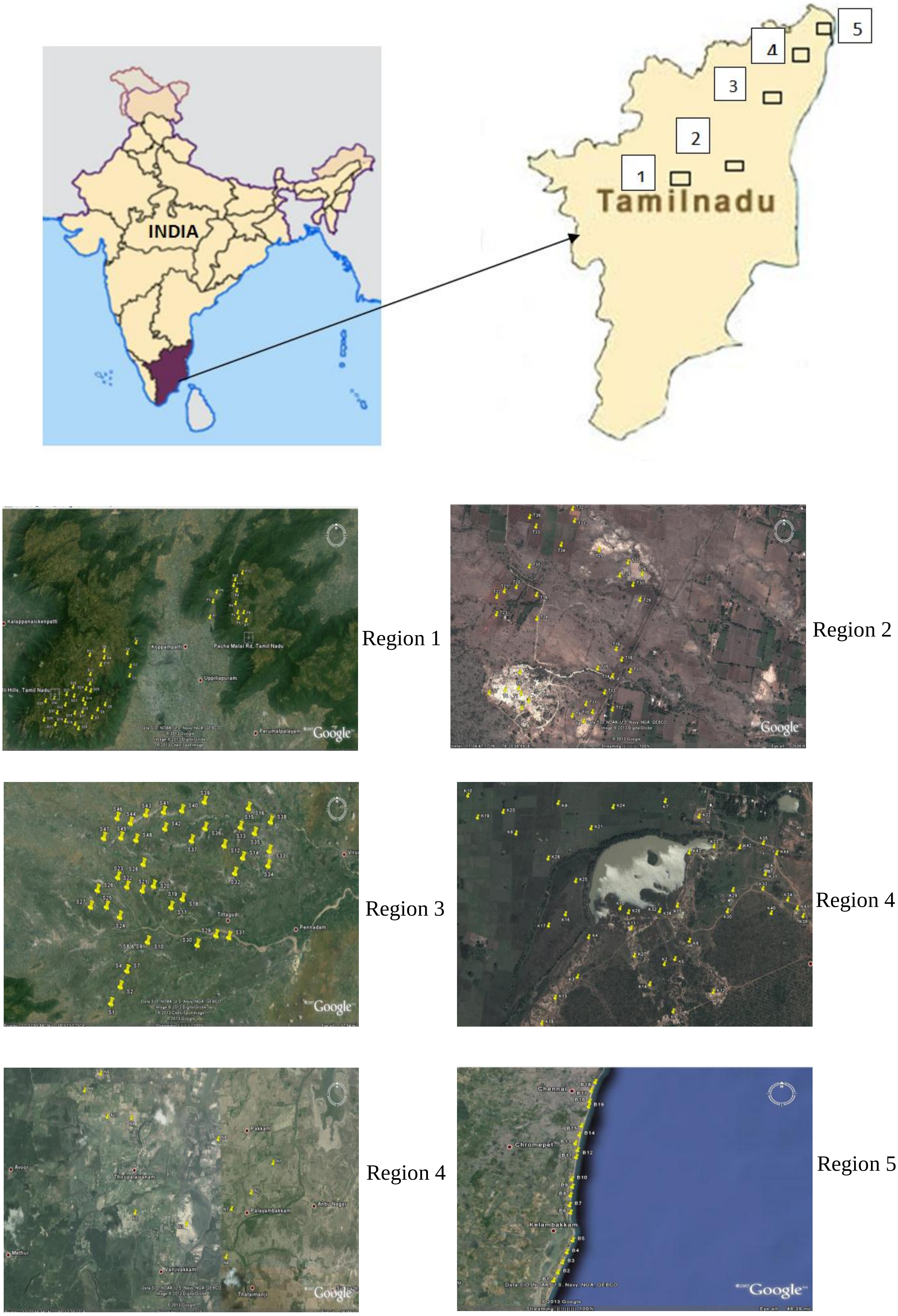

Figure 3.2 **Map showing the regions (1 to 5) and the corresponding satellite images of sample locations**

Figure 3.2 shows the locations from where the soil samples were collected. It may be seen from the figure that the samples collected from various locations are different from their characteristics in order to represent applicability of hyperspectral method for the soils of varied properties.

3.3 PROCEDURE FOR SAMPLE COLLECTION

In this research particle sizes and their distribution are important variables. Therefore it was proposed to collect sand and clay samples which are distinct from their texture. Sand samples were collected from the river banks and sea shores. River sand samples were collected from Palar and Pennayar, sea sand samples were collected from the Chennai coast. Clay and other soil (organic soil, red soil, etc.) samples were collected from Veppur, Kolli hills, Pachaimalai, Neyveli, Guduvanchery, and north Chennai. Commercial clay samples were also used in this study.

Figure 3.3 Pitting for sample collection

Natural soil samples were collected within a depth of 20cm from the surface. The surface of sampling site is cleaned to ensure that the samples are free from roots of plants and grasses. Once the surface is cleaned, a small pit of size 300mm X 300mm is made to a depth of 150mm. The following tools and materials are used to dig the pit and preserve the sample. (i) showel (ii) GPS (iii) airtight containers (iv) sample cover, and (v) field book. About 750 grams of soil were collected for spectral study and laboratory tests. Each sample was labelled and it was noted in the field book after visual identification. The nature and colour of the samples was also noted in the field book. The geographical co-ordinates of each sample were noted using a handheld GPS (Global Positioning System) and it was recorded in the field book. The positional accuracy of the GPS used is 7m.

After collection of the samples from the sites they were transported to the laboratory. The samples were then prepared depending upon the soil test to be performed.

In this study nearly 250 samples were collected and the samples were prepared for chemical analysis, Sieve analysis, Water content test, Liquid limit, Plastic limit, etc. and for spectral studies.

Table 3.1 Sample details

Region no	Region name	Number of samples	Principal character	Remarks
1	Kolli hills and Pacha malai	42 (1-42)	Red soil Organic soil Clayey soil	Hill area
2	Musiri and its surroundings.	36 (43-79)	Black soil Red soil Sandy soil	Near foot hills (Thalamalai), agricultural areas , near lake (Thathiengarpet)
3	Veppur and its surroundings	48 (80-128)	Black organic soil River sand	Agricultural areas (Veppur), on the river bed
4	Guduvanchery	44 (129-173)	Sandy soil White and Off white soils	Clayey soil
5	North Chennai	39 (174-213)	Beach sand White clay	Near coastal area (Marina beach, Besant nagar, Kovalam), swelling clays (Near Thiruvallur)

The sample names are denoted by its place name. All Guduvanchery samples are denoted as K (K1 to K 44). Beach sands from the Marina are denoted as M. Pacha malai samples are denoted as DP. Veppur samples are denoted as D. All sample names are given in the chapter 4.

From the table it is clear that there exists an appreciable diversity in the types and characteristics of soils collected and used in this study. In terms of geo-technical variety (coarse sand, medium sand, fine sand and clay). In terms of diversity in composition clay (Ball clay, kaolinite and bentonite), sand (beach and river sand), lateritic, black and red soil, the samples were collected. In terms of location/origin/genesis, samples were collected from rivers, plains, beach & hill slopes, summits, mining areas, agricultural fields, industrial parks. In addition to the above, commercial clays were used / mixed with regular soils to result in several other soil types.

Apart from giving an outline of the characteristics of the given soil, it would be relevant if a brief description of the nature, origin and geographical distribution of the soils be given. Such a description is as follows:

3.3.1 Sand

Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. The composition of sand is highly variable, depending on the local rock sources and conditions, but the most common constituent of sand in inland continental settings and non-tropical coastal settings is silica (silicon dioxide, or SiO_2), usually in the form of quartz.

3.3.2 Clay

Clays are distinguished from other fine-grained (0.02mm in diameter) soils by differences in size and mineralogy. The particles are extremly closely packed. As the particles are very small the clay has a high surface area and can retain a lot of water when wet. Clay minerals are typically formed over long periods of time by the gradual chemical weathering of rocks, usually silicate-bearing, by low concentrations of carbonic acid and other diluted solvents.

3.3.3 Red Soil

Ultisols, commonly known as red clay soils, are one of twelve soil orders in the United States Department of Agriculture soil taxonomy. They are defined as mineral soils which contain no calcareous material anywhere within the soil, have less than 10% weatherable minerals in the extreme top layer of soil, and have less than 35% base saturation throughout the soil. Ultisols occur in humid temperate or tropical regions.

3.3.4 Black Soil

Black soils are black in colour and are also known as regular soils. Black soil is ideal for growing cotton and is also known as black cotton soil. It is believed that climatic condition along with the parent rock material are the important factors for the formation of black soil. The black soils are made up of extremely fine i.e. clayey material. They are well-known for their capacity to hold moisture.

3.4 INSTRUMENT USED

A portable Spectro-radiometer (Figure 3.4) was used in this study; it is a general-purpose spectrometer useful in many application areas requiring the measurement of reflectance, transmittance, radiance, or irradiance. A spectrometer is an optical instrument that uses detectors other than photographic film to measure the distribution of radiation in a particular wavelength region.

A spectro radiometer is a special kind of spectrometer that can measure radiant energy (radiance and irradiance.) The FieldSpec3 instrument used in this study can perform radiance measurements by default coming from the factory, as its Fibre optic cable is fixed. The FieldSpec3 spectro radiometer is specifically designed for field environment remote sensing to acquire visible near-infrared (VNIR) and short-wave infrared (SWIR) spectra. The salient features of the Fieldspec3 include: Spectral Range of 350 nm to 2500 nm; 512 Channels, spectral resolution of 3nm at 700nm and 10nm at 1400/2100nm, sampling interval 1.4nm at 350-1050nm and 2nm at 1000-2500nm, 25^{o} Field of View; 16 bit Quantization. This instrument is very sensitive to the chemical composition of the target.

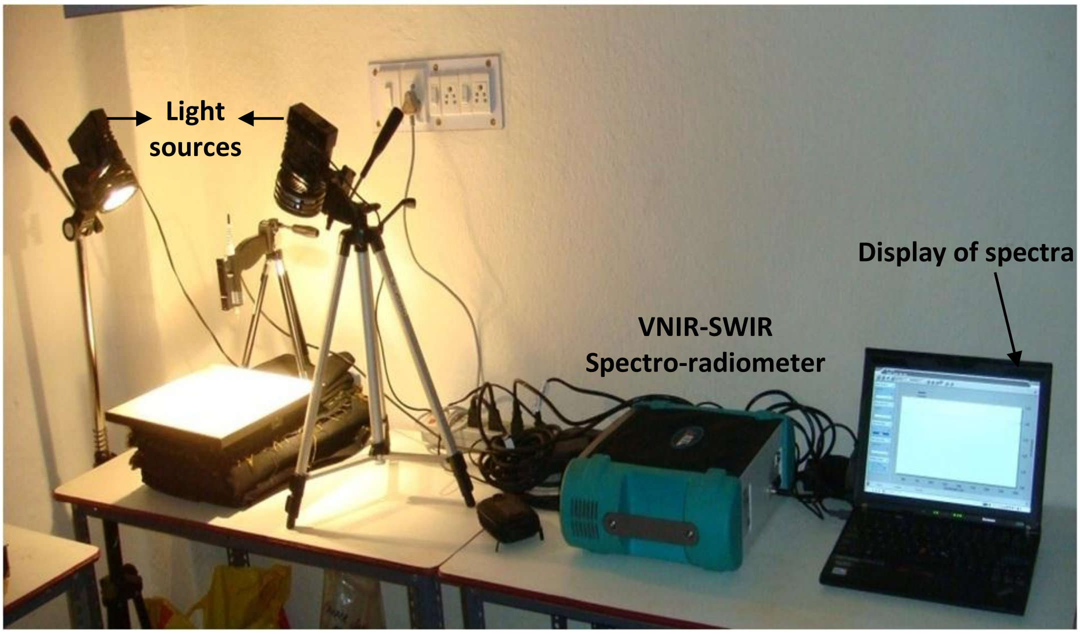

Figure 3.4 Picture depicting the instrument setup

The FieldSpec3 spectro radiometer has a rapid data collection time of 0.1 second per spectrum offered in various subsections of the spectral range (www.asdi.com).

The features of the instrument (Fieldspec3) used in this study are as follows in table 3.2:

Table 3.2 Features of the spectro-radiometer used in this study

Spectral resolution
1. 3nm (Full-Width-Half-Maximum) at 700 nm. 2. 10 nm (Full-Width-Half-Maximum) at 1400 nm. 3. 10nm (Full-Width-Half-Maximum) at 2100 nm.
Sampling interval
1. 1.4nm for the spectral region 350-1000 nm. 2. 2nm for the spectral region 1000-2500 nm.

The FieldSpec3 spectro radiometer may be configured to have three separate holographic diffraction gratings with three separate detectors. Each detector is also covered with the appropriate order separation filters to eliminate second and higher order light. VNIR: 512 element silicon photo-diode array for the spectral region 350-1000 nm. SWIR1: graded index, TE-cooled, extended range, InGaAs, photo-diode for the spectral region 1000 nm to 1830 nm. SWIR2: graded index, TE-cooled, extended range, InGaAs, photo-diode for the spectral region 1830 nm to 2500 nm (ASD User Manual 2008).

The fundamental work involved in this research is the measurement of the spectral reflectance of the various soils and their mixtures, using a standard Visible-NIR-SWIR (400-2500nm) spectro radiometer.

3.5 EXPERIMENTAL SETUP

The instrument was standardized by few readings taken for pure artificial clays. The height between the detector and the sample, the sample spread diameter and thickness of the sample were standardized. Initial observation was made from pure samples of bentonite and kaolinite to ascertain the proper working of the instrument and the experimental set up.

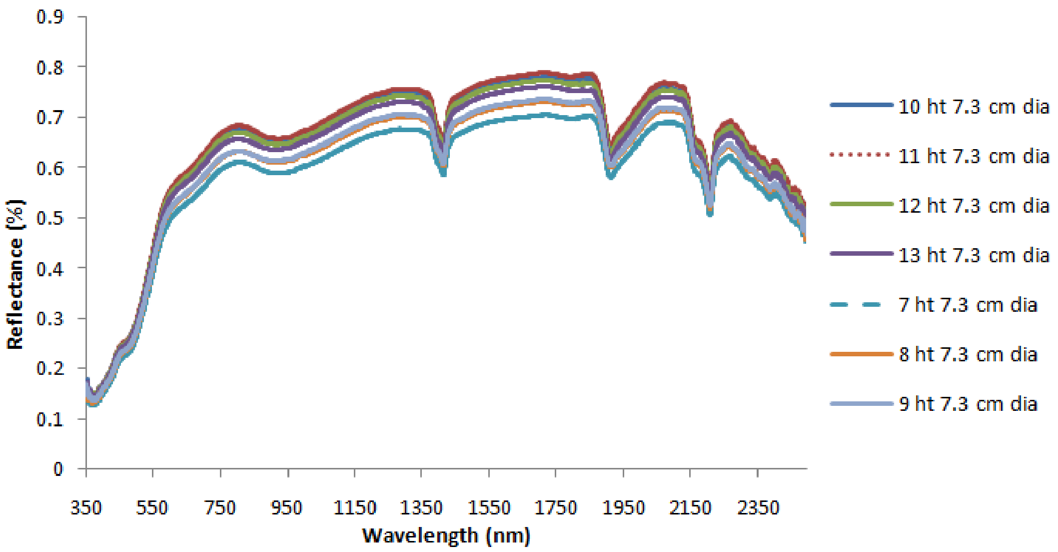

Figure 3.5 Spectra of pure bentonite obtained from different heights of observation

Figure 3.5 shows the spectra of bentonite sample with different view-height from instrument. Here the quantity of the sample and diameter spread of sample are same. The only variable is height of instrument. This shows that if the instrument-to-sample height (from 7 cm to 11 cm) is increased then the reflectance of overall spectra also increased but the pattern of the spectra is maintained. After 11 cm height, the overall spectra is seen to decrease. From this, we can conclude that the height of instrument plays a role in the intensity of reflectance but it does not affect the pattern. If the height of instrument differs for the entire experiment, then the results may not be accurate. Therefore, for this study, the instrument height is fixed at 7.5 cm for all the experiments. The IFOV of this instrument is 25^o. Accordingly, if the height of instrument is varied, then the portion of sample covered by instrument also will vary. If the height is 7.5 cm, then the portion covered by the instrument is 3.33 cm. Hence, the diameter of the sample kept for taking spectra should be more than 3.3 cm.

Table 3.3 Area coverage by instrument with respect to height

Instrument height (cm)	Diameter of area covered by instrument (cm)	Sample diameter (cm)
7	3.108	> 3.108
7.5	3.33	> 3.33
8	3.552	> 3.552
9	3.996	> 3.996
10	4.444	> 4.444
11	4.884	> 4.884
12	5.328	> 5.328
13	5.772	> 5.772

Table 3.3 shows the portion of a sample covered by the instrument according to the height of instrument. This relationship is calculated based on the IFOV of the instrument. The relationship is expressed as:

$$A = 2B / \tan 77.5^o$$

where, A = Area of sample covered by the instrument

B = Instrument height.

Using the above relationship, the area covered by the instrument (Field of View) can be determined for any instrument height. Whatever is the height, the sample quantity and the diameter of the spread should be greater than the portion covered by instrument.

When the quantity of sample is small and minimum portion coverage cannot be obtained, then the height of observation can be reduced. If the instrument height is reduced, the area covered will decrease. However, for a given experiment, consistency in the height should be maintained to obtain better results.

The diameter of the sample is also taken into account for standardization of the experimental set-up. There were three different diameters for a kaolinite sample with standard instrument height for this experiment. The spectra obtained in this experiment are shown below.

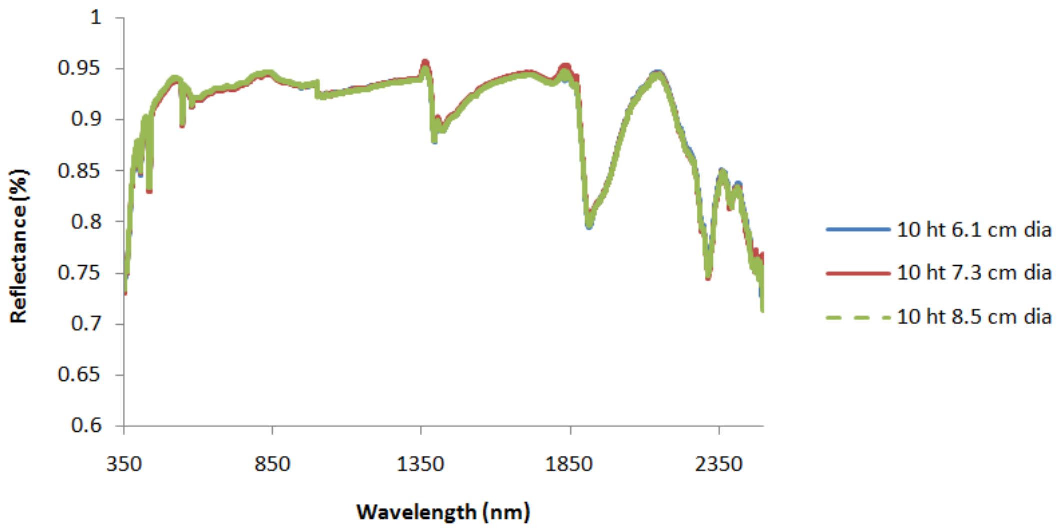

Figure 3.6 Spectra of Kaolinite sample with different diameter of the sample spread

Figure 3.6 shows the spectra for different sample diameter for a kaolinite sample. Here the sample and instrument height is standard for all the three spectra. But the diameter of the sample spread differs. The three spectra are same by pattern and overall reflectance. From this observation, we can conclude that the diameter of the sample does not affect the spectra. An important aspect is that the diameter should be more than the IFOV (instrument portion coverage / Instantaneous Field of View). Here again, the three diameters (6.1 cm, 7.3 cm and 8.5 cm) are greater than the IFOV for 10 cm height (4.44 cm).

The effect of the thickness of the sample is already explained in the section dealing with the instrument used. To reiterate this fact one more experiment was carried out. One sample of kaolinite is taken with the standard instrument height and diameter but with varying sample depth. The result of the spectra is shown in Figure 3.6.

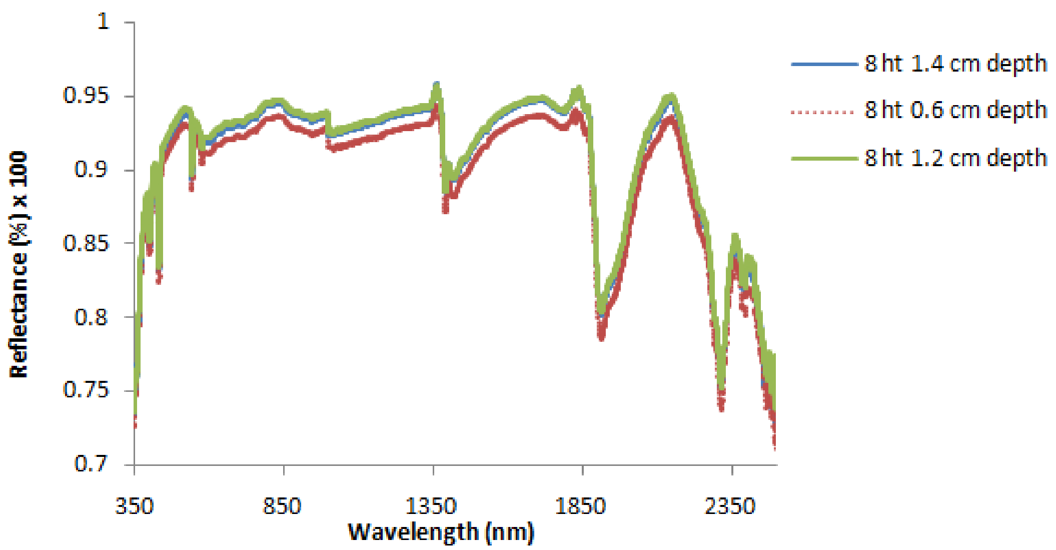

Figure 3.7 Spectra of Kaolinite sample with different sample depth

Figure 3.7 shows the spectra of kaolinite samples with differing thickness (0.6 cm, 1.2 cm and 1.4 cm). This shows that a thinner sample has lower reflectance compared to a thicker sample. Samples with thickness greater than 1 cm result in similar reflectance curves. Hence it may be inferred that the sample should be at least 1cm thick.

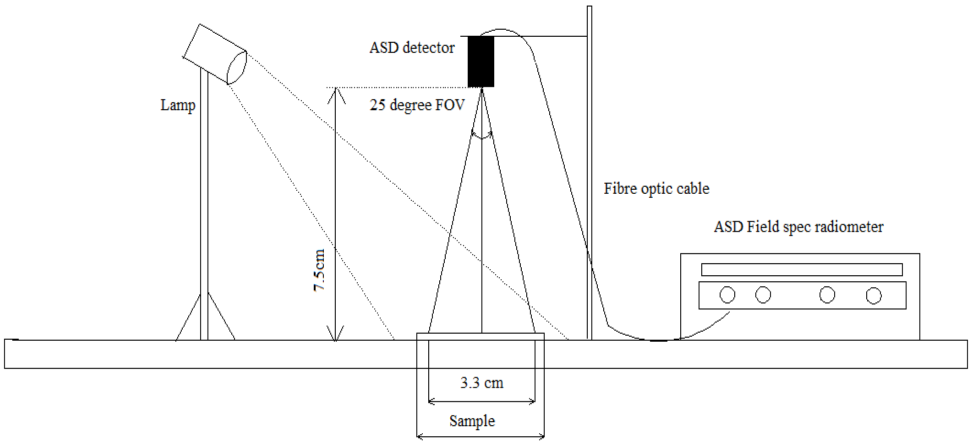

Figure 3.8 Line sketch of the experimental setup for this study

The finalized experimental set up is shown in Figure 3.8. It is seen from the figure that the sample when kept or spread on the experiment table should occupy a circular area whose diameter is more than 3.3 cm. Further, the thickness of the sample on the observation table should be at least 1 cm primarily to avoid interference with the observation table. The above aspects were taken into account for all the samples and the spectro-radiometric measurements were made. The distance between the instrument and sample is standardised.

3.6 MEASUREMENT AND ANALYSIS OF SPECTRAL CURVES

Using the VNIR-SWIR spectro radiometer described earlier, and by following the standards of measurement height and IFOV of samples, spectra were obtained for all the samples and their mixtures. These spectra in general, follow the spectra of typical soils, but vary in their shape and intensity depending on the composition, texture, moisture content and organic content of the soil. Since a visual observation and interpretation of the spectra can only lead to interpretation of qualitative information about the soils, it is pertinent to derive certain spectral parameters from the curves to obtain quantitative information about the soils. The list of such spectral parameters derived from spectral curves is as follows:

a) Maximum reflectance value

b) Depth of absorption value at a particular region

c) Width of spectral curve at a particular region

d) Slope of the spectral curve at a particular region

e) Area under the spectral curve

f) Radius of curvature at a particular region

g) Shift in the position of maximum / minimum reflectance value

Dematte et al (2006), Lesaignoux et al (2012) and Bendor et al(2003) have used such parameters to derive quantitative information about soil properties such as soil moisture, mineralogy and texture. In a similar fashion, in this study also the above listed spectral parametes to quantify soil properties (texture, water content, organic matter, mineralogy, etc.) were used. Such an exercise, however requires inputs in the form of certain index properties of the soils which are to be determined in laboratory and are subsequently related to the spectral parameters. The following section describes the methodology adopted to derive the index properties of soils.

3.7 DETERMINATION OF INDEX PROPERTIES OF COLLECTED SAMPLES

Index properties of soils are used to classify the type of soil and it provides the structural properties of soils. Laboratory and field tests are available for determining the index properties of soil. In this study, properties were determined by the laboratory methods which are described below.

3.7.1 Sieve Analysis – for Texture

The texture of the soil refers to the grain size of the soil. Based on the grain size, the soil is classified as sand (coarse & fine), silt and clay. Sieve analysis is the test which is used to classify the soil based on grain size. Sieve sets are available with different sizes of mesh in this test. And the sets are fixed with mechanical sieve shaker as shown in figure. The soil was dried and weighed after drying. The dried soil passes through the sieve sets after the instrument is switched on. After ten minutes of shaking, we obtain the soil classification based on the texture. Further details of laboratory method of textural classification are available in Reddy & Sastri (2002).

Figure 3.9 Electronic sieve shaker and the instrument setup

3.7.2 Oven Drying Method to Estimate Moisture Content

Water content of the soil is the capacity of water it can hold. It is an index property which plays a major role in geotechnical engineering. It is the ratio of the weight of water to the weight of solids in the soil. Oven drying method for determining soil moisture content can be referred from the text book ‘Measurement of engineering properties of soils’ by Reddy & Sastri (2002).

3.7.3 Determining Organic Matter Content

The percentage of organic matter in any soil influences its density, permeability and other index properties. Hence, it is pertinent that we determine the OMC of soil samples. The organic content is the ratio, expressed as a percentage, of the mass of organic matter in a given mass of soil to the mass of the dry soil solids. Organic matter content for this study is conducted based on ASTM D 2974-87 method.

3.7.4 Mineralogy

Since mineralogy of soil influences the index properties such as density, texture, atterberg limits. Minerals present in the soil samples were determined by XRF (X-ray fluorescence) analysis.

3.7.4 Basic soil tests

The test procedure for determination of liquid limit and plastic limit of soils can be referred from the text book ‘Measurement of engineering properties of soils' by Reddy & Sastri (2002). The results of the tests are given in chapter 4.5 and table 4.31.

3.8 SPECTROSCOPIC STUDY OF SOIL SAMPLES

Samples taken for spectral study is prepared based on the purpose of the experiment. For example, if the spectra are taken for textural study, then grain size of soil sample should be known. Hence, the sample was first prepared by sieve analysis. The only variable of soil samples in this study should be 'Grain size'. The other properties should be the same. Since the spectra obtained from radiometry is very sensitive and it will be affected by soil moisture, texture, surface, minerals, colour, organic content, etc., the spectro radiometric study was carefully done for getting accurate results. Further, the instrument set-up (height from instrument to sample, quantity and depth of sample) is correctly followed. The standard is followed throughout the study except for very few samples that are in small quantity.

3.9 RELATING SPECTRA AND INDEX PROPERTIES

The spectral parameters are derived from the spectra and simple linear regression is performed with respect to the soil index properties. Based on the accuracy of each parameter, the suitable parameter has been chosen. Subsequently, the soil index properties are estimated.