CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter reviews several researches related to hyperspectral radiometry and remote sensing in determining index properties of soils. The review includes geotechnical properties of soils particularly index properties of soils, conventional methods of determining such properties, issues related to such methods, remote sensing of soils and hyperspectral radiometry to study index properties of soils.

2.2 GEOTECHNICAL PROPERTIES OF SOILS – A REVIEW:

To emphasize the significance of geotechnical engineering, Fang & Daniels (2006) described that all civil infrastructures are in direct contact with soil and as such are dependent on engineering properties. Strength, compressibility and permeability are known as engineering properties. Engineering properties are indicative of how soil will response to a structure built on it. Determination of these properties is time consuming and requires good quality undisturbed samples, sophisticated equipment and expertise (Gulhati & Datta 2005). However the researchers are working for several years to estimate these important properties from index properties of soils which can be determined by conducting simple and less time consuming tests on disturbed but representative soil samples. Apart from the effort on above said direction, researchers are working on to estimate certain index properties through non-distructive testing (Geo-physical methods) field instruments such as nuclear diversity test, infra red moisture meter, etc.

2.3 INDEX PROPERTIES OF SOILS

A long history can be traced for the various works carried out by various authors to study the index properties of soils. Terzaghi et al (1996) give a scientific definition of index properties as "the properties which help in discriminating among different kinds of soils in a given category". The authors also outlined the practical importance of the index properties and grouped index properties into two classes: (i) Soil grain properties, and (ii) Soil aggregate properties. Further added that the important soil grain properties are the size and shape of individual grains and, in clayey soils, the mineralogical composition is very important. The most significant aggregate property of cohesionless soils is the relative density, whereas that for cohesive soils is the consistency.

Emphasizing the significance of index properties, Raj (2008) mentions that "the common problems faced by civil engineers are related to the bearing capacity and compressibility of soils, and the seepage through the soil. The possible solution to this problem, the author opines, can be arrived based on the physical and index properties of the soil. Such observations and comments by Terzaghi et al (1996) and Raj (2008) perhaps form the most fundamental aspect of the index properties of soils.

Punmia (1970) lists the index properties of soils as: (I) Water content, (ii) Specific gravity, (iii) In-situ density, (iv) particle size distribution, (v) consistency limits and (vi) relative density. Water content is certainly a significant parameter that affects the engineering behaviour of soils. Fang & Daniels (2006) emphasize the importance of soil water interaction and state that the amount of water existing in the soil mass will significantly influence the engineering behaviour of soil. The authors further quote Terzhaghi et al (1996) and add that there would be no need for soil mechanics, if not for water.

Fredlund & Xing (1994) listed the various works carried out to derive equations for the soil-water characteristic curve. The authors opine that while a theoretical framework for unsaturated soil mechanics has been established over the past two decades before 1994, the work by Fredlund & Rahardjo (1993) indicates that constitutive equations for volume change shear strength and flow trough unsaturated soils have been accepted in geotechnical engineering. The authors further stated that the measurement of soil properties for unsaturated soils demands intensive laboratory studies.

Several works that predict empirically the permeability function for unsaturated soil (Marshall 1958 and Maulem 1986), shear strength of unsaturated soils (Fredlund & Rahardjo 1993) have been discussed in the past.

Mathematical equations have been suggested to characterise the soil-water characteristic curve. A few of these are listed in Table 2.1.

Measuring water content in soils is an important task and many authors have suggested and attempted several innovative, cost-effective and time saving approaches. Sun et al (2006) designed a combined horizontal penetrometer for the on-the-go and simultaneous measurement of soil water content and mechanical resistance. The maximum sampling rate for both sensors was 10 Hz and the maximum operating depth was 20 cm. For the water-content sensor, its measurement principle depends on the electric field of the fringe-capacitance. In order to evaluate the applicability of this combined penetrometer, the author conducted the following four experiments in the field (i) soil water content profiles test; (ii) soil compaction measurement test; (iii) effect of the operating velocity on the water content and resistant force measurement, and (iv) effect of operating depth on the force measurement. The experimental results show that the combined horizontal penetrometer is a practical tool since it can provide information of soil physical properties. Finally it was concluded that though this tool is effective, it cannot be used as a tool for rapid assessment of water content.

Sun et al (2008) developed a multi-sensor system, which consists of a cell with three sensors for measuring soil water content, mechanical strength and Electrical Conductivity (EC). Additionally a Hall-current sensor was proposed to measure the operating current of a dc-motor, which generated the penetrating force during operating process. Based on the transformation from electrical to mechanical energy, it was feasible to evaluate the soil mechanical strength from the operating current of the dc-motor. The results demonstrate that the multi-sensor system could be beneficial and practical for field surveys; however, this tool cannot be used for rapid assessment of water content.

Since rapid measurement of soil-water is not possible even equipment with sensors, an alternative tool was sought. Many researchers have demonstrated the potential of remote sensing as an alternate tool to measure soil-moisture. Accordingly, brief review of various works carried out in this regard. Including brief history of the remote sensing of soil properties are presented in the next session (adopted from Ge et al 2011).

2.4 ASSESSING SOIL PROPERTIES BY REMOTE SENSING TECHNIQUE

Nearly 80 years ago when optical and radiometric instruments were in limited use, colours were the most obvious and useful attributes to document differences among soils (Rice et al 1941 and Munsell 1975). Although great progress was made in standardizing methods to measure and designate soil colour; since the concept was first introduced, measurement of soil colour remained subjective and in many cases non-repeatable (Baumgardner et al 1986). Soil scientists anticipated new devices and methods for measuring soil spectra and relating them to soil properties more accurately and objectively, and they focused, their attention towards remote sensing (RS) technique. Evidently the earliest attempt to use RS for soil studies occurred in the 1930s when black-and-white aerial photographs were prepared as the base maps for soil surveys in the US (Baumgardner et al 1986). In the late 1960s and early 1970s, soil scientists began to investigate using multispectral-sensor (MSS) data to delineate differences in surface soils (Kristof 1971).

Soon thereafter Kristof & Zachary (1974) reported partial success in delineating soil series in an Alfisol-Mollisol region through digital analysis of aerial MSS data. Development was slow because RS images were not readily obtainable. However, the first satellite to provide publicly available RS data in the US, LANDSAT-1, was launched in 1972. After that, several imaging satellites were placed in orbit and images have become more and more available to researchers. An early attempt to quantify soil reflectance and define differences between soil reflectance spectra by means of proximal sensing was conducted by Condit (1970, 1972). He collected 160 soil samples from 36 states in the US and classified soil spectral curves into three general types based on Near-Infrared Reflectance Spectroscopy (NIRS). However, no attempt was made to quantitatively relate these spectral properties to physical and chemical properties of soils.

Stoner et al (1980) collected soil samples representing more than 240 soil series from 17 different temperature-moisture regimes and measured visible and infrared reflectance (0.52–2.36 µm). The spectral curves into five basic forms and related them to five soil types (organic dominated, minerally altered, iron affected, organic affected, and iron dominated). Baumgardner et al (1986) reviewed reflectance properties of soil in 1985 and confined their discussion to soil colours, principles and limitations of RS, and effects of soil constituents on soil reflectance.

Moran et al (1997) included several sections on remote sensing of soil properties in their overall discussion of image-based RS in PA. Pierce & Nowak (1999) briefly discussed RS of soils as one of many aspects of PA. These two reviews summarized studies conducted over 15 years ago and highlighted early application of RS to PA, but later developments need to be reviewed as well. Ben-Dor (2002) and Ben-Dor et al (2003) reviewed quantitative RS of soil properties with hyperspectral sensors. They included almost all important issues regarding RS of soil properties and provided detailed information on the state of the art at the time.

Remote sensing has witnessed concurrent advancement of sensing technology and data analysis techniques in recent years. As RS soil spectra data are recorded in hundreds or even thousands of contiguous narrow bands that contain detailed information on soils, sophisticated data analysis techniques have been designed to extract useful soil property information from these extremely large data sets. Recent literature has included how these techniques have been deployed for soil property determination in PA.

Different researchers aim at different soil properties and encounter different environmental conditions in their fields. They also use different sensing platforms, sensor types, and data analysis techniques. The procedures for selecting appropriate devices and techniques are more art than science. No single sensor type or data analysis method has yet been reported as ideal for a particular soil property.

2.5 REMOTE SENSING OF SOIL MOISTURE

It is a well-known fact that soil becomes dark when wet with little colour change. This commonly observed phenomenon is an obvious and dominant characteristic of the reflectance of soils. Angstrom (1925) attributed the reduction to total internal reflection within the film of water coating soil particles. The multiple interactions of light with the soil that result from repeated reflections increase the probability of absorption and, thus decrease the total light reflected.

Twomey et al (1986) opined that, since the relative index of refraction between water and soil is considerably less than that between air and soil, forward light is much more likely with wetted soil. As with the case of internal reflection, this increases the interaction of light with soil and results in increased probability of absorption by the soil.

Realizing the need for a fast and convenient soil analytical technique for soil quality assessment and precision soil management, Chang et al (2001) evaluated the ability of near-infrared reflectance spectroscopy to predict diverse soil properties using a spectro-radiometer. Chemical, physical, and biochemical properties were studied for 802 samples. Surface (0|3or0|10 cm) and subsurface (3|10 or 10|30 cm) soils were collected from the Palouse and Nez Perce Prairies located in eastern Washington and western Idaho, the Central High Plains located in eastern Colourado, southeastern Wyoming, and west-ern Nebraska, the Southern High Plains located in New Mexico and the panhandle of Texas, the Northern Mississippi Valley Loess Hills, located in northeastern Iowa, south eastern Minnesota, and southwestern Wisconsin. Total C, total N, moisture, cation-exchange capacity (CEC), 1.5 MPa water, basal respiration rate, sand, silt, and extractable Ca were successfully predicted by the technique (r^2=0.80). Some other extractable metals (Fe, K, Mg, Mn) and exchangeable cations (Ca, Mg, and K), sum of exchangeable bases, exchangeable acidity, clay, potentially mineralizable N, total respiration rate, biomass C, and pH were also estimated by NIRS but with less accuracy (r^2=0.50). The predicted results for aggregation (>2mm, >1mm, >0.5mm and >0.25mm) including macro-aggregation (sum of the percentage of aggregates >0.25mm) were not reliable. Cu, P, and Zn, and exchangeable Na could not be predicted using this technique (r^2=0.50). The results indicate that near infra-red spectroscopy can be used as a rapid analytical technique to simultaneously estimate several soil properties with acceptable accuracy in a very short time.

In another study using airborne remote sensing, Ben-Dor et al (2002) acquired image data from the hyperspectral airborne sensor DAIS-7915 over Izrael Valley in northern Israel and processed it to yield quantitative soil properties maps of organic matter, soil held moisture, soil saturated moisture, and soil salinity. Based on the success of the work, a procedure was developed in order to create a soil property map of the entire area, including soils under vegetated areas. This study has demonstrated that that the VNIRA method is a promising strategy for quantitative soil surface mapping and the method could be improved if a better quality of hyperspectral image data were used.

Soil moisture affects the reflectance of the soil, although the manner in which it does so varies across the electromagnetic spectrum. Several researchers have found bands in the shortwave infrared region (SWIR, 1.5 to 2.5 nm) to be suitable for soil moisture prediction (Whiting et al., 2004; Liu et al., 2002).

Whiting et al (2004) measured the laboratory spectra, from 0.4 to 2.5 microns, at sequential moisture levels in soil samples collected in Castilla-La Mancha, Spain and in California, USA. The Gaussian area was determined to be the best indicator of gravimetric water content with the initial modelling of 2592 spectra. The Soil Moisture Gaussian Model (SMGM) was validated with a separate set of 849 spectra. The model performance significantly improved for water contents below a critical level of 0.32 g water/g soil. This study proved that the SMGM provides practical water content estimates and has a potential use in correcting the effects of soil moisture in hyperspectral images.

2.6 REMOTE SENSING APPLICATION OF SOIL TEXTURE

In a general sense, texture of soil refers to its surface appearance. Soil texture is influenced by the size of the individual particles present in it. In most cases, natural soils are mixtures of particles from several size groups. In the textural classification system, the soils are named after their principal components, such as sandy clay, silty clay and so forth (Das 2010).

It is an obvious fact that natural soils occur in many varieties and types. Engineering classification of soils is chiefly based on the texture as: (i) coarse grained soils and (ii) fine grained soils (Kaniraj & Kaniraj (1988). Terzaghi et al (1996) mentioned that despite its shortcomings, soil classification based on grain-size characteristics such as boulders, cobbles, gravel, sand, silt, clay etc are widely used. The authors add that it was the Unified Soil Classification System, adopted in 1952 by the U.S Corps of Engineers and Bureau of Reclamation, which divided all soils into three major groups : coarse grained, fine grained and highly organic (peaty). The coarse grained soils are divided into gravelly (G) or sandy (S) soils. The fine grained soils are divided into three groups: inorganic silt (M), inorganic clays (c) and organic silts and clays (O). According to the authors, the soils are further divided into those having liquid limits lower than 50% (L) or higher than 50% (H).

Grain-size distribution is commonly used for soil classification; however, there is also potential to use the grain-size distribution as a basis for estimating soil behaviour (Fredlund et al 2000). Grain size distribution is used for modelling of soil water characteristic curve (Haverkamp & Parlange 1986). Soil hydraulic properties frequently require information on the particle size distribution (Segal et al 2009). Mishra et al (1989) also supported this view. A model to predict the moisture characteristic of a soil from its particle-size distribution, bulk density, and particle density parameters was developed by Lalit et al(1981).

Since texture is an important index property that determines the suitability of soils for different engineering projects, many authors have attempted to study the role of texture in influencing the geotechnical properties of soils.

Nemes & Rawls (2004) provided an overview on the way soil texture can be characterized and described in addition to presenting a study that compares different representations of soil particle-size distribution (PSD) in estimating soil water retention. The authors compared the usefulness of some of the most common representations of PSD in estimating water retention at −10, −33, and −1500 kPa and the available water content (AWC) of the soil, which is defined as the difference between water contents at −33 and −1500 kPa matric potentials. Several PTFs (pedotransfer functions) are developed to relate the soil hydraulic properties to soil texture. The predictive models are tested using three different representations of the silt/sand boundary along with clay content. Use of the same index letter within the same block and for the same estimated property means that differences are not significant at a 95% confidence level.

Outlining the role of low temperatures on the textures of soil in cold regions, Jumikis (1979) elucidated some factors affecting the formation of soil cryogenic textures upon artificial active and passive soil freezing to form a soil-ice wall cofferdam. The author opined that depending upon the soil type, the thermal regimen of the stages of active and passive freezing of the soil-ice wall brings about various kinds of cryogenic textures. The cryogenic textures, in their turn, affect the strength of the artificially frozen soil-ice wall. After conducting a series of experiments, the author postulated that the strength and performance of the composite frozen soil – the ice wall – is a function of its components, such as the soil cryogenic texture, its thermal regimen and the strength of the ice.

Zhao et al (2009) developed an artificial neural network (ANN) model to predict soil texture (sand, clay and silt contents) based on soil attributes obtained from existing coarse resolution soil maps combined with hydrographic parameters derived from a digital elevation model (DEM) of the Black Brook Watershed (BBW) in northwestern New Brunswick, Canada. The calibrated ANN model then can be used to produce high-resolution soil maps in area with similar conditions without additional field surveys. The hydrographic parameters derived from DEM were soil terrain factor, sediment delivery ratio and vertical slope position. Field measured soil texture was used to train and test the ANN model. Results indicated that the Levenberg–Marquardt optimization algorithm was better than the commonly used training method based on the resilient back-propagation algorithm. The root mean square errors between model predictions and field determination were 4.0 for clay and 6.6 for sand contents. The relative overall accuracy (within ±5% of field measurement) was 88% for clay content and 81% for sand content.

Though the importance of soil texture has been emphasized by many authors including those listed above, it is known that determining texture by field or laboratory based methods is a tedious task. Accordingly, several authors have attempted to use certain tools to rapidly determine the texture of soils. An early attempt by Beverwijk (1967) included the hydrometer method, in which a hydrometer was used to determine the colloidal content of soils. This method produced results suitable for use in the research activities in the Netherlands

Soil texture affects reflectance, as incoming radiation is scattered differently by coarse particles as compared to fine particles (Thomasson et al 2001). This is because of shadowing effects and surface roughness. The effects on soil colour and texture, the mineral composition of the soil, including the soil organic matter content, play a role in the measured reflectance from the soil surface (Orueta & Ustin 1998; Ben−Dor et al 2002).

In another work demonstrating the role of hyperspectral image analysis, Casa et al (2013) showed that imaging spectroscopy using airborne MIVIS (430–1270 nm; spatial resolution: 4.8 m) and space-borne CHRIS-PROBA (415–1050 nm; spatial resolution: 17 m) has considerable potential for the estimation of soil texture in the Maccarese S.p.A. farm near Rome (Central Italy). Extensive soil sampling was carried out for the determination of soil particle size fractions. Soil texture was related to the spectral signature of corresponding CHRIS or MIVIS pixels. The spectral behavior of the soil samples was also examined in the laboratory, by using a spectroradiometer in the 400–2500 nm range. Spectra were used to calibrate prediction models for the estimation of clay, silt and sand, through partial least-square regression (PLSR). The tests with remote sensing data show a sufficient accuracy of prediction (Ratio of Performance to Deviation : RPD > 1.4) for clay and sand using both MIVIS and CHRIS-PROBA data. However, the results were found to be sensitive to the difference in support between point and pixel data and to the geometric registration error, especially for MIVIS data.

Though a few authors have carried out work to estimate the textural characteristics from remotely sensed data, it is the mineralogical composition of soils that have been extensively studied by many authors. It is perhaps the high rate of accuracy that prompted many authors to study the mineralogy of soils.

Since soils are essentially made up of minerals, one of the earliest works on understanding the spectra of minerals was by Hunt (1977) in which the author observes that the intrinsic spectral features that appear in the form of bands and slopes in the visible and near infrared bidirectional spectra of minerals are caused by a variety of electronic and vibrational processes. The author lists the processes as crystal field effects, charge transfer, colour centers, transitions to the conduction band, and overtone and combination tone vibrational transitions. Based on the observations from spectra collected from a large selection of minerals, the author states that in the visible-near infrared region, the most commonly observed features in minerals are due to the presence of iron in some form or the other, or to the presence of water or pH groups. This work may be considered as a pioneering work that set in motion a series of researches in the following years by several authors.

In a classic demonstration of the potential of mid-infrared reflectance spectroscopy, Minasny et al (2009) observed that the tool can predict fundamental soil properties related to soil matrix or solid mineral constituents and soil solution concentrations which are in equilibrium with the solid phases. The author was made possible by obtaining three datasets from the states of Queensland, New South Wales, and Victoria, Australia. The authors further observed that cation exchange capacity, clay content, organic and total C, total N and the chemical properties that are related to the mineral and organic components can also be predicted, including: total K, total P, elemental Fe, Si, and Al. The relationships with soil properties found by MIR have been explored by the authors by empirical results from pedo-transfer functions. They conclude that it is important to have sufficient samples and to leave a part of data as validation to test the accuracy of MIR prediction. As a word of caution, the authors state that because the predictor variables consist of hundreds of spectra, the model can be easily over-fitted. Thus, testing the model on an independent validation data is the only way to test the accuracy of the model.

Since carbonate minerals form an important constituent of many soils and rocks, Zaini et al (2012) studied the reflectance spectra of carbonate minerals by analyzing the spectral absorption feature characteristics of calcite and dolomite in the Short Wave Infra Red (SWIR) (features at 2.3 and 2.5 μm) and Thermal Infra Red (TIR) (features at 11.5 and 14 μm) wavelength regions, as a function of grain size and carbonate mineral mixtures. The author observed that these spectra contain a number of diagnostic absorption features and the shape of these features depends on various physical and chemical parameters. To accurately identify carbonate minerals or rocks in pure and mixed form, it is necessary to analyze the effects of the parameters on spectral characteristics. The inference drawn by the author is that the varying grain sizes and mineral contents in the sample, influence reflectance values and absorption feature characteristics. The band positions of calcite and dolomite varied relative to grain size only in the TIR region. These positions shifted to longer wavelengths for the feature at 11.5 μm and to shorter wavelengths for the feature at 14 μm from fine to coarse grain size. The author further opine that these results can be applied for the identification of pure and mixed calcite and dolomite, as well as estimating the relative abundance of both minerals with different grain size and mineral mixtures.

To demonstrate the concentration of even minor constituents of soils such as phosphorous can be determined using spectral data, Bogrekci and Lee (2004) collected a total of 150 grass samples and 150 soil samples from three sites in the Lake Okeechobee drainage basins, Florida, USA and the spectra was measured in the 174-2550nm region with an interval of 1mm. Reflectance of all samples were converted into absorbance for further analysis to determine the relationship between the concentrations of Phosporous in the samples and absorption of light at different wavelength using the Beer-Lambert's Law. Stepwise multiple linear regressions and linear partial least squares were estimated and strong relationships (R^2=0.92) between absorbance and phosphorous concentration in soil were observed.

Other than optical remote sensing, TIR spectroscopy can also yield much information about the composition of soils. This fact was demonstrated by Hewson et al (2010), who evaluated soil samples collected in the semi-arid environment of North - west Queensland, Australia. The initial results show the intimate connection between mineralogy and texture when using thermal infrared spectroscopy to investigate soils. In particular, coarse and fine grained quartz components have distinct TIR spectral features. Spectral band parameters, based on thermal infrared specular and volume scattering features, were found to discriminate fine clay mineral–rich soil from mostly coarser quartz-rich sandy soil, and to a lesser extent, from the silty quartz-rich soil.

2.7 A REMOTE SENSING VIEW OF SOIL ORGANIC MATTER

Organic matter accumulates largely due to the decomposition of plants and tree roots, animal and aquatic remains and wastes. The presence of organic matter is undesirable in soils. Such soils undergo large volume change with changes in moisture content and temperature (Khan 2005). The importance of organic soils is recognized in many different disciplines including geotechnical engineering, soil science and environmental engineering. The presence of organic matter confers soils distinct engineering properties (High compressibility, high hydraulic conductivity and high creep) which set them apart from other soft soils and make them considered 'Problem' soils, requiring special consideration both during design and construction (Joonho Hwang 2008) and organic matter content impart black colour to soil (Venkatramaiah 2006).

Schumacher (2002) gives an elaborate account of the methods for determining total organic carbon in soils and sediments apart from listing the sources and forms of carbon in soils, procedure for sample collection and handling of the sample. Quantitative, semi-quantitative and analytical techniques described by the author make us realize that a lot of time, effort and man power is required to determine total organic carbon in soils, thereby prompting us to look for simpler, rapid and efficient approaches to soil organic carbon estimation. Perhaps, spectro-radiometry and remote sensing may be one such approach. This has been proved by many authors as discussed in the following paragraphs.

The organic matter in soils exhibit typical spectral properties, thus making it easy for one to identify the nature and concentration of such materials in soils. One of the earliest studies on spectral mapping of soil organic matter, was attempted by Kristof et al (1973). The objective of the research reported by the authors was to test the hypothesis that multispectral reflectance data can be analyzed by computer to delineate and map different levels of soil organic matter for different soil associations and types. It was further hypothesized that (1) the spectral properties of cultivated soils do not change significantly from one year to the next and that (2) soil sample training sets (ground measurements and observations) from a small area could be used for the analysis of spectral data from a much larger area. Airborne multispectral scanner data was collected in 1969 and 1970 over a north-south flightline extending 40 km in Tippecanoe County, Indiana, USA. Two specific test fields 15 km apart were designated for detailed investigations. Results from this and related experiments have proved to be valuable in planning soils studies under the Earth Resources Technology Satellite (ERTS) and Skylab experiments. Repetitive coverage by ERTS every 18 days has provided the opportunity to choose satellite-acquired data obtained at the optimum season for mapping or delineating soil patterns. These results are very important when planning experiments or operational mapping of soil patterns over land areas receiving repetitive coverage.

A study that relates the laboratory and field based spectral signature to soil organic matter (SOM) in the Pathanna Nikom area of Thailand was carried out by Daniel et al (2001). The authors introduced a new approach to develop prediction models from the SOM-sensitive spectral signatures. In both the reflectance and absorption measurements, bands with 960, 1120 and 520 nm are found to be the best suited. The authors also noted that the spectral-chemical composition allows the delineation of boundaries between different soils. Spectral-based SOM polynomial prediction models were suggested by the authors. One notable comment by the authors is that variation of distance between the sensors and the object of investigation is an important factors that affects the observations and inferences. As regards the present thesis, this study has helped in defining the standards of experimental set-up for spectral measurements of soils.

Realising the need for simple and efficient instruments for insitu organic detection and characterisation for the planetary surfaces, Chenovar and Glenar (2011) developed and demonstrated the use of a miniature near infrared point spectrometer, operating in the 1.7-4 mm region, based on acousto-optic tunable filter (AOTF) technology. The authors opine that this instrument may be used to screen and corroborate analyses of samples containing organic biomarkers or mineralogical signatures suggestive of extant or extinct organic material collected *in situ* from planetary surfaces. They also add that the instrument offers the powerful advantage of cross-checked chemical analyses of individual samples, which can reduce chemical and biological interpretation ambiguities.

2.8 REMOTE SENSING APPLICATION OF MISCELLANEOUS SOIL PARAMETERS

While several authors have attempted to determine certain index properties in the laboratory and by using remote sensing methods, properties such as density, liquid limit and plastic limit have been rarely studied. Only a few examples exist for these properties.

In a classic work carried out in Kurdistan, Abed et al (2008) demonstrated the ability of spectral reflectance to recognise different soil types and relate the same to laboratory derived liquid limit, plastic limit and moisture content. This study included four stages. The first included the use of various data sets such as Landsat-7 satellite image of 14.25m resolution and topographic map (1:1000000 scale) and from this maps the authors recognized eight sub basins. The second stage included site visits to collect soil samples from specified locations found by using GPS device. A radiometer was also used in this stage with four filters (blue-green-yellow-red) to recognize different soil type by their reflectance. The third stage included laboratory work to find soil properties and soil type. The different soil samples were tested in the soil laboratory their liquid limit, plastic limit and moisture content. The authors conclude that field work by using spectro-radiometer could recognize eight types of soils based on the spectral reflectance, while the laboratory work recognized only five types of soil based on the water content in soil and other parameters.

Highlighting the need to study expansive soils and determine their index properties, another work was carried out in Addis Ababa by Yitagesu et al (2008). For this study, soil samples were collected from eastern part of Addis Ababa city. Engineering parameters such as Consistency limits (liquid limits (LL), plastic limits (PL) and plasticity indices (PI)), free swell and cation exchange capacity (CEC) related to expansive soils, were measured in a soil mechanics laboratory. Reflectance spectra of all the samples were acquired a full range spectrometer. Multivariate calibration and partial least squares regression (PLSR) analysis was used to relate the engineering parameters and absorption feature parameters calculated from the reflectance spectra at 1400 nm, 1900 nm and 2200 nm. Correlation coefficients "obtained", showed that a large portion of the variation in the engineering parameters (R=0.85, 0.86, 0.68, 0.83 and 0.64 for CEC, LL, PL, PI and FS respectively) could be accounted for by the spectral parameters. A high degree of correlation indicated the potential of spectroscopy in deriving engineering parameters of expansive soils from their respective reflectance spectra, and hence its potential applicability in geotechnical investigations of such soils.

In another earlier work carried out in a detailed manner, Yitagesu (2006) discusses the rudiments of spectroscopy, expansive soils and the statistical analysis relating engineering parameters and spectral parameters. A comprehensive study carried out by the author in Ethiopia lists the problems due to expansive soils in Ethiopia, the need to rapidly identify expansive soils and the potential of spectroscopy in such studies. The results of this work in general confirm that spectroscopy has a great potential in contributing to geotechnical investigation of expansive soils. Apart from supplying a great deal of information within a short period of time and being cheaper, the accuracy of spectroscopic measurements are also reliable. Hence, the authors conclude that spectroscopy can play an important role in identifying sites that might need due attention and further detailed geotechnical assessment with respect to the presence of potentially expensive soils.

2.9 USE OF SATELLITE IMAGE DATA

Though spectral measurements yield information on few of the index properties of soils, it is impossible to take measurements of many locations spread over a large area. However, it is known that satellite images, which offer a synoptic coverage of large areas, contain enormous spectral information about the terrain. Such spectral information can be judiciously analysed to yield geotechnical information about soils. A few of such works, carried out in different types of terrains has been reviewed and listed below.

Emilio Hubert Horvath (1981) studied that the relationships between the spectral properties of Arizona soils and rangelands and their characteristics. The percent reflectance of soils was determined using a multispectral hand-held radiometer. And the spectral response of Arizona rangeland sites was measured by scanners aboard an orbiting satellite. In this study, few soil properties (colour, organic carbon, and carbonates) were identified using multispectral radiometer from the spectral reflectance. But if hyperspectral radiometer would have used, then the quantitative and qualitative information about the soils can be determined.

The relative merits of aerial photography and remote sensing by multi-spectral scanner was studied by Coulson & Bridges (1985). The authors have experience of MSS data with 2.5 m resolution of a large site with metalliferous contaminants in the Lower Swansea Valley, Wales, flown in 1982 and repeated in 1984. The authors consider two test sites, and show that although there are problems of spatial precision and identification with MSS data, the spectral advantages for site survey, and the monitoring of contaminants, are very considerable. The demerit concluded in this paper can be avoided if hyperspectral images are used in this study.

Barnes & Baker (2000) used multispectral airborne (green, red, near infrared, and thermal) and satellite (SPOT and Landsat TM) data to derive soil maps for a 770-ha research and demonstration farm in Maricopa, Arizona. Spectral classification procedures based on aerial and satellite images were used to map soil textural classes i.e., sandy clay loam, clay loam, etc. in individual fields with a reasonable degree of accuracy. The degree of accuracy can be increased in soil textural estimation if hyperspectral data is used.

Farifteh Jamshid & Farshed Abbas (2002) presented the overview of the possibilities and to outline the conceptual frame work of a method where the data obtained from air and space-born multi-spectral systems. Landsat TM was used in this study. Conventional sensor system data was used to model the reflectance of some individual soil components to some extent.

The review details of Govender et al (2006), differenced between multispectral and hyperspectral data; spatial and spectral resolutions and focuses on the application of hyperspectral imagery in water resource studies and, in particular the classification and mapping of land uses and vegetation. The availability of hyperspectral data has overcome the constraints and limitations of low spectral and spatial resolution imagery, and discreet spectral signatures. Hyperspectral images provide high spectral resolution data, with many narrow contiguous spectral bands allowing for detailed applications. From this review, it can be known that hyperspectral remote sensing is an effective technique in land use studies.

The work of Ignacio Melendez-Pastor et al (2008) deals with soils in SE Spain and explores the use of spectral derivative analysis to predict several soil properties using field based visible-near infrared (VNIR) spectro-radiometry. Robust regression models were obtained for electric conductivity (EC), carbonates, soil organic matter (SOM) and sand content with the first and/or Second derivative approximation. This study concluded that spectral derivative analysis is an excellent technique for the identification of highly correlated bands with several soil properties.

The potential of near infrared reflectance spectroscopy was studied by Zornoza et al (2008) to predict physical, chemical and biochemical properties in Mediterranean soils from South east of Spain. Soil samples from 13 locations were collected. These samples had a wide range of soil characteristics due to variations in land use, vegetation cover and specific climatic conditions. Partial least squares regression with cross validation was used to establish relationships between the NIR spectra and the reference data from physical, chemical and biochemical analyses. The results obtained from the study indicate that NIR spectroscopy could be a rapid, inexpensive and non-destructive technique to predict some physical, chemical and biochemical soil properties for Mediterranean soils, including variables related to the composition of the soil microbial community composition.

Expansive soils were collected from eastern part of Addis Ababa by Yitagesu et al (2009). The purpose of this study is to develop empirical models for predicting specific engineering parameters of expansive soils from their respective reflectance spectra. Samples were tested in soil lab (Atterberg limits, cation exchange capacity and free swell). Reflectance spectra were obtained from lab using full range spectrometer. From this study results we may know that certain soil index and geotechnical properties can be found using hyperspectral radiometer.

Cierniewski et al (2010) took spectral reflectance of the soil samples was measured in the 350 nm to 2500 nm region, at 1nm intervals using a spectro radiometer. The raw and transformed spectral data were then correlated with the soil properties using a simple linear regression. The correlation was calculated for the total dataset and for subsets obtained by clustering methods. The correlations between the raw hyperspectral reflectance of soils collected throughout the arable land in Poland representing various taxonomic units and textural groups, and their properties that significantly influence the soil reflectance are weak. These correlations, described by the coefficients of determination R^2, range from 0.04 to 0.36 for clay, Fe, $CaCO_3$, soil organic carbon (SOC), sand and silt contents. This study concluded that Using simple empirical models from the spectra of soil, certain soil properties can be determined.

2.10 SUMMARY AND CONCLUSIONS

Review of the above listed literature has clearly indicated the need to understand and determine the potential of hyperspectral radiometry and hyperspectral remote sensing in rapidly assessing the index properties of soils in large and inaccessible areas.

The above literature show that there is not much work has been carried out for soil particle size/ texture/grain size analysis using hyperspectral remote sensing and radiometer.

Many works were done for soil mineralogy, moisture content and organic matter content. That was also for mostly in agricultural studies. Because the spectra of soil is easily affected by those three soil properties.

Very few spectral studies were carried out for soil liquid limit, plastic limit and plasticity index.

From literature, we may infer that spectral studies were applied for particular type of soil or particular area.

Compared to image based studies, less amount of laboratory works were carried out. In Indian context, the spectroscopy study for analysing soil properties is not carried out much.