APPLICATION OF REMOTE SENSING AND GIS TECHNIQUES IN THE INVESTIGATION OF GROUNDWATER POTENTIAL OF JOS METROPOLIS

BY

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DECLARATION

I hereby declare that this dissertation has been written by me and it is a report of my research work. It has not been presented in any previous application for the award of Postgraduate Diploma. All quotations are indicated and sources of information specifically acknowledge by means of references.

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CERTIFICATION

This dissertation "Application Of Remote Sensing And GIS Techniques In The Investigation Of Groundwater Potential Of Jos Metropolis", meets the regulations governing the award of Postgraduate Diploma, Faculty of Environmental Science of Nasarawa State University, Keffi.

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DEDICATION

This work is dedicated to god Almighty who grant me the opportunity to complete this academic carrier.

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Abstract

Remote sensing relies on the interaction between materials on the surface of the earth and electromagnetic radiation. Information about an object is transmitted from the source of the radiation (eg. the sun) to the sensor by means of electromagnetic energy. This study seeks to the application of remote sensing and GIS techniques in the investigation of groundwater potential of Jos Metropolis. Both primary and secondary sources of data were utilized for this study. the image interpretation process involves various levels of complexity from a simple direct recognition of objects in the scene to the inference of site conditions, Analysis of lineament density is performed by counting number of lineaments contained in specified unit area, Data from drilled boreholes in the study area was collected and analyzed. The yield, surface elevation and coordinates are acquired and the data is plotted to create a spatial borehole yield map over the study area. Results shows that Grid Area A, B, D, E, I, K, L express mid to high groundwater potential while grid area C, F, G, H and N may express low to mid range groundwater potential, it was therefore concluded and recommended that the use of grids to comment on groundwater potential based on lineament maps should be explored. Other factors that affect groundwater potential could be mapped into grids and a more detailed and precise map on groundwater potential produced and presented in grid form. Such a study will greatly aid ground water exploration activities.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Geographers have used aerial photographs for decades to serve as database to perform structural mapping, lithology identification, geomorphologic studies, geo-hazard mapping, hydrocarbon /or mineral exploration and hydrogeologic studies. However, with the advent of space imagery, geoscientists now can extend that use in three important ways:

a. The advantage of large area or synoptic coverage allows them to examine in single scenes (or in mosaics) the geological portrayal of Earth on a regional basis

b. The ability to analyze multispectral bands (especially hyperspectral data sets) quantitatively in terms of numbers (DNs) and permits them to apply special computer processing routines to discern and enhance certain compositional properties of Earth materials

c. The capability of merging different types of remote sensing products (e.g., reflectance images with radar or with thermal imagery) or combining these with topographic elevation data and with other kinds of information bases (e.g., thematic maps; geophysical measurements and chemical sampling surveys) enables new solutions to determining interrelations among various natural properties of earth phenomena.

These new techniques also known as remote sensing can be defined as the ability to acquire information about an array of characteristics and attributes of an item without being in contact with that item. For instance, acquiring information about the color of an object by just looking at it with the eyes is a form of remote sensing. The idea of remote sensing as regards earth sciences, deals more with the interaction of the materials on the earth surface with electromagnetic radiation from the sun.

Remote sensing relies on the interaction between materials on the surface of the earth and electromagnetic radiation. Information about an object is transmitted from the source of the

radiation (eg. the sun) to the sensor by means of electromagnetic energy. The sensor gets the radiation either directly from the source or by reflection from the surface being investigated or by scattering. In a nutshell, when there is a source of radiation of EM spectra, materials on the earth surface, reflect it in different ways. This phenomenon is called reflectance and the reflectance signature of any object depends on its properties and attributes. For instance in plants, chlorophyll absorbs the red and blue ends of a near Infra Red wave making the reflectance of green band higher. This shows that reaction of electromagnetic waves with matter is controlled by the dynamics of the frequency of the wave, and the chemical composition, which is further controlled by the energy level structure of the matter.

Remote sensors are able to measure reflected electromagnetic waves within a range of wavelength spectra comprising of the visible, infra red, and microwave bands therefore when different surfaces exhibit their reflectance signatures with respect to the band of EM waves incident upon them, multispectral sensors like the landsat Thematic Mapper (TM) are able to produce a collage of different images which then help an experienced field expert make informed inferences from the remotely sensed image. A material therefore, can be identified based on its reflective signature if the sensor has the adequate resolution.

1.2 Statement of Research Problem

The landforms within the study area include hills, valleys and plains. The hills correspond to outcrops of granite located mostly at the extreme north and north-eastern parts of the study area. These hills rise from 1020 to 1425m above sea level. Other areas like Tudunwada and federal lowcost located along the western part of the study also exhibit high relief. Areas along the eastern and southern parts namely Anguldi, Airforce base, and Rayfield are generally low lying. The drainage within the study area is mainly structurally controlled and the pattern is partially dendritic and partially trellis. Tributaries of the Dilimi

River in the north, the Shen River in the eastern part and River N'gell through the western part of the study area drain the area.

1.3 Aim and Objectives of the Study

This research is aim at studying the application of remote sensing and GIS techniques in the investigation of groundwater potential of Jos Metropolis through the following objectives.

i. To delineate groundwater potential zones within the study area

ii. To demonstrate the effectiveness of remote sensing techniques in groundwater exploration

1.7 Research Question

i. What are the groundwater potential zones within the study area

ii. What is the effectiveness of remote sensing techniques in groundwater exploration.

1.5 Significance of the study

The landforms within the study area include hills, valleys and plains. The hills correspond to outcrops of granite located mostly at the extreme north and north-eastern parts of the study area. These hills rise from 1020 to 1425m above sea level. Other areas like Tudun wada and federal lowcost located along the western part of the study also exhibit high relief. Areas along the eastern and southern parts namely Anguldi, Airforce base, and Rayfield are generally low lying. The drainage within the study area is mainly structurally co..trolled and the pattern is partially dendritic and partially trellis. Tributaries of the Dilimi River in the north, the Shen River in the eastern part and River N'gell through the western part of the study area drain the area

CHAPTER TWO

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 Conceptual Framework

On the Jos Plateau of central Nigeria, the study area lies between the latitud and 10° 0' 0''N and longitudes 8° 45' 0''E and 9° 0'0" E. (Fig. 1). It is locat Federal Survey of Nigeria Naraguta Sheet 168 NE and S.E. Geologically, largely Jurassic Younger Granites underlie most of the area. The surface are (about 923,768 sq. km) is covered in nearly equal proportions by crystallin sedimentary rocks. The crystalline rocks are further sub-divided into three n namely: the Basement Complex, the Younger Granites, and the Tertiary–Rece (Ogezi, 2002). The term "Younger Granites" was introduced by Falconer distinguish these high-level anorogenic volcanic and hypabyssal rocks centered Plateau, (the study location in this research), from the plutonic Pan-African orog 600 million years old) "Older Granites" of the Basement Complex. These largely Jurassic, cassiterite-bearing Younger Granites of central Nigeria, in ge been extensively investigated (MacLeod et al., 1971). Associated with the cas accessory minerals such as columbite–tantalite, zircon, and monazite. The Granites are known to have significantly high concentrations of radioactive bearing minerals (Ike et al., 2002).

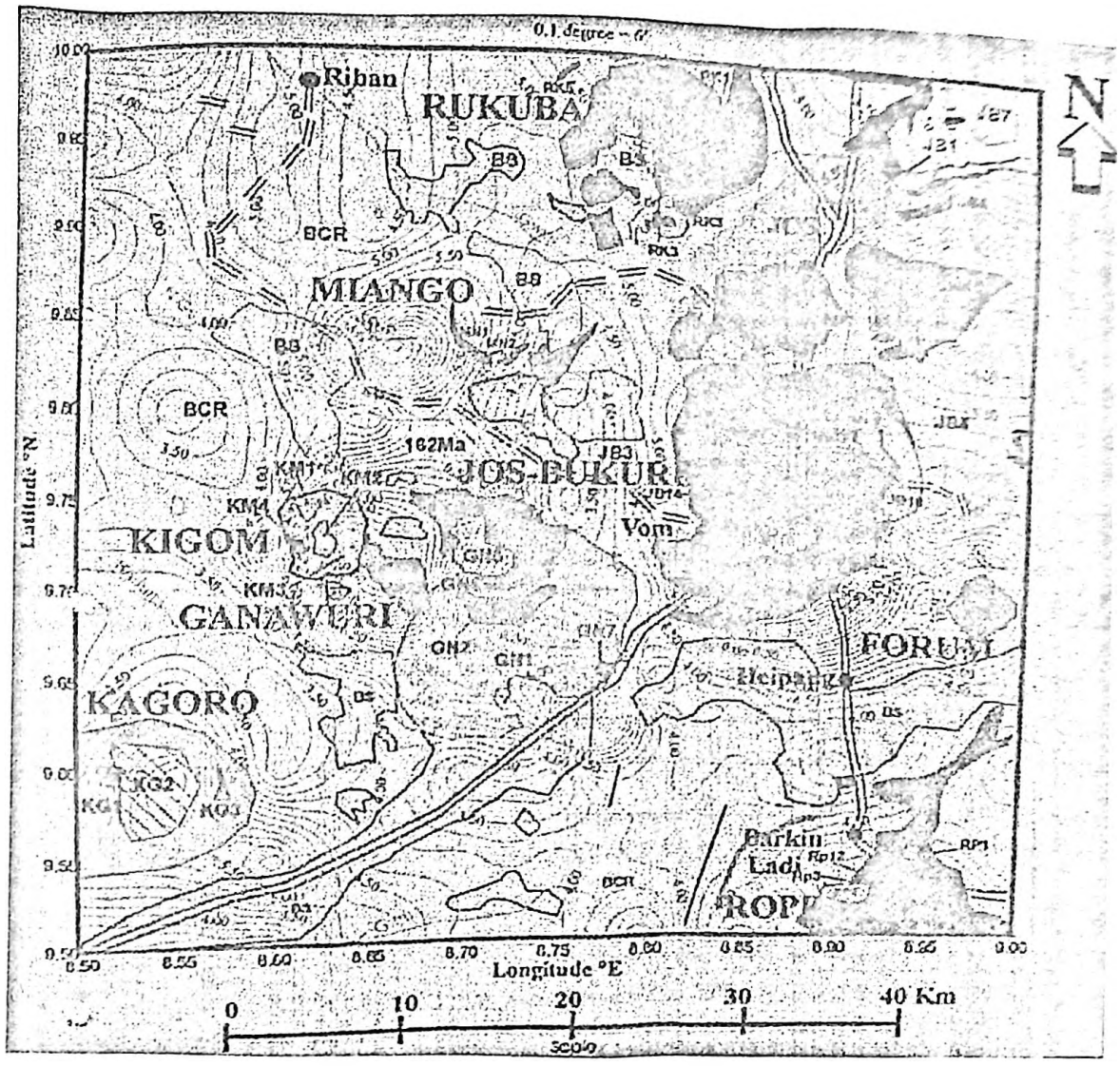


Fig 4 -Regional geology. The Naraguta Sheet (Source: National Centre for Remote Sensing)

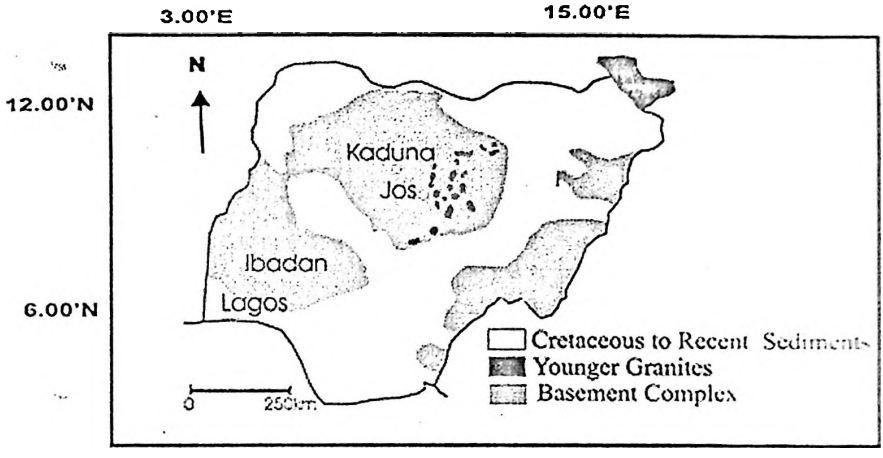


Fig 5- Map showing spatial occurrence of younger granites in Nigeria (Source : National Centre for Remote Sensing)

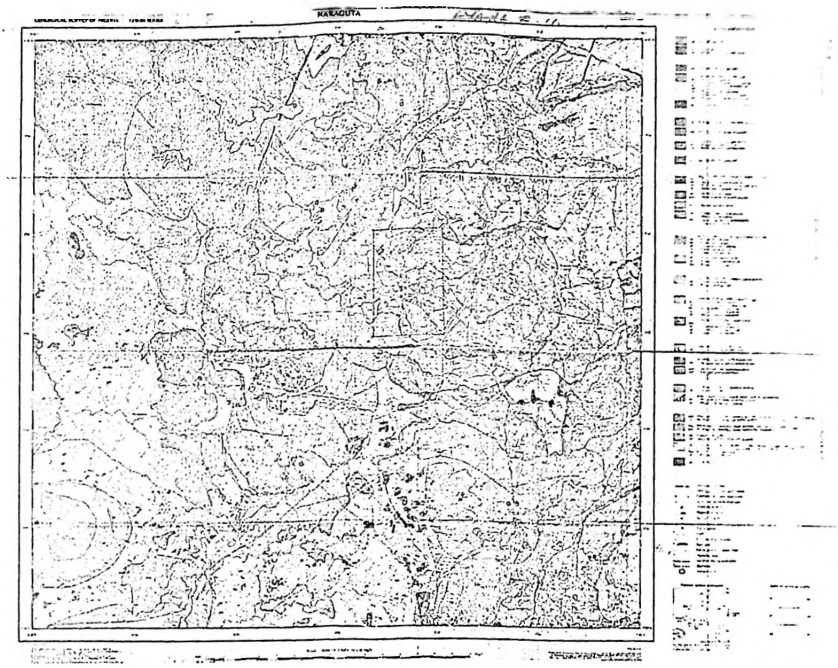


Fig 6- Map showing geology of the Jos (After Buchamenetal 1971) see enlarged map in appendix

2.2 Remote Sensing

As discussed in Chapter one, Remote sensing is a method of obtaining information about an object without being in direct contact with that object. It uses the reflected or emitted electromagnetic waves to decipher characteristics of the object or surface in question.

Remote sensing is a maturing discipline that calls on a wide range of specialties and crosses boundaries between traditional scientific and technological disciplines. Its multi-disciplinary nature requires its practitioner to have a good basic knowledge in many areas of science and requires interaction with researchers in a wide range of areas

2.3 The physics of remote sensing

Electromagnetic energy is the means by which information is transmitted from an object to a sensor. Information could be encoded in the frequency content, intensity, or polarization of the electromagnetic wave. The information is propagated by electromagnetic radiation at the velocity of light from the source directly through free space, or indirectly by reflection, scattering, and re-radiation to the sensor. The interaction of electromagnetic waves with natural surfaces and atmospheres is strongly dependent on the frequency of the waves. Waves in different spectral bands tend to excite different interaction mechanisms such as electronic, molecular, or conductive mechanisms.

2.3.1 Electromagnetic spectrum

The electromagnetic spectrum is divided into a number of spectral regions. For the purpose of this text, we use the classification illustrated in Figure 7.

The radio band covers the region of wavelengths longer than 10 cm (frequency less than 3 GHz). This region is used by active radio sensors such as imaging radars, altimeters, and sounders, and, to a lesser extent, passive radiometers.

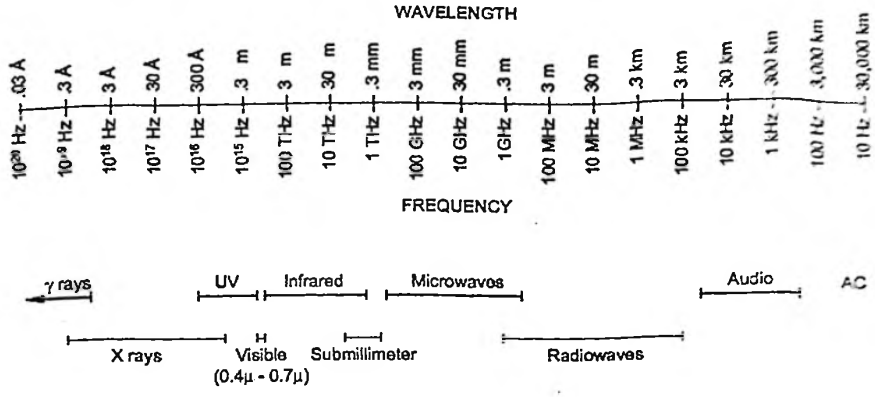


Fig7: Electromagnetic spectrum (source: Introduction to the physics and techniques of Remote Sensing, John Wiley and Sons, 2006)

The microwave band covers the neighboring region, down to a wavelength of 1 mm (300 GHz frequency). In this region, most of the interactions are governed by molecular rotation, particularly at the shorter wavelengths. This region is mostly used by microwave radiometers/spectrometers and radar systems.

The infrared band covers the spectral region from 1 mm to 0.7 m. This region is sub-divided into subregions called sub millimeter, far infrared, thermal infrared, and near infrared. In this region, molecular rotation and vibration play important roles. Imagers, spectrometers, radiometers, polarimeters, and lasers are used in this region for remote sensing. The same is true in the neighboring region, the visible region (0.7m– 0.4m) where electronic energy levels start to play a key role.

In the next region, the ultraviolet (0.4m to 300 Å), electronic energy levels play the main role in wave–matter interaction. Ultraviolet sensors have been used mainly to study planetary atmospheres or to study surfaces with no atmospheres because of the opacity of gases at these short wavelengths.

X-rays (300 Å to 0.3 Å) and gamma rays (shorter than 0.3 Å) have been used to an even lesser extent because of atmospheric opacity. Their use has been limited to low-flying aircraft platforms or to the study of planetary surfaces with no atmosphere (e.g., the Moon).

2.3.2 Interaction of electromagnetic wave with matter

The interaction of electromagnetic waves with matter (e.g., molecular and atomic structures) calls into play a variety of mechanisms that are mainly dependent on the frequency of the wave (i.e., its photon energy) and the energy level structure of the matter. As the wave interacts with a certain material—be it gas, liquid, or solid—the electrons, molecules, and/or nuclei are put into motion (rotation, vibration, or displacement), which leads to exchange of energy between the wave and the material. Atomic and molecular

systems exist in certain stationary states with well-defined energy levels. In the case of isolated atoms, the energy levels are related to the orbits and spins of the electrons. These are called the electronic levels. In the case of molecules, there are additional rotational and vibration energy levels that correspond to the dynamics of the constituent atoms relative to each other. Rotational excitations occur in gases where molecules are free to rotate. The exact distribution of the energy levels depends on the exact atomic and molecular structure of the material. In the case of solids, the crystalline structure also affects the energy level distribution.

2.3.3 Interaction mechanisms throughout the electromagnetic spectrum

Starting from the highest spectral region used in remote sensing, gamma and x-ray interactions with matter call into play atomic and electronic forces such as the photoelectric effect (absorption of photon with ejection of electron), Compton effect (absorption of photon with ejection of electron and radiation of lower-energy photon), and pair production

effect (absorption of photon and generation of an electron–positron pair). The photon energy in this spectral region is larger than 40 eV. This spectral region is used mainly to sense the presence of radioactive materials.

In the ultraviolet region (photon energy between 3 eV and 40 eV), the interactions call into play electronic excitation and transfer mechanisms, with their associated spectral bands. This spectral region is used mostly for remote sensing of the composition of the upper layers of the Earth and planetary atmospheres.

In the visible and near infrared (energy between 0.2 eV and 3 eV), vibration and electronic energy transitions play the key role. In the case of gases, these interactions usually occur at well-defined spectral lines, which are broadened due to the gas pressure and temperature. In the case of solids, the closeness of the atoms in the crystalline structure leads to a wide

variety of energy transfer phenomena with broad interaction bands. These include molecular vibration, ionic vibration, crystal field effects, charge transfer, and electronic conduction. Some of the most important solid surface spectral features in this wavelength region include the following:

1. The steep fall-off of reflectance in the visible toward the ultraviolet and an absorption band between 0.84 and 0.92m associated with the Fe3+ electronic transition. These features are characteristic of iron oxides and hydrous iron oxides, collectively referred to as limonite.
2. The sharp variation of chlorophyll reflectivity in the neighborhood of 0.75m, which has been extensively used in vegetation remote sensing.

3. The fundamental and overtone bending/stretching vibration of hydroxyl (OH) bearing materials in the 2.1 to 2.8m region, which are being used to identify clay-rich areas associated with hydrothermal alteration zones.

In the mid-infrared region (8 to 14m), the Si–O fundamental stretching vibration provides diagnostics of the major types of silicates. The position of the restrahlen bands, or regions of metallic-like reflection, is dependent on the extent of inter- connection of the Si–O tetrahedra comprising the crystal lattice. This spectral region also corresponds to vibrational excitation in atmospheric gaseous constituents.

In the thermal infrared, the emissions from the Earth's and other planets' surfaces and atmospheres are strongly dependent on the local temperature, and the resulting radiation is governed by Planck's law. This spectral region provides information about the temperature and heat constant of the object under observation. In addition, a number of vibrational bands provide diagnostic information about the emitting object's constituents.

In the sub millimeter region, a large number of rotational bands provide information about

the atmospheric constituents. These bands occur all across this spectral region, making most planetary atmospheres completely opaque for surface observation. For some gases such as water vapor and oxygen, the rotational band extends into the upper regions of the microwave spectrum.

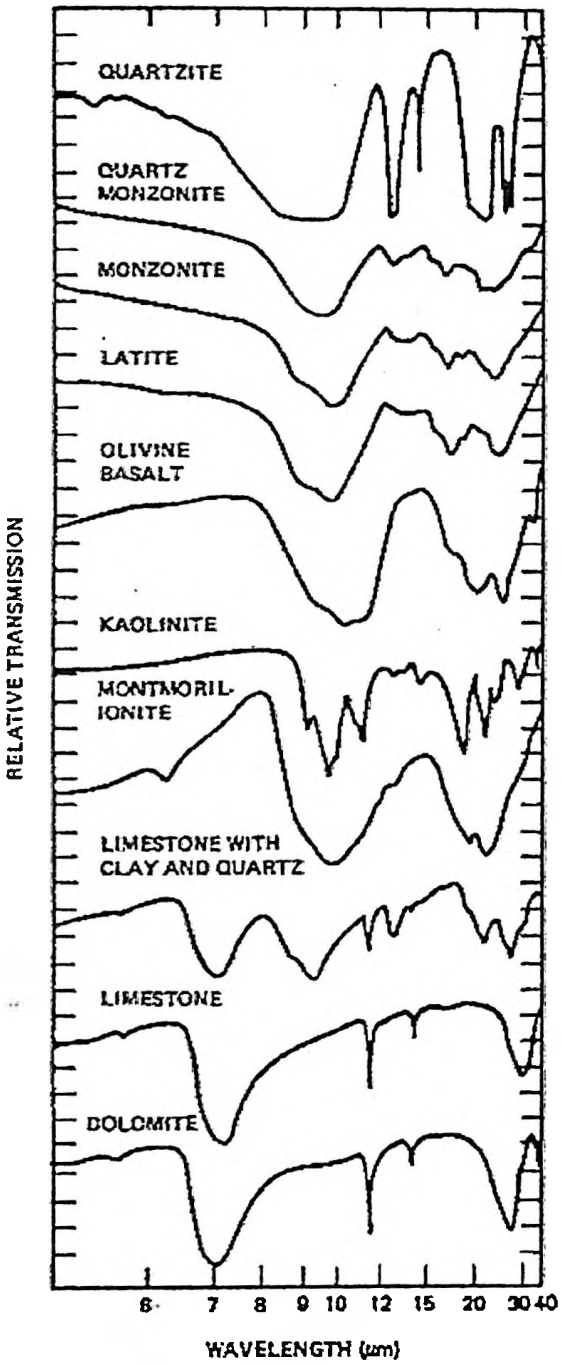


fig8: Transmission spectra of common silicates (Hunt and Salisbury 1974)

Spectral region	Main interaction mechanisms	Examples of remote sensing applications
Gamma rays, x-rays	Atomic processes	Mapping of radioactive materials
Ultraviolet	Electronic processes	Presence of H and He in atmosphere
Visible and near infrared	Electronic and vibration molecular processes	Surface chemical composition, vegetation cover, and biological properties
Mid-infrared	Vibrational, vibrational–rotational molecular processes	Surface chemical composition, atmospheric chemical composition
Thermal infrared	Thermal emission, vibrational and rotational processes	Surface heat capacity, surface temperature, atmospheric temperature, atmospheric and surface constituents
Microwave	Rotational processes, thermal emission, scattering, conduction	Atmospheric constituents, surface temperature, surface physical properties, atmospheric precipitation
Radio frequency	Scattering, conduction, ionospheric effect	Surface physical properties, subsurface sounding, ionospheric sounding

Table 1: Wave–Matter Interaction Mechanisms across the Electromagnetic Spectrum(source: Introduction to the physics and techniques of Remote Sensing, John Wiley and Sons, 2006)

2.4 Application of Remote Sensing to Hydrogeology

Most remote sensing techniques, with the exception of airborne geophysics and radar, have no penetrating capabilities beyond the uppermost layer. However, the synergism of satellite imagery and airborne geophysical data can be a valuable asset in the early stages of groundwater exploration and in groundwater modelling. In the physical applications of imaging sensors, long wave radar can sometimes detect groundwater levels at depths of a few metres and other subsurface features, such as buried channels (McCauley *etal.*, 1982), but only if all conditions are suitable, i.e. coarse-grained deposits, dry vadose zone without vegetation and some *a priori* knowledge of the geology. Radar imagery has its general use in hydrogeology for the interpretation of geological structures.

2.4.1 General techniques in Groundwater studies

Springs, when flow is appreciable and especially along coastlines, represent important losses of groundwater into sea. The ability of remotely sensed data to detect springs and seeps exists.

Infra-red (I.R.) and Colour I.R. photographs taken during spring when plant growth begins help in the detection of springs due to spot location of dark tone of water near spring zone in I.R. and lush plant growth near springs showing as a cluster of red in Colour I.R. Film.

Recent work on this aspect by Wood (1972) and by Lyon and Lee (1968) have indicated that springs with flows of about 0.06 - 0.13 litres/ second are detectable on thermal images. Lyon and Lee used thermal data obtained at Mono Lake, California, in June, 1968, to detect thermal springs issuing along the lake's shoreline. An isothermal map prepared from the thermal imagery delineated spring discharge patterns. Spring temperatures ranged from about 78°C to 85.6°C, where as the lake temperature was about 14°C to 18°C. Imagery was obtained at 2100 and 0400 hours at a height of 350m and 1000m above the ground. The early morning data showed the springs most clearly. Spring discharges of less than 0.063 L/Sec. were detected. Sub-lacustrine springs were not detected except where nearby springs had created an anomalous surface sheet of cold fresh water.

The issuance of fresh water from submarine springs has become a subject of some interest. As per studies by U.S. Geological Survey, in 1972, such springs often have high volume of flow indicating that the related coastal aquifers may be under developed. In order to capture this water before it reaches the sea, wells might be drilled into permeable zones on the mainland. On the other hand, such fresh water outlets might conceivably become the source of salt water intrusion should a coastal aquifer become over-developed. Aerial photography has also been used successfully to map submarine springs located 4 km off-shore from Crescent Beach on the Northeast coast of Florida, and thermal imagery (8 to

14μm) has also been used to map a submarine spring about 19 km off the Southwest coast of Florida. Fischer et al, 1966 described more than 25 large discharges of groundwater from the island of Hawaii seen as anomalies on thermal infrared imagery.

Mayers (1970) examined the ability of thermal infrared data to detect the presence of shallow aquifers in an area in South Dakota covered by glacial drift. Thermal infrared data were obtained during predawn hours on August 5, 1970. At this time of the year, shallow aquifers would be cooler than their surroundings, and the presence of cool areas in the imagery was expected to indicate the presence of shallow aquifers. The maximum and minimum temperatures recorded by an airborne radiometer during the flight were 17.8°C and 14.2°C respectively.

In an effort by U.S.G.S. (Kohout) to utilize infrared colour and colour photography to map areas of groundwater discharge around the coastal waters of Jamaica, it was found that submarine springs on the north-central coast of Jamaica discharged primarily clear water from Karstic limestone and were not discernible in the aerial photographs. In contrast, submarine springs on the south coast discharge from sand and gravel aquifers, and turbidity plumes were clearly visible in colour photographs. Large-scale aerial photography can be utilized to map streams or parts of stream channels where localized gain (such as base flow or seeps), and loss (regions of no surface flow) occur in the channel. This information allows to locate the "gaining" and "losing" reaches, and thereby gives some indication of groundwater motion in near surface rocks. Further, when combined with geologic data localized sites of gain or loss of stream-flow may indicate the presence of confined or unconfined aquifers and of geologic controls of groundwater.

2.4.2 Drainage analysis and other special indicators

Occurrence of vegetation is likely to be different according to soils derived from shale, limestone, sandstone, granite etc. The flora characteristics for any locality vis-à-vis rock

occurring in the area must be learnt. Linear vegetation patterns may represent faults, fracture or dykes, all of which have control on groundwater occurrence and movement. Xerophytes indicate arid conditions. Occurrence of Phreatophytic vegetation generally indicates fresh groundwater availability at shallower depths. Brackish/ saline water loving plants Halophytes indicate poor water quality.

Drainage network analysis is important for hydrologic and hydrogeologic studies. Drainage density of a region depends on the climatic factors, landforms, slopes and stage of geomorphic cycle, lithology and its permeability etc. Hence drainage density is an important index in hydrogeologic studies, and can be evaluated from aerial photographs. Ray and Fischer (1960) have emphasized that permeability has a fundamental influence on drainage density. In bedrock areas drainage textures and patterns depend, among others, on the lithologic character of underlying rocks and their structural disposition. For example. fine textured (high density) drainage over flat area may lead to the inference that the underlying materials are shaly (impermeable) and favour high run-off and erosion, thereby indicating poor infiltration possibilities. Centripetal drainage pattern develops in basinal areas/ closed synclines. Braided drainages indicate possibility of high channel-bed infiltration into coarse bed materials. Gaining and losing reaches of rivers, base flows in valley area, changes in water spread in rivers and drainage anomalies can be observed through analysis of remotely sensed data. In alluvial areas, low drainage density (coarse texture) braided pattern develops over highly porous and permeable coarse sands/ gravels indicating high recharge potential into underlying aquifers. Drainage features have to be observed in details.

2.5 Principles of remote sensing in groundwater exploration

Groundwater exploration means to identify and to locate the zone of occurrence and recharge of groundwater in a particular basin or a catchment. Geological set up is

established for knowing about surface and subsurface nature of terrain. In other words the composition of rock with its hydrological character is known. Topographic and surficial features are mapped in order to ascertain from highest to lowest area, where water from different higher places can move and accumulate. These particular zones are present in various terrain. The identification of such focal places from the entire area are thus selected for groundwater exploration. The spectral, spatial and temporal contents of terrain are recorded by airborne scanners and cameras, as well as remote sensing satellites having repetitive coverage. Data in digital form from satellites allows for enhanced computer aided data processing and analysis.

Visual interpretation of aerial and satellite pictures using standard interpretation keys/ criteria can aid in the deciphering of specific site conditions such as location of spring and seepage zones (dark tone, lush vegetation clusters, abrupt appearance of water course at the base of hills), infiltration / recharge zones for groundwater (dry channels, abruptly ending streams), effluence (stream bank moistures), flooding, and water logged areas etc. also act as a guide to further field studies, location of likely exploration sites for groundwater selection of gauge sites for hydrologic observations, to name a few usage. These together with the additional "tools" of other remote sensing techniques can allow the assessment of water resources more readily in an integrated manner.

Hydrologic studies are largely confined to assist in geologic & structural mapping of water bearing formations, geomorphologic mapping, drainage basin analysis, determining locations in field, evaluating ground conditions, determining flood plain areas and areas of lakes, swamps etc. Qualitative interpretation of features of groundwater interest are largely possible through remote sensing and field checks. Heath and Trainer (1968) gave the types of inferences of geologic and groundwater conditions from analysis of aerial photographs. Hydromorphogeologic mapping approach using visual analysis of aerial

photographs and satellite images and field checks for groundwater surveys has been successfully used. Hydromorphogeologicmaps depict the important geomorphic units, landforms and underlying geology so as to provide an understanding of the forms versus processes, materials/ lithology, structures and geologic controls vis-à-vis groundwater occurrence as well as prospects. The approach is useful in siting of exploratory water well sites and forms an effective exploration base for area wise groundwater exploration.

Such applied geoscientific maps depicting prospective zones for groundwater targeting are essential, as base, for planning and execution of groundwater exploration. Hydromorphogeology mapping is an integrated, applied geoscientific approach for groundwater prospective zonation. Groundwater-worthy features can thus be targeted, and can be grouped in Alluvial and Hard rock terrain.

Alluvial morphologic features can be readily mapped giving clues to groundwater occurrence in different groundwater-worthy landforms vis-à-vis materials composing them. whereas in hard rock area, the weaker zones are also considered. Areas can be studied in the following manner -

- Granular sedimentary rocks (Consolidated and semi-consolidated); water table and confined aquifers.

- Crystalline (Igneous and metamorphic rocks) - Hard rocks; water table to semi-confined conditions.

- Soluble rocks - Limestones; Karst water table condition, groundwater occurrences in solution cavities/ Karsted rock voids.

2.5.1 Granular (Consolidated) Sedimentary Rocks :

In granular (consolidated) sedimentary rocks with development of open fractures, faults and weathering, groundwater possibilities are moderately good while highly compacted, cemented, and folded rocks have poor prospects. Gently inclined, semi-consolidated

sandstone formations (occupying cuestas) form good aquifers in down-dip sectors. Unconsolidated granular materials like gravel and coarse to medium sand deposits are highly prospective aquifers. Recharge areas over such deposits can be easily located by a pictorial analysis of drainage features (disappearance of surface flow, dry streams) and related terrain analysis. Patterns of groundwater bearing forms/ deposits and formations such as : Alluvial fans (coarse deposits), Terrace deposits (silt, sandy, gravelly), Intermontane valley deposits (coarse), Abandoned channels (sands), water bearing sandstones etc, can be readily recognized in remotely sensed data.

2.5.2 Crystalline and Hard Rocks :

Crystalline, hard rocks hold groundwater depending on the depth and extent of weathered materials overlying unweatheredbed rock (variable pediment zones), and the size, nature, intensity, orientation and inter-connection of joints, fractures, fissures, and faults in these rocks. Study of fractures, their pattern, density, frequency, nature ("open" or "closed") and orientation, extension into covered areas using air photo and satellite picture analysis are specially useful in targeting groundwater in hard rock areas. "Open" fracture zones are good yielders of groundwater from wells located along them. Geomorphic mapping of outcrop and weathered zones, as well as delineation of fault- fractures systems in hard rock areas can be greatly aided by image interpretation. Major faults and fracture zones are known to yield good quantities of groundwater in such areas. Deeper weathered pediments are also good.

2.5.3 Limestones :

In limestones, solution cavities and solutionally enlarged joints creating secondary porosity allow the occurrence of good amounts of groundwater therein. Internal drainages are indicated over limestone terrain by sink/swallow holes, which imply possibility of large amount of subsurface water occurrence in solution caverns, cavity inter-connections.

subsurface channel-ways etc. (KARST).

2.6 Image Processing

Interpretation and analysis of remote sensing imagery involves the identification and or measurement of various targets in an image in order to extract useful information about them. Targets in remote sensing images may be any feature or object which can be observed in an image, and have the following characteristics. Basically, all satellite image-processing operations can be grouped into three categories: Image Rectification and Restoration, Enhancement and Information Extraction. The former deals with initial processing of raw image data to correct for geometric distortion, to calibrate the data radiometrically and to eliminate noise present in the data. The enhancement procedures are applied to image data in order to effectively display the data for subsequent visual interpretation. It involves techniques for increasing the visual distinction between features in a scene. The objective of the information extraction operations is to replace visual analysis of the image data with quantitative techniques for automating the identification of features in a scene. This involves the analysis of multispectral image data and the application of statistically based decision rules for determining the land cover identity of each pixel in an image. The intent of classification process is to categorize all pixels in a digital image into one of several land cover classes or themes. This classified data may be used to produce thematic maps of the land cover present in an image.

2.6.1 A digital Image

A digital remotely sensed image is typically composed of picture elements (pixels) located at the intersection of each row i and column j in each K bands of imagery. Associated with each pixel is a number known as Digital Number (DN) or Brightness Value (BV), that depicts the average radiance of a relatively small area within a scene. A smaller number indicates low average radiance from the area and the high number is an indicator of high

radiant properties of the area.

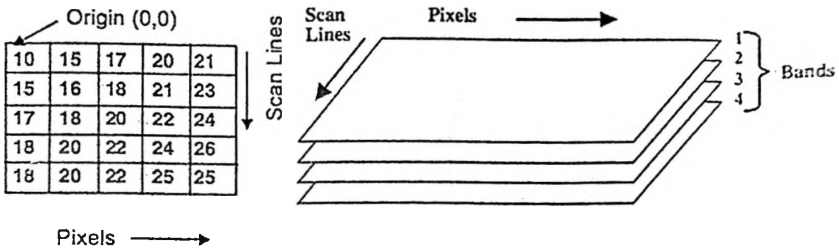


Fig 9: Structure of a Digital Image and Multispectral Image (Indian institute for Remote Sensing)

2.6.2 Image rectification and registration

Rectification is a process of geometrically correcting an image so that it can be represented on a planar surface , conform to other images or conform to a map. That is, it is the process by which geometry of an image is made planimetric. It is necessary when accurate area, distance and direction measurements are required to be made from the imagery. It is achieved by transforming the data from one grid system into another grid system using a geometric transformation.

2.6.3 Image enhancement techniques

Image enhancement techniques improve the quality of an image as perceived by a human. These techniques are most useful because many satellite images when examined on a colour display give inadequate information for image interpretation. There is no conscious effort to improve the fidelity of the image with regard to some ideal form of the image. There exists a wide variety of techniques for improving image quality. The contrast stretch, density slicing, edge enhancement, and spatial filtering are the more commonly used

techniques. Image enhancement is attempted after the image is corrected for geometric and radiometric distortions. Image enhancement methods are applied separately to each band of a multispectral image. Digital techniques have been found to be most satisfactory than the photographic technique for image enhancement, because of the precision and wide variety of digital processes.

2.6.3.1 Contrast

Contrast generally refers to the difference in luminance or grey level values in an image and is an important characteristic. It can be defined as the ratio of the maximum intensity to the minimum intensity over an image.

Contrast ratio has a strong bearing on the resolving power and detectability of an image. Larger this ratio, more easy it is to interpret the image. Satellite images lack adequate contrast and require contrast improvement.

2.6.3.2 Contrast Enhancement

Contrast enhancement techniques expand the range of brightness values in an image so that the image can be efficiently displayed in a manner desired by the analyst. The density values in a scene are literally pulled farther apart, that is, expanded over a greater range. The effect is to increase the visual contrast between two areas of different uniform densities. This enables the analyst to discriminate easily between areas initially having a small difference in density.

2.6.3.3 Linear Contrast Stretch

This is the simplest contrast stretch algorithm. The grey values in the original image and the modified image follow a linear relation in this algorithm. A density number in the low range of the original histogram is assigned to extremely black and a value at the high end is assigned to extremely white. The remaining pixel values are distributed linearly between these extremes. The features or details that were obscure on the original image will be clear

in the contrast stretched image. Linear contrast stretch operation can be represented

graphically as shown in Fig. 4. To provide optimal contrast and colour variation in colour composites the small range of grey values in each band is stretched to the full brightness range of the output or display unit.

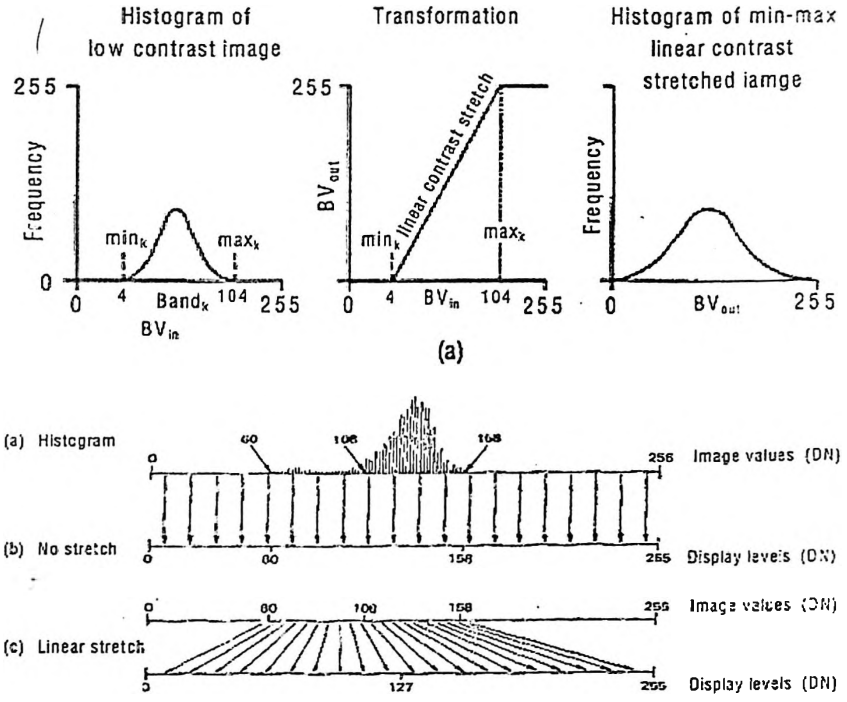


Fig 10: Linear Contrast Stretch (source Lillesand and Kiefer, 1993)

2.6.3.4 Non-Linear Contrast Enhancement

In these methods, the input and output data values follow a non-linear transformation. The general form of the non-linear contrast enhancement is defined by y = f (x), where x is the input data value and y is the output data value. The non-linear contrast enhancement techniques have been found to be useful for enhancing the colour contrast between the nearly classes and subclasses of a main class.

2.6.3.5 Spatial Filtering

A characteristic of remotely sensed images is a parameter called spatial frequency defined as number of changes in Brightness Value per unit distance for any particular part of an image. If there are very few changes in Brightness Value once a given area in an image, this is referred to as low frequency area. Conversely, if the Brightness Value changes dramatically over short distances, this is an area of high frequency.

Spatial filtering is the process of dividing the image into its constituent spatial frequencies, and selectively altering certain spatial frequencies to emphasize some image features. This technique increases the analyst's ability to discriminate detail. The three types of spatial filters used in remote sensor data processing are: Low pass filters, Band pass filters and High pass filters.

2.6.3.6 Principal component analysis

The multispectral image data is usually strongly correlated from one band to the other. The level of a given picture element on one band can to some extent be predicted from the level of that same pixel in another band.

Principal component analysis is a pre-processing transformation that creates new images from the uncorrelated values of different images. This is accomplished by a linear transformation of variables that corresponds to a rotation and translation of the original coordinate system.

Principal component analysis operates on all bands together. Thus, it alleviates the difficulty of selecting appropriate bands associated with the band ratioing operation. Principal components describe the data more efficiently than the original band reflectance values. The first principal component accounts for a maximum portion of the variance in the data set, often as high as 98%. Subsequent principal components account for successively smaller portions of the remaining variance.

2.6.4 Image classification

The overall objective of image classification is to automatically categorize all pixels in an image into land cover classes or themes. Normally, multispectral data are used to perform the classification, and the spectral pattern present within the data for each pixel is used as numerical basis for categorization. That is, different feature types manifest different combination of DNs based on their inherent spectral reflectance and emittance properties.

The term classifier refers loosely to a computer program that implements a specific procedure for image classification. Over the years scientists have devised many classification strategies. From these alternatives the analyst must select the classifier that will best accomplish a specific task. At present it is not possible to state that a given classifier is "best" for all situations because characteristics of each image and the circumstances for each study vary so greatly. Therefore, it is essential that the analyst understands the alternative strategies for image classification.

The traditional methods of classification mainly follow two approaches: unsupervised and supervised. The unsupervised approach attempts spectral grouping that may have an unclear meaning from the user's point of view. Having established these, the analyst then tries to associate an information class with each group. The unsupervised approach is often referred to as clustering and results in statistics that are for spectral, statistical clusters. In the supervised approach to classification, the image analyst supervises the pixel categorization process by specifying to the computer algorithm; numerical descriptors of the various land cover types present in the scene. To do this, representative sample sites of known cover types, called training areas or training sites, are used to compile a numerical interpretation key that describes the spectral attributes for each feature type of interest. Each pixel in the data set is then compared numerically to each category in the interpretation key and labeled with the name of the category it looks most like. In the

supervised approach the user defines useful information categories and then examines their spectral separability whereas in the unsupervised approach he first determines spectrally separable classes and then defines their informational utility.

It has been found that in areas of complex terrain, the unsupervised approach is preferable to the supervised one. In such conditions if the supervised approach is used, the user will have difficulty in selecting training sites because of the variability of spectral response within each class. Consequently, a prior ground data collection can be very time consuming. Also, the supervised approach is subjective in the sense that the analyst tries to classify information categories, which are often composed of several spectral classes whereas spectrally distinguishable classes will be revealed by the unsupervised approach, and hence ground data collection requirements may be reduced. Additionally, the unsupervised approach has the potential advantage of revealing discriminable classes unknown from previous work. However, when definition of representative training areas is possible and statistical information classes show a close correspondence, the results of supervised classification will be superior to unsupervised classification.

2.6.4.1 Unsupervised classification

Unsupervised classifiers do not utilize training data as the basis for classification. Rather, this family of classifiers involves algorithms that examine the unknown pixels in an image and aggregate them into a number of classes based on the natural groupings or clusters present in the image values. It performs very well in cases where the values within a given cover type are close together in the measurement space, data in different classes are comparatively well separated.

2.6.4.2 Supervised classification

Supervised classification can be defined normally as the process of samples of known identity to classify pixels of unknown identity. Samples of known identity are those pixels

located within training areas. Pixels located within these areas term the training samples used to guide the classification algorithm to assigning specific spectral values to

appropriate informational class.

2.7 Lineament interpretation

Structural trends such as discontinuities can be detected in many forms, such as faults, joints, bedding planes or foliations, and may be useful in several environmental applications including landslide studies, hydrogeology and mineral exploration. Such discontinuities can be detected in the form of lineaments detected not only using ground mapping but also using remotely sensed data such as conventional aerial photographs and satellite imagery. Good correlation between structures mapped in the field and using the lineament system enables the lineaments to be regarded as representative of the structural manifestation of a particular area (Morelli and Piana, 2006). Lineament in this study is defined as a mappable, linear feature of a surface whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differ from the pattern of adjacent features and presumably reflect some subsurface phenomenon(Hobbs, 1904). This definition is chosen because it is the most practical definition in the context of remote sensing image interpretation (Gupta, 1991).

Lineament analysis in hard-rock terrains has been performed widely as a means for groundwater exploration. Using remotely sensed satellite imagery, lineaments are detected by alignment trends of features such as vegetation, drainage patterns, outcrop truncations, soil moisture and topography. These can be identified with attributes including tone, color, texture, pattern and association. Such lineaments are indicative of secondary porosity in the form of fractures and if intersected by a well at depth, have the potential to supply large and reliable quantities of water (Meijerink et al., 2007; Kann and Glenn, 2006; Park et al., 2000; Mabee, 1999; Magowe and Carr, 1999; Edet et al., 1998; Sander et al., 1997; Kresic,

1995; Mabee et al., 1994).

Remote sensing provides a means for regional understanding of groundwater systems. Its data provides information on spatial patterns of groundwater dependent vegetation or salinization, and is often the only source to study the history of change. The interpretation of remotely sensed data for linear features mapping is an integral part of groundwater exploration programs in hard rock terrains (Greenbaum, 1992a, b; Gustafsson, 1993). Remote sensing with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within short time has become a very handy tool in assessing, monitoring and conserving groundwater resources. In addition, satellite data provides quick and useful baseline information on the parameters controlling the occurrence and movement of groundwater, such as geology, lithology geomorphology, soils, land use cover, lineaments etc.

CHAPTER THREE

STUDY AREA AND RESEARCH METHODOLOGY

3.1 The Study Area

3.1.1 Location

The study area is the Jos metropolis, Plateau state, North central Nigeria. It lies between longitudes 8° 48' E and 8° 57' E and latitudes 9° 49' N and 9° 59' N. It encompasses the following communities- NNPC depot, Farin Gada, Neils valley, Rukuba Barracks, Airforce base, Rayfield and Tudunwada. It covers a total area of 313.8km^2. The study location is known for its incessant water supply problems. In 2002, the Plateau State Economic Empowerment Development Strategy (PLASEEDS) described Plateau state as being very poor in water supply and sanitation. Jos, according to UN- HABITAT, 2006 is said to supply water to only 20% of its inhabitants. Resident depend on hand- dug wells and boreholes for water supply and the water supply problems get worst during the dry season which spans from November till May (Adiuku-Brown 2004).

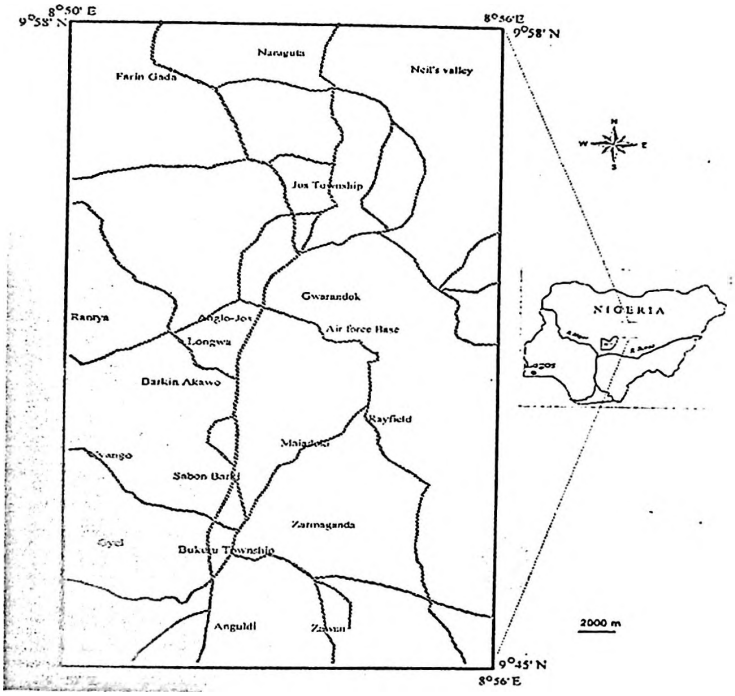


Fig 1 – Location map of the study area(National Centre for Remote sensing,jos)

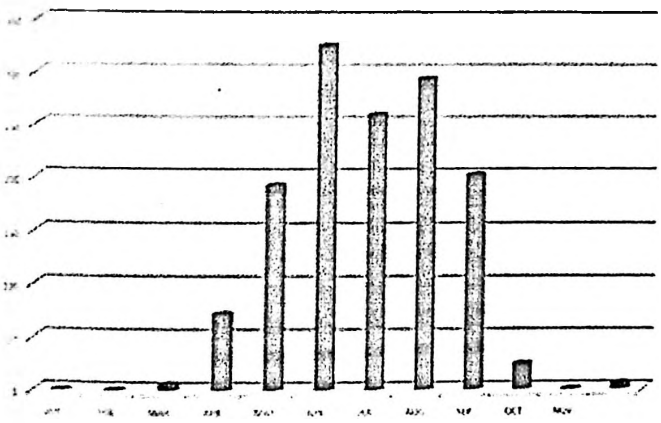


Fig 2 Mean monthly rainfall (Source: Geography observation station University of Jos)

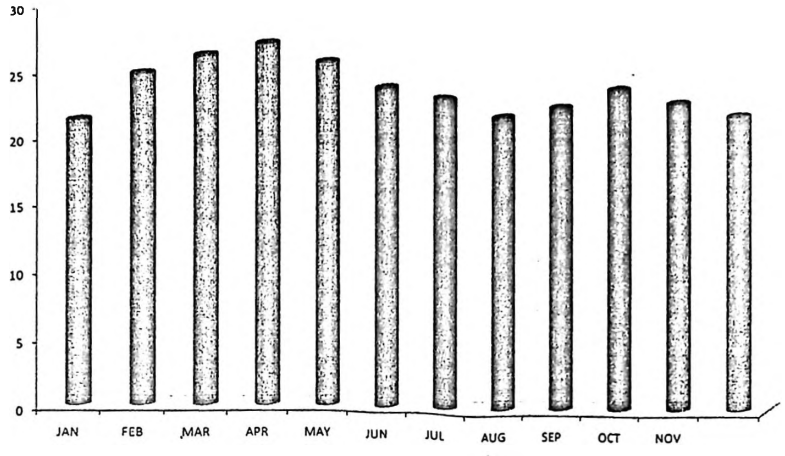


Fig 3-Mean monthly temperature of the study area(Source: Geography observation station University of Jos)

The Jos Plateau is a highland standing at about 1,300m a.s.l. and covering an area of almost 8,000 sq.km. It is thus, by far, the most conspicuous morphological feature formed on old basement complex rocks influenced by volcanic activities, with thick basalt surfaces from lava flows. The rocks in the study area are basically crystalline rocks belonging to the Younger Granite and the Basement Complex, lacking primary porosity where ground water could accumulate for exploitation. Water can only be stored where there is secondary porosity resulting from geodynamic processes leading to the creation of fractures. Borehole sitting for water abstraction is difficult in the area study because the occurrence of water is sporadic. The location of water bearing structures in these rocks need a hydro-geophysical investigation. Remote sensing is a very robust scientific tool for monitoring the physico-chemical and biological environment. This stems from its ability to furnish spatio-temporal data on the earth's atmosphere, the surface of the earth and underneath the earth in a rapid and cost effective manner. In this research, the application of remote sensing for

groundwater exploration is carried out.

3.2 Location Study

In order to establish the goals and objectives of this research, a number of tasks were carried out in sequence. These included image processing which involves establishment of interpretation goals, image acquisition, and establishment of interpretation keys. Others were image interpretation, lineament mapping, lineament analysis finally, hydrogeological data for the area under investigation was acquired and used in the study.

For this study, two images were used. aLandsat 7 ETM image covering the study area and a high resolution 3 band image of the Jos metropolis were used. The image of the study area was acquired from the National Remote Sensing Centre. The map was geo-referenced and the study area was subset from the acquired image because the latter had much larger scenes. These operations were carried out using Ilwis 3.3.andErdas imagine software



Fig 11- Satellite image of study area showing bands 7-4-1

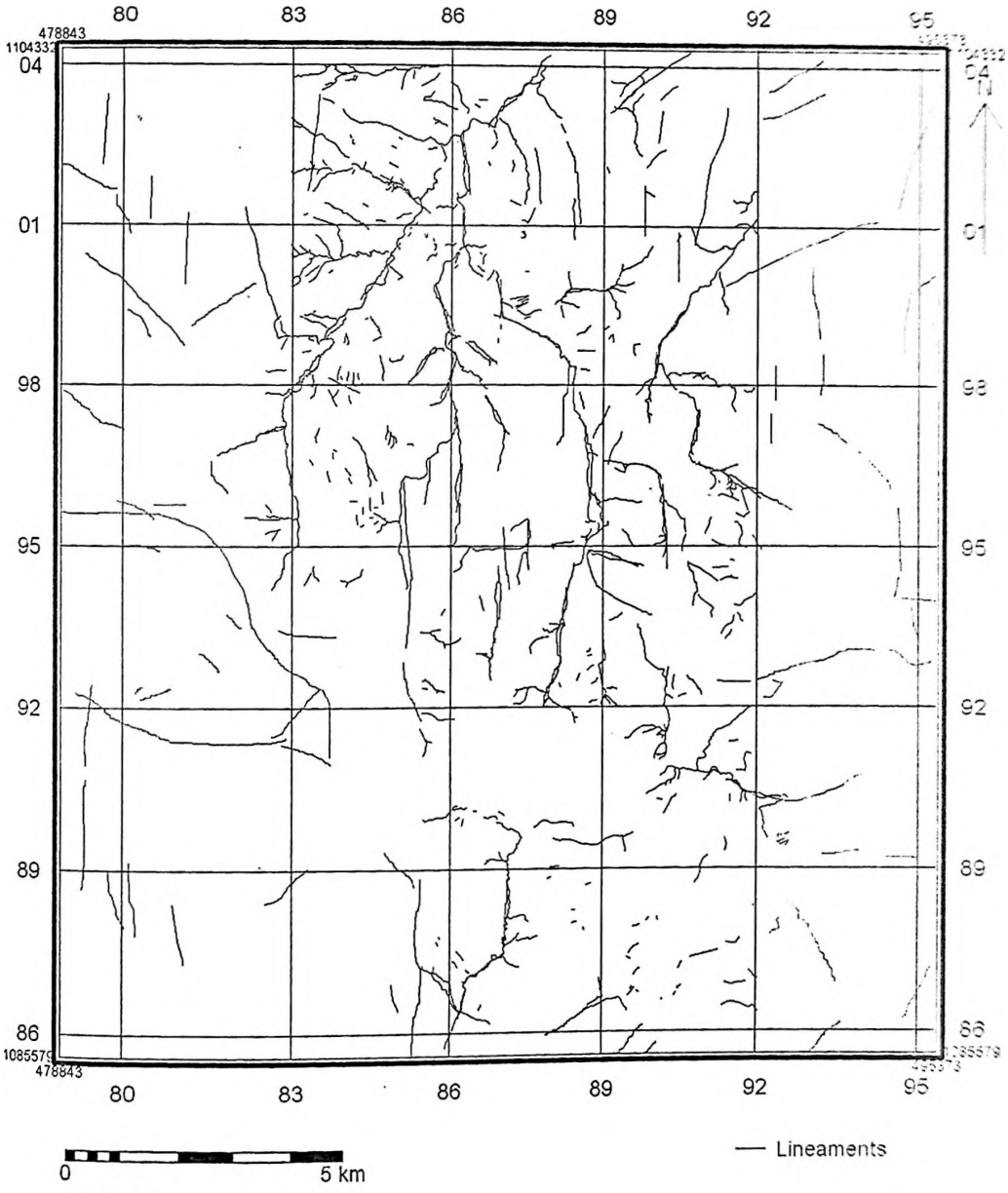


Fig 12 Lineament map extracted from satellite image of study area

The table below shows the applications of landsat spectral bands

Table 2 -Thematic mapper bands and their applications (Canada Centre for Remote Sensing, 1997).

Channel	Wavelength	Application
TM1	0.45 - 0.52 (Blue)	oil/vegetation discrimination; bathymetry/coastal mapping; cultural;/ urban feature identification.
TM2	0 .52 - 06. (Green)	Green vegetation mapping (measures reflectance peak); cultural/urban features identification.
TM3	0.63 - 0.69 (Red)	Vegetation vs.; non-vegetation and plant species discrimination (plant chlorophyll absorption); cultural/urban features identification.
TM4	0 .76 - 0.90 (Near 1R)	Identification of plant/vegetation types, health, and biomass content; water body delineation; soil moisture
TM5	0 .55 - 1.75 (Short wave 1R)	Sensitive to moisture in soil and vegetation; discriminating snow and cloud-covered areas.
TM6	0.4 - 12.5 (Thermal 1R)	getation stress and soil moisture discrimination related to thermal radiation; thermal mapping (urban, water).
TM7	0.08 - 2.35 (Short wave 1R)	scrimination of mineral and rock types; sensitive to vegetation moisture content.

3.2 Interpretation

As previously mentioned, the image interpretation process involves various levels of complexity from a simple direct recognition of objects in the scene to the inference of site conditions. The following are some of the characteristics that were sought after in the interpretation of the map

Shape, which refers to the general form, configuration or outline of individual objects

Pattern, which relates to the spatial arrangement of objects viewed

Tone, which refers to the relative brightness or color of objects on the image

Texture, which is the frequency of tonal change on the image

Association, which refers to the occurrence of certain features in relation

To others From our knowledge of the hydrogeology of basement complex, we know that groundwater in basement complex terrain is structurally controlled. Therefore, one major goal of our remotely sensed image is to figure out lineaments represented as straight or slightly curved structures. Differences in color, texture and shape often help analysts delineate the lineaments. From the above table detailing Landsat spectral bands, an intelligent combination of bands 7, 5 and 3 false color composites help us identify lineaments. It is assumed that stream channels, rivers, and other linear structures that show high moisture content evidenced by high vegetation are lineaments. therefore, while band 7 discriminates on behalf of rock and minerals, bands 3 and 5 are sensitive to vegetation/ non vegetation and soil moisture/vegetation respectively.

3.3 Establish interpretation goals: This is arguably the most important step. The aim and objectives for the image interpretation must be clearly established in the beginning of the project. Without clear goals, the analyst may waste a great deal of resources and time on

something that may be not even be relevant. Decisions need to be made at this stage include: a) types of maps to be produced, b) map scale, and c) output products (digital or hardcopy).

3.4 **Establish classification system:** Since the most interpretation projects aim to produce maps, it is essential to establish the classification for the end product. Sometimes, a disciplinary or national standard must be followed. Practically, however, it may be difficult to completely follow the standard, therefore, a compromise might be needed to simplify or modify the classification system that may be different from the standard. Regardless to what extent that the classification has to be varied, it is important to understand that the classification must serve the project goals properly.

3.5 **Collection of reference material:** Reference materials such as maps, field records and photographs can greatly help image interpretation, particular in the area where the analyst is not very familiar. With today's development of GIS technology, thematic information can also be available from sources such as national and regional geographical databases, or even from Internet. For example, Microsoft's terra server web site now provides on-line catalogue and ordering services for image data distribution, together with ancillary materials such as digital maps, text and multimedia presentations.

3.6 **Establish interpretation keys:** Interpretation keys need to be established in the early stage of interpretation. Usually, this is done by selecting the typical combination of colour, pattern and texture for a known feature. These keys will then be used as the guidance for later mapping and interpretation operations.

3.7 **Interpretation and draft map:** With the established interpretation keys and classification system, the image can be interpreted and classified, and draft map can be produced.

3.8 Lineament analysis

There are several image enhancement techniques that can contribute to lineament extraction as shown in Fig 12. Lineaments are commonly analyzed using rose-diagrams or azimuth-frequency and/or lineament density maps. The commonest method used to calculate lineament density is based on the number of lineaments per unit area (number/km2), or the total length of lineaments per unit area (km/km2) or combining both. The lineament density maps are very important in groundwater exploration especially in areas underlain by basement rocks and other hard rocks. High lineament density areas usually imply areas with high fracture density. It is known that groundwater accumulation and water well production or yields increase with increasing lineament density. As a result, areas having high lineament density represent areas with relatively high groundwater potentials. Therefore groundwater exploration in the study area should be concentrated on areas with high lineament density. In this study two processes of evaluation are applied. These are: 1) density analysis, 2) and orientation analysis.

3.9 Density analysis

The purpose of the lineament density analysis is to calculate frequency of the lineaments per unit area. This is also known as lineament-frequency. This analysis will produce a map showing concentrations of the lineaments over the area.

Analysis of lineament density is performed by counting number of lineaments contained in specified unit area. As the search radius increases, frequency of high density areas increases. If the purpose is to see the details of certain fault sets in local scale then smaller search radius should be selected. If the purpose is to have an idea on the distribution of the faults at regional scale, then larger radius should be selected.

3.10 Borehole data

Data from drilled boreholes in the study area was collected and analyzed. The yield,

surface elevation and coordinates are acquired and the data is plotted to create a spatial borehole yield map over the study area. Since from literature, we know that groundwater in basement complex area is structurally controlled and also depends on topography we superimposed the lineament density map over the borehole yield map and the elevation map to observe the interaction and analyze our findings

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will examine the data acquire data from several sources as described in chapter 3 and will seek to discuss and analyse these data in respect of the goals of this thesis.

Data acquired include remotely sensed data from field studies and older research work.

4.2 Lineament and lineament density.

According to Edet et al (1998), zones of relatively high lineament density are identified as zones of high degree of rock fracturing which in turn s a prerequisite for groundwater conduit development in basement complex terrain. Further research (Nagowa and Carr 1990) on well yield indicates that more than the density of lineaments themselves, the density lineament intersections showed more importance in predicting the yield of a well.

The figure below shows the spatial distribution of lineament

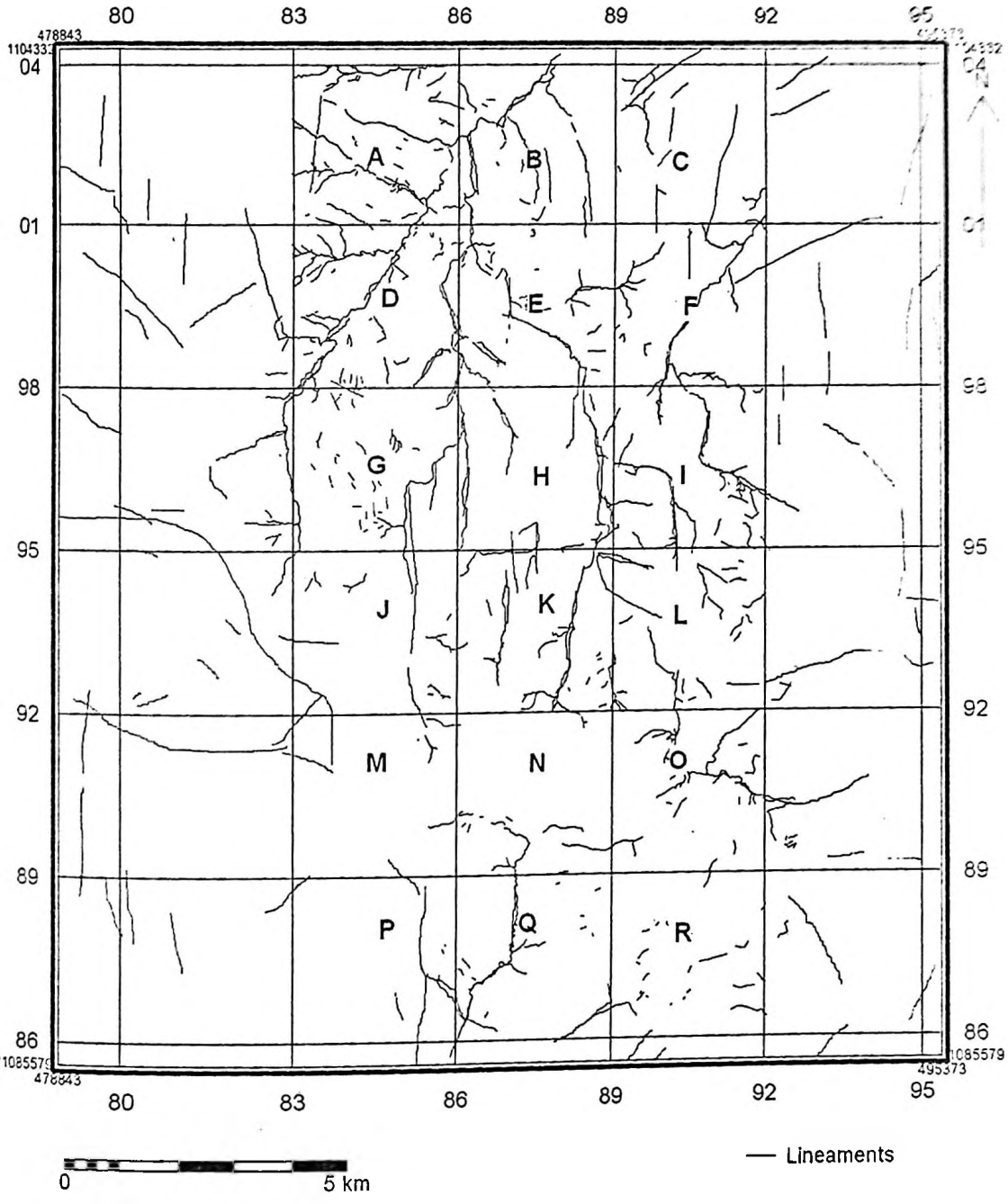


Fig 13 Lineament map extracted from satellite image of study area

For purposes of this research, we shall assume that a borehole yield of 0.3l/s and lower can be described as low yield, while a borehole yield of 0.4l/s - 1.0 l/s can be described as medium yield and finally, a yield above 1 /s is high. This assumption is strictly relative and the values are based on the average range of values obtained in the study area.

Firstly, It can be observed from the lineament map that the north central to north-western areas of the study location have higher lineament densities than other areas. However, the central and eastern areas of the study area do not present as much surface lineament expression as compares to the northern areas but have they express significant lineament intersection

4.3 Ground water flow

The natural flow of groundwater occurs from areas of recharge to areas of discharge and the pattern is perpendicular to the direction of decreasing head. (Umaru and Shoeneick 1992) The areas of recharge that represent ground water divergence zones also represent areas of low to medium groundwater potential while areas of discharge correspond to convergence zones and represent zones with potentially medium to high discharge

4.4 Analysis of potential by grid

The high-resolution satellite image covered the area's comprising grid area's A through R. however the map did not include grid areas J, M and P. The map includes the Jos area starting from Nepa in the far north west to Unijos in the far north east through to rayfield areas down south of the map and lamingo to the south east

4.4.1 Grid area A

This area will show possibly medium to high groundwater potential due to the lineament density and interconnectedness. The presence of a stream channel crossing the area indicates higher possibilities of medium to high groundwater potential as it indicates an area of groundwater convergence

4.4.2 Grid area B

This area, like grid area A will show possibly medium to high groundwater potential due to the lineament density. However, the interconnectedness is low and indicating that more areas especially to the west of this grid may have low groundwater potential.

4.4.3 Grid area C

This are will express possible medium to low groundwater potential due to sparse lineament density.

4.4.4 Grid area D

Ground water potential in this area lies possibly between medium ad high range of groundwater yield. This is due to the high lineament density and interconnectedness in the area in addition to the stream channel flowing across it

4.4.5 Grid area E

Grid area E possesses similar lineation characteristics to grid area B and therefore may possess like B, medium to high groundwater potential

4.4.6 Grid area F

Grid area F, has a stream area passing through it, however, it has a relatively low lineament density. Areas around the water-course may have good groundwater potential but on the average, the grid area may express between low and mid range groundwater potential

4.4.7 Grid area G

This area may express low to midrange groundwater potential owing mainly to its lack of interconnected lineaments

4.4.8 Grid area H

This area may express low to midrange groundwater potential due to low density of lineaments in the area

4.4.9 Grid area I

This grid area may express mid to high ground water potential owing to the stream channel canvassing the area and the density and interconnectedness of the lineaments

4.4.10 Grid area K

The area corresponding to grid area k may express mid to high ground water yield owing to the density and interconnectedness of its lineaments

4.4.11 Grid area L

Area L, may also show a groundwater potential of mid to high range due to its lineament

4.4.12 Grid area N

Grid area N and P may express low to mid range groundwater potential due to the sparse density of lineaments within that area.

4.4.13 Grid areas O, Q and R

These areas will present mid to high groundwater potential owing majorly to their lineament density. Although these areas generally present thicker overburden than the northern part of the study area and generally have fewer lineament expression. It can be assumed that the burden will contribute to higher ground water potential

From the grid analysis, it can be noted that the north west, central, eastern and south eastern areas of the study area present more potential for higher ground water yield than the western and south western areas.

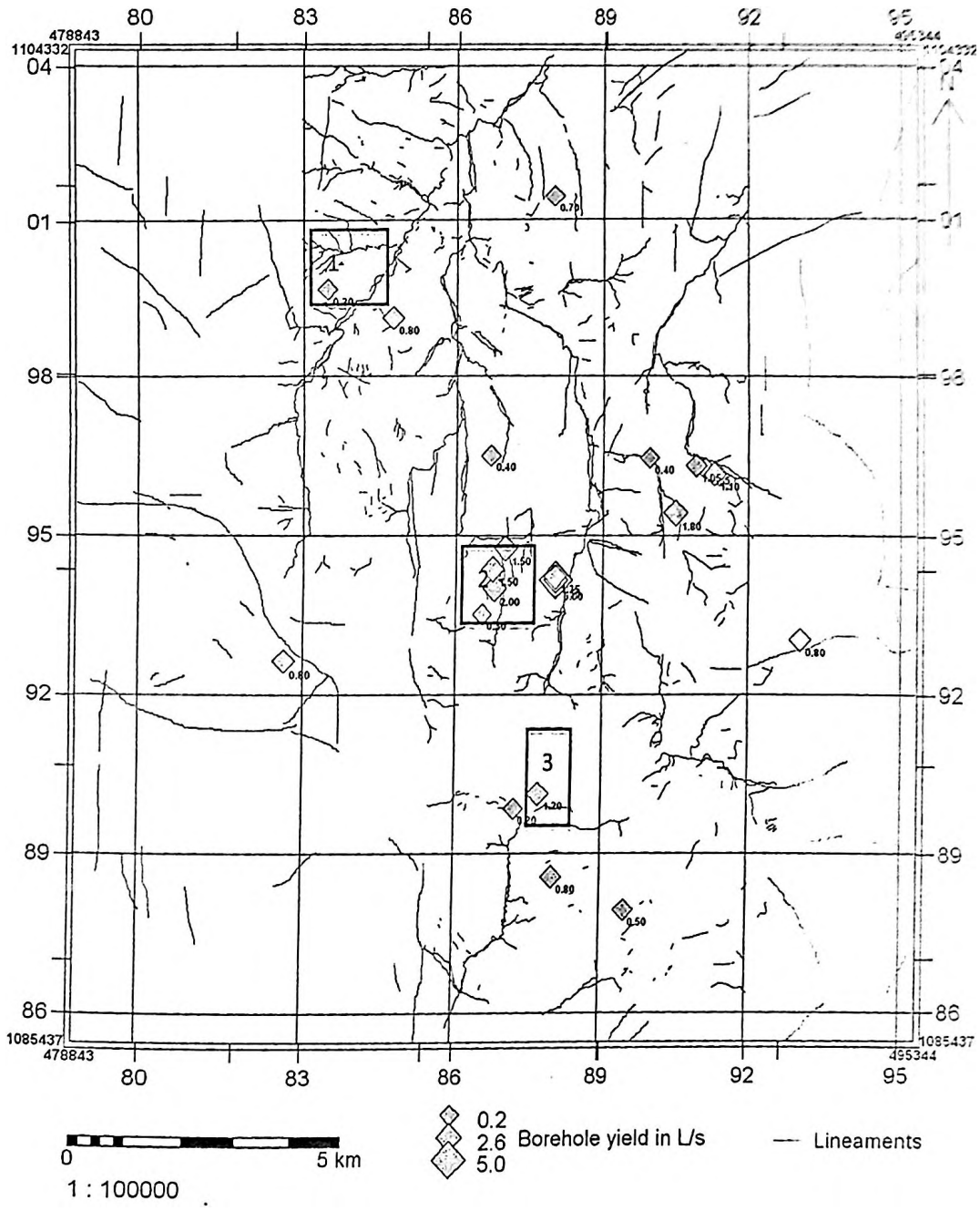


Fig 14 Grided view of study area with borehole yields superimposed on lineament map

It can also be noticed from fig 14 that borehole data acquired from the various locations in the study area largely agrees with the theory that lineament density and intersection may have an effect on the yield of boreholes.

From the data, only 3 out of 22 sampled boreholes do not correspond to the predictions of this study. These points are:

Point 1& 2 from fig 14 which show low borehole yields in areas predicted to express mid to high range yields and Point 3 which shows a high yield of 1.2 l/s from a borehole in an area expected to express low to mid groundwater potential

CHAPTER FIVE

SUMMARY AND CONCLUSION

5.1 Introduction

This chapter summarizes the entire research and draws conclusion from its findings. Recommendations are made thereafter for future

5.2 Summary

Groundwater exploration means to identify and to locate the zone of occurrence and recharge of groundwater in a particular basin or a catchment. Geological set up is established for knowing about surface and subsurface nature of terrain. In other words the composition of rock with its hydrological character is known. Topographic and surficial features are mapped in order to ascertain from highest to lowest area, where water from different higher places can move and accumulate. These particular zones are present in various terrains. The identification of such focal places from the entire area, are thus selected for groundwater exploration. The spectral, spatial and temporal contents of terrains are recorded by airborne scanners and cameras, and remote sensing satellites, which have repetitive coverage. Data in digital form from satellites allows for enhanced computer aided data processing and analysis to effectively utilize by various combination.

In this study, A 6m-resolution satellite image of the study area was acquired and imaging interpretation techniques were used to identify delineate and map lineaments.

The study area is underlain by basement complex rocks, which make it difficult to predict the yield of boreholes in the area. Whereas other researchers who have undertaken studies in the groundwater potential of the Jos metropolis, have commented on the potential on a regional basis, often delineating the areas based on land use, the author is unaware of any

other research that has broken up the area into grids and commented on the groundwater potential of each grid.

A grid approach offers a more precise method for predicting the potential of areas without embarking on geophysical investigations. From this grid approach, Grid Area A, B, D, E, I, K, L express mid to high groundwater potential while grid area C, F, G, H and N may express low to mid range groundwater potential

5.3 Further research and Recommendations

While this study explored the use of grids to comment on groundwater potential based on lineament maps. Other factors that affect groundwater potential could be mapped into grids and a more detailed and precise map on groundwater potential produced and presented in grid form. Such a study will greatly aid ground water exploration activities.

Appendix

Borehole data acquired from various boreholes in the study area

Location	Coordinates (deg) (East/North)	Yield (l/s)	elevation(m)
Rest house GRA	008.88143/09.90449	1.5	1235
Niger creek	008.87903/09.90097	1.5	1248
Pastoral centre I	008.87856/09.92051	0.2	1179
Pastoral centre II	8.87856/09.92051	0.4	1174
Kwata village (zawan)	008.83949/09.76452	0.3	1232
Bukuru (danbaba)	008.85805/09.77917	0.25	1280
Fwavei (beesnice)	008.89067/9.84849	0.8	NA
TCNN Bukuru	008.89084/09.89906	1.5	1200
Ceder tree	008.5236/09.71723	0.2	1213
City lodge	008.52485/09.53895	0.4	
Lamingo	8.93647/09.88890	0.8	1308
Fatigen drilling (ningyi)	8.88790/09.86260	1.2	1296
Bauchiringg road (sch. of biblical studies)	8.91339/9.91044	1.8	1215
TCC nig. Ltd	8.88335/9.86010	0.2	1166
Mista Ali	008.35020/10.03328	4	NA
Hillcrest	008.52865/09.53856	1.33	NA
Fed. Low costs	09.37713/008.84958	0.2	1314
UnguwarRukuba 1	8.9207/9.91718	1.11	1242
Unguwar Rukuba 2	8.91903/9.91795	0.98	1239
Unguwar Rukuba 3	8.91849/9.9182	1.5	1239

UnguwarRukuba 4	8.91725/9.91861	1.07	1239
Unguwar Rukuba 5	8.91945/9.91744	0.87	1251
Unguwar Rukuba 6	8.91894/9.91804	0.56	1240
Unguwar Rukuba 7	008.53386/09.57471	0.2	NA
British America junction	008.89084/09.89906	5	1226
Funmikay	008.89866/09.60401	1.5	1200
Jos, Jarawa	008.90848/09.91994	0.4	1198
pollo crescent	008.87711/09.89333	0.3	1242
Ev angel hospital 1	8.52617/9.55849	0.2	NA
angel hospital 2	8.52617/9.55849	0.3	NA
araguta avenue	008.87941/9.89765	2	1252
Rock haven	NA	0. 4	NA
Ray field	NA	0.3	NA
Ecwa staff school	NA	1.5	NA
Gold and base	NA	0.1	NA
Ray field	NA	0.3	NA
GRA tudunwada	NA	1.5	NA
Kwang village rayfield	NA	0.3	NA
Zaramaganda	NA	1	NA
Fwaveiray field	NA	1.5	NA
Ray field (silk suit)	NA	0.2	NA
Rock haven (fabianeze)	08.51517/09.51707	0.2	NA
Apollo crescent (SIM)	N/A	0.2	NA
May-adiko (lar)	N/A	0. 5	NA
Ningi village	N/A	0.2	NA

(dilimicntral)			
Baptist high school	009°57.550'E/08°53.252'N	0.7	NA

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