Assessing the Suitability of using Plant Indicators in

Groundwater Prospecting in the Midlands Province.

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A project submitted in partial fulfillment of the requirements of the Bachelor of Science Honours Degree in Land and Water Resources Management

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November 2015

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ABSTRACT

There have been challenges in groundwater prospecting especially in the Midlands Province of Zimbabwe. Prospecting has not been accurate with frequent occurrences of dry holes for both geophysical and traditional groundwater prospecting techniques. The study involved an assessment of the suitability of using plant indicators for ground water prospecting in the Midlands Province of Zimbabwe. To achieve this, indicator species were first identified and their abundances and biometric characteristics were used to predict borehole yields and depths. The study area is dominated by bush and tree savanna and hence it was necessary to establish and eliminate baseline species from the study. After elimination of baseline species, five species were identified as indicators. The relationships between indicator species' biometric characteristics / species abundances and borehole depths / yields were determined through regression analysis. Identified species were *Acacia burkei benth*, *Acacia negrecens, Lonchocarpus capassa, Piliostigma thonningii* and S*clerocarya birrea caffra*. *Acacia burkei benth*, *Acacia negrecens* and *Lonchocarpus capassa* were the most powerful indicators in that order in terms of yield prediction respectively. *Piliostigma thonningii* and S*clerocarya birrea caffra* showed the ability to form combinations with both *Acacia negrecens* and *Lonchocarpus capassa* but however they were not confined to any yield ranges. The biometric characteristics of the indicator species had weak correlations with borehole depth and yields ($0 < R < 0.38$). The study also showed that there exists a strong positive linear relationship between the abundance of *Acacia negrecens* ($R = 0.68$) and the yield of boreholes. Finally, *Sclerocarya birrea caffra* was discovered to also have a strong linear relationship ($R = 0.78$) with borehole depth. The identified indicator species can be used for identification of ground water sites but it is not possible to predict the yield and depth of boreholes using species' biometric characteristics in the study area.

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ACKNOWLEDGEMENTS

My profound gratitude goes to my father Mr. M. Ben a groundwater prospector, for his valuable insight on groundwater prospecting and groundwater engineering. I would also like to thank my supervisor, Mr. F.S. Zirebwa for his excellent supervision and for his great depths of knowledge. Special thanks and deserving mention of the following is inevitable for various reasons: Mrs. Fritz and Aleck Toramvura Drilling and Mr. Mugandani of the Midlands State University. I would like to thank my friends, all my classmates and my family for their encouragements and support. Above all, l would like to thank God who is the keeper of all man.

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DEDICATION

I dedicate this work to my immediate family, boreholes are our life.

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CHAPTER ONE: INTRODUCTION

1.1 Background

Groundwater is water present beneath the earth's surface (USGS, 1995). Its distribution is almost everywhere whether under mountains, beneath hills, in plains or in deserts. Groundwater is not always easily accessible and can be difficult to locate at times; it may lie close to the surface like in marshes or may be hundreds of metres below the surface like in deserts. Groundwater is stored and moves slowly through permeable rock forming what are called aquifers (USGS, 1995).

In order to be able to abstract water from these aquifers, groundwater prospecting is necessary to determine the best possible location and depth of the aquifers. (Carruthers et al., 1992). Various techniques are currently used to prospect for groundwater, this include both traditional and modern scientific methods (Barker et al., 1992). Traditional methods involve divining using different types of apparatus which include forked sticks, wire, bottles etc. water diving is also called dowsing, traditional methods might even go as far as involving spiritualism.

Zimbabwe generally has a limited amount of groundwater resources (ZINWA, 2015). The Zimbabwe National Water Authority (ZINWA) recognizes this limitation and has even gone as far as to highlighted 'difficult groundwater finding areas' in Zimbabwe, including in the Midlands Province namely Tongogara Rural District Council (ZINWA, 2015). The difficulty of finding water in some parts of the province necessitate the need to improve or enhance current groundwater prospecting technics in order to increase the probability of finding water necessary for abstraction purposes. Plant indicators in the groundwater regime can play an important role in increasing the accuracy of water finds.

The use of plant indicators for groundwater prospecting in the Midlands Province has been more of an oral subject with groundwater prospectors claiming to use them but no academic research has been done to assess their suitability. However (Meinzer, 1927), did use plant indicators to determine the presence of groundwater in North America and (Malyuga, 1964), pointed out how *Acacia grandulifer* was used by the inhabitants of Central Africa to determine the occurrence of fresh water springs.

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1.2 Problem statement

Borehole siting has not been an exact method with occurrences of dry hole situations for both dowsing and electrical resistivity methods. Both geophysical and traditional methods struggle in mineral rich areas, thus pointers like specific vegetation species will greatly improve siting accuracy and consistency, by providing a basis for sampling sights. Furthermore there are also some minerals like mica that even experienced dowsers find problematic and which turn electrical resistivity methods into a hopeless case thus vegetation indicators could be helpful.

1.3 Justification

After the land reform programme, Zimbabwe experienced an increase in the number of both small scale and large scale farming units. By the end of 2004, they had been 130 438 new households created under the A1 scheme (small scale) and 12 556 new farms under the A2 scheme (large scale), (World Bank, 2005). The majority of these large and small scale units are not near any perennial water sources. The creation of these new units necessitated the need for an increase in groundwater abstraction to satisfy the needs of the new farmers hence the need to drill more boreholes. Furthermore an increase in urban residential development due to the recent increase in economic growth which occurred mainly between 2009 and 2012 with an average GDP of 8.7% (Ross, 2015), coupled with the failure of most city councils to meet the rising water demand also led to an increase in the demand for boreholes for the purpose of groundwater abstraction as a water solution amongst many urban residents.

Also both town and rural councils have been facing water shortage problems, resulting in Gweru City Council having 25 boreholes drilled and Tongogara Community Share Ownership Trust acquiring a rotary-pneumatic drilling rig. There are challenges in groundwater prospecting in some areas e.g. Tongogara district (ZINWA, 2015). Coupled together with the high cost of drilling a borehole it has made it very important for the accuracy of siting boreholes to be increased. ZINWA (2015) acknowledges that Zimbabwe has 2 distinct hydrological seasons, (season dry and a dry season). There exists few water holding structures to retain run-off during the wet season for use in the dry season. The need for boreholes to supplying water during the time of shortage (dry season) is imperative.

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1.4 Objectives

1.4.1 Main objective

The main objective of the study is to assess the suitability of using plant indicators in groundwater prospecting in the Midlands Province of Zimbabwe.

1.4.2 Specific objectives

1. To identify and link tree species' to groundwater availability.
2. To determine relationships between indicator species' biometric parameters (girth and crown radius) and the depth/yield of the boreholes.
3. To determine the relationship between borehole yield and abundance of indicator species' around the boreholes.

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CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The idea of applying vegetation parameters as indicators for groundwater is not a new idea. Meinzer (1927) wrote about plant indicators as an application for determining the presence of groundwater. Studies showed how deserts plants formed a definitive group that indicated the presence of groundwater. Le Maitre (1999) pointed out how vegetation and groundwater interacted sitting the influence of vegetation on recharge.

Lewis (2011) defines that eco-hydrological indicators are plant species whose occurrence or morphology can provide information on the hydrogeological set up of an area in semi-arid or arid regions. Roberts (1999) provides information on how eco-hydrological indicators can be used as a basis for groundwater evaluation in arid and semi-arid climates. Lewis (2011) argues that Eco-hydrological indicators can be used to provide information on the absolute depth of the water table, patterns of groundwater fluctuations and mineralization of aquifers.

Plants that have roots that extend to the water table and depend on groundwater for all, most or some of their water requirements are called phreatophytes (Meinzer, 1927). These types of plants are able to act as indicator species because their morphology is affected to a larger extent by fluctuations in the groundwater table. Lewis (2011) sites some species that are phreatophytic together with their depth thresholds and common and maximum reported rooting depths (Table 2.1).

Phreatophytes are valuable freshwater indicators in arid regions. The people of Central Africa have been using *Acacia grandulifer* to identify areas with freshwater springs (Malyuga, 1964). Acacia mesquite and Acacia greggii were also used by settlers in the south western part of the United States to find underground freshwater (Meinzer, 1927).

Table 2.1: Rooting depth characteristics of Common Woody Phreatophytes (Lewis, 2011)

Adult Phreatophyte	Common Rooting Depth (m)	Depth to Groundwater Survival Threshold (m)	Maximum Reported Rooting Depth (m)
Salix spp.		2.5 to 3.0	
Willow		3.5	
	1.4 + 0.9	3.2	
			6.7
Populus spp.		2.5 to 3.0.	
Cottonwood		3.5	
		2.6	
	1.5 ± 1.1	5.1	
			3.0
Tamarix spp.	1.4 ± 0.6	2.6.	
Saltcedar	3		
		6	
			20
Prosopis spp.	3.4 ± 1.7	8.0	
Mesquite			53
			13.0
		15	
	5		
		10	
Acacia spp.			68
			35
			30
			68
			<70

2.2 Phreatophytes

Phreatophytes are plants that can send their roots down to the capillary fringe just above the water table or to the water table itself; this enables them to have a secure, perennial water source (Meinzer, 1927). Phreatophytes can provide information on the geo-hydrological setup of an area. There are two types of phreatophytes, obligate and facultative. Obligate phreatophytes need to have continuous access to groundwater for their survival (Preobrazhenskaya, 1965). Facultative phreatophytes preferentially require groundwater but not exclusively, they can still survive on water form unsaturated soil when groundwater supplies are depleted. Consequently obligate phreatophytes exhibit higher sensitivity to groundwater aquifer conditions and thus are better vegetation indicators for groundwater characteristics (Lewis, 2011).

Differentiating between obligate or facultative phreatophytic species is difficult even for botanists; the physiological difference between obligate and facultative phreatophytes is blurred (Webb et al., 2006). The extraction of groundwater as a water source has been shown to be

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inconsistent even for individual phreatophytic plants, thus hydrogeologists will usually have to be content with just identifying a species as phreatophytic without being able to determine whether they are obligate or facultative (Zencich et al., 2002).

Determination of whether species are phreatophytic is possible mainly for arid or semi-arid regions. During dry months phreatophytic species will stay green and maintain physiological activity while those that cannot obtain water from the water table will show obvious signs of water stress such as wilting (Horton et al., 2001). Morphology, vegetation density and species composition changes considerably within a short distance between plant communities that are using an aquifer as a water source compared to those that are not, vegetation benefiting from groundwater is more robust compared to any vegetation that might be near-by that is not. However in humid climates these obvious visual signs are non-existent (Lewis, 2011).

2.3 Groundwater

When rain enters the earth’s surface some will flow as overland flow and some will flow just below the surface as interflow, the rest percolates into the soil. A large percentage of rainwater is transferred back into the atmosphere as vapour through transpiration and evapotranspiration. Rainwater causes the water table to change drastically. 20mm of rainfall can change the water table by 50cm (USGS, 1995). Groundwater moves slowly through aquifers where it is stored. Aquifers exist in moderately permeable or highly permeable rocks. The term aquifer is derived from the Latin words *aqua* and *ferre*, which mean water, and to carry or bear respectively. An aquifer maybe made by one or more layers of gravel or sand, sandstone or even cavernous limestone rock (Fetter, 2001). It can also exist at the base of old lava flows or in fractured granite having sizeable openings. Existing between the ground surface and the aquifer is the unsaturated zone (vadose zone); it usually contains some water in the pore spaces of soil and in small openings in rocks. Large rock openings are usually filled with air not water. This zone is affected greatly by precipitation patterns, being saturated after a significant rainfall event and drying out after a long dry spell. Water is also held in this zone by molecular attraction to rock and soil particles, this water cannot flow into a well (USGS, 1995).

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Excess water infiltrates down to a level called the water table; below this level all openings and pore spaces are saturated with water. The saturated zone constitutes aquifer water that moves to springs or wells. Groundwater moves slowly through the vadose zone thus natural refilling of aquifers is a slow process. Water also moves slowly through the aquifer its self-such that the rate of recharge is an important consideration for purposes of abstraction. (Fetter, 2001)

Clay and solid granite may actually have a few hairline cracks which restrict water movement, such that small quantities of water are transmitted, these are poor aquifers. On the other hand fractured sandstones and limestone may have large interconnected openings that transmit a lot of water and these are good aquifers (Todd et al., 2005). Aquifers have a varying degree of thickness, from less than 1 m to a few metres or can be tens of metres thick. Aquifers also vary in their depth ranging from a few metres to hundreds of metres. Furthermore some aquifer carry water for long distances such as sandstone aquifers while other are only local such as sand and gravel deposit aquifers (USGS, 1995).

Porosity determines the quantity of water any given rock type will hold, porosity is a ratio measuring spaces or cracks within the rock that can hold water. A well-sorted media with same size grains will store and transmitted more water than a media with poorly-sorted different sized grains, the smaller grains will fill the pore spaces in place of water (Todd et al., 2005). Sand and gravel aquifers store and transmitted a lot of water because of their well sorted grains. Inter-connectivity of pore spaces increases the area in which water can move thus increasing the permeability of the rock. Rocks that yield large volumes of water for well purposes have many interconnected pores. Compact consolidated rocks such as granite can also be water bearing if they have interconnected cracks or fractures. Gradual processes of weathering continue to open these cracks increasing their water bearing potential (USGS, 1995).

2.4 Technics of groundwater prospecting

Most technics for groundwater prospecting are dependent on geology (Beeson, 1988). A technic might be very successful in one area but be useless in the next. In places where groundwater is easily found hydrogeology is of little consideration, in areas were groundwater is not so obvious standard techniques for groundwater survey can be employed. In order to have an accurate

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assessment of groundwater potential it's important to rely on more than one approach. Integration of various techniques is necessary for an accurate assessment (Telford et al., 1990). Geological triangulation is necessary, this involves looking at maps, taking observations and then applying geophysical techniques. It is important to accurately and correctly locate areas were surveying is to take place on topographic and geological maps. These provide initial information on the basic geology of an area. The co-ordinates for any given area can be determined using GPS, for purposes of location on a map (Carruthers et al., 1992).

Observation of the local geology must be done with care and discussions carried out with the locals. Exploiting local knowledge and experience is important for realizing the geology of an area. Locals know the environment of the area and usually any water development that might have already occurred (MacDonald et al., 2001). Rock types should be observed and noted. An evaluation of local perennial and seasonal water sources should be carried out. Sources of groundwater should be noted and collection rock of samples from exposures and shallow well for further analysis can also be done. This information gives an indication of the probability of finding groundwater in the area. If existing wells and boreholes have water throughout the year then the probability of finding wet holes is also high (MacDonald et al., 2001).

If maps and observations fail to provide satisfactory answers to aid in the siting of a successful borehole then geophysical techniques have to be employed. Geophysical techniques are not fail safe as they do not directly detect the presence of water however they measure physical rock properties and help to increase the probability of finding groundwater (Reynolds, 1997). They aid in the interpretation of rocks present in an area and help determine where specific rock formations maybe more fractured. They are a great number of geophysical techniques and numerous pieces of equipment. Many due to the sophisticated equipment and complex analysis are not suitable for rural water development programs. The two most commonly used geophysical techniques in sub-Saharan Africa are ground conductivity and electrical resistivity. Magnetic techniques can also be applied at times (Barker et al., 1992). Table 2.2 summarises some geophysical techniques employed in groundwater surveys;

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Table 2.2: Summary of common geophysical techniques used in groundwater prospecting (MacDonald et al, 2001)

Geophysical technique	What it measures	Output	Approximate maximum depth of penetration	Comments
Frequency domain EM (FEM)	Apparent terrain electrical conductivity (calculated from the ratio of secondary to primary EM fields)	Single traverse lines or 2D contoured surfaces of bulk ground conductivity	50 m	Quick and easy method for determining changes in thickness of weathered zones or alluvium. Interpretation is non-unique and requires careful geological control. Can also be used in basement rocks to help identify fracture zones.
Transient EM (TEM)	Apparent electrical resistance of ground (calculated from the transient decay of induced secondary EM fields)	Output generally interpreted to give 1D resistivity profile	100 m	Better at locating targets through conductive overburden than FEM, also better depth of penetration. Expensive and difficult to operate.
Ground penetrating radar (GPR)	Reflections from boundaries between bodies of different dielectric constant	2D section showing time for EM waves to reach reflectors	10 m	Accurate method for determining thickness of sand and gravel. The technique will not penetrate clay, however, and has a depth of penetration of about 10 m in saturated sand or gravel.
Resistivity	Apparent electrical resistivity of ground	1-D vertical geoelectric section; more complex equipment gives 2-D or even 3-D geoelectric sections	50 m	Can locate changes in the weathered zone and differences in geology. Also useful for identifying thickness of sand or gravel within superficial deposits. Often used to calibrate EM surveys. Slow survey method and requires careful interpretation.
Seismic refraction	P-wave velocity through the ground	2-D vertical section of P-wave velocity	100 m	Can locate fracture zones in basement rock and also thickness of drift deposits. Not particularly suited to measuring variations in composition of drift. Fairly slow and difficult to interpret.
Magnetic	Intensity (and sometimes direction) of earth's magnetic field	Variations in the earth's magnetic field either along a traverse or on a contoured grid	30 m	Can locate magnetic bodies such as dykes or sills. Susceptible to noise from any metallic objects or power cables.
VLF (very low frequency)	Secondary magnetic fields induced in the ground by military communications transmitters	Single traverse lines, or 2D contoured surfaces.	40 m	Can locate vertical fracture zones and dykes within basement rocks or major aquifers

2.4 Indicator species

Indicator species are determined by analyzing the frequency at which the species is occurring in specific sites, the sites are classified into groups each having a specific desirable characteristic required for observation. The classification of site groups may be derived from

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similarities in environmental conditions across sites (e.g. types of habitat i.e. disturbed/undisturbed), or in composition of species' (e.g. community types or vegetation). Site groups may also be derived from the study design (e.g. comparison across geographic regions or repeated surveys) or obtained using various criteria, like land use classes. A site group might fail to have an indicator species even if its community composition is clearly different from other types of sites, such that indicators can become a specific combination of species' rather than one species (DeCa´ceres et al., 2012).

Background information about a specific region or area is very important when interpreting what species indicators are telling us about an aquifer. Understanding both the seasonal and meteorological cycles of an area are important in understanding if the range of an indicator species is limited by water table absolute depth or by fluctuations in groundwater levels **(**Wierda et al.,1997). Where mature woody indicator species are present in the absence of immature ones, it's a direct sign that the water table is probably deeper or that there are large fluctuations in groundwater levels in comparison to areas that have both immature and mature indicators. The mixture of different species types maybe an indication of different subsurface conditions. Information important to a hydrogeologist is usually acquired from observing patterns of behaviour through a range of various indicator species. Assessment of patterns usually requires good judgment rather than measurement. There is subjectivity in the interpretation of species indicators which may be uncomfortable to practitioners who require accurate depth readings for groundwater surveys (Lewis, 2011).

Identifying the frequency of occurrence and relative abundance of a particular species indicator eliminates the need to sample an entire community or area; this is useful in management of ecological systems and in the long term bio-monitoring of the environment for purposes of conservation. Species qualify as indicators if they reflect the abiotic or biotic conditions of an area or environment and if they reflect changes in the environment. Analyzing the frequency of occurrence of an indicator species to specific site groups characterizes the species preferred habitat niche and can allow for the ecological specialization to be assessed (DeCa´ceres et al., 2011).

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For site groups the frequency of occurrence of a particular species or a combination of species allows for the classification of a newly surveyed site or area exhibiting the same species characteristics to be classified in the same site group. Due to their predictive value, indicator species have a strong appeal to land managers and conservationists for assessment of ecosystem change as they are cost-effective and time-efficient (McGeoch, 1998). There are several methods to statistically determine an indicator species. Among them, the most commonly used method includes the assessment on the association between species and site groups by way of correlation or indicator value indices (Dufreˆ ne et al., 1997).

Correlation investigates the relative negative or positive preference of a species for a particular site group, compared with any other remaining groups. However, indicator values are not negative and investigate the extent to which sites of the target site group match the sites to which particular species are found (Chytry´ et al., 2002).

Usually, the results of an analysis for indicator values for any site group contains a list of species that are significantly observed in it, outputted in decreasing order of the indicator values. When an already observed indicator species or a combination of species is discovered in a newly surveyed site, the site can be assigned to the site group. The more indicator species are found in the newly surveyed site, the higher the confidence on the assignment (Lewis, 2011)

2.4.1 Indicator value analysis for single species

It is important to determine the *specificity* or *positive predictive* value of a species as an indicator for a particular site group (DeCa´ceres et al., 2012). The positive predictive value is the conditional probability(A), that a particular surveyed target area or site belongs to a site group(G) given that it contains indicator species (S) derived from a given site group (Equation 2.1).

$$A \quad P\ G\,|\,S\ . \qquad \textbf{(2.1)}$$

Useful indicator species give both a high positive predictive value and are easy to identify. If the probability of identifying a species in a given site group is high, then the probability of finding

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the same species in a newly surveyed site of the same area is higher. This is the *sensitivity* or *fidelity* of the indicator species for determining a target site group (DeCa´ceres et al., 2012). Sensitivity is the conditional probability (B), that a species (S) will be found in a given site group (G) (Equation 2.1);

$$B \quad P\ S|G\ . \qquad \textbf{(2.2)}$$

In order to determine the indicator value two elements are necessary; (i) division of sites into non- overlapping classes and, (ii) site versus species data table showing frequency and abundance of species for the sites. A good indicator species is one restricted ecologically to its specific site group and also occurs frequently within its site group. The indicator value index is given by the product of specificity and sensitivity i.e.

Indicator value index (IndVal) = Conditional probability (A) x Conditional probability (B),
(Dufreˆ ne et al., 1997).

The species sensitivity also called its fidelity (B) can be simply estimated from the relative frequency of occurrence exhibited by the species in the sites belonging to the target site group. The positive predictive value also called its specificity (A) of a species can be determined from either its presence or absence or from the species abundance in a target site group. Assuming there is a sample representative of all the sites, an estimator of (A) can be calculated from number of occurrence of the species in the target site group, divided by occurrence of the species across all sites. As an alternative (A) can be calculated from the addition of abundances with the sites of the target site group divided by the total abundance values from all sites (Dufreˆ ne et al., 1997). These first two methods assume that the target site group was properly sampled, no under sampling or over sampling occurred. However if sampling is improper and if over presentation of site groups occurred then we can divide the relative frequency of the species across a target site group by the sum of the relative frequencies across all groups to calculate (A). This gives equal weight to all site groups for presence or absence data in the calculation. For abundance data when over presentation of samples occurs we can divide the average abundance of species in a target site group by the average abundance values across all sites (DeCa´ceres et al., 2012).

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2.4.2 Indicator value analysis for species combinations

Species indicators can be determined by combining absence or presence data of different species’ provided they have joint occurrence. However most sites usually have single species acting as indicators when compared to species combinations, this results’ in the positive predictive value and the sensitivity of species combinations being estimated from a smaller sample resulting in a less precise estimation of indicator value. (DeCa´ceres et al., 2012) However the underlying principles for calculation of positive predictive value and sensitivity are still the same. The positive predictive value is given by Equation 2.3;

$$A \quad P\,G|S_1\hat{}\ \ S_2\ , \qquad \textbf{(2.3)}$$

While the sensitivity is given by Equation 2.4;

$$B \quad P\,S_1\hat{}\ \ S_2|G\ , \qquad \textbf{(2.4)}$$

(DeCa´ceres et al., 2012).

Due to the lack of correlation of information from the two independent species under consideration, joint IndVal of the two species may have a higher value than that of a single species’. The number of species that can be used jointly as a combination is not infinite due to lowered (B) values and decreasing precision of (A) estimates (Pignatti, 1980).

A set of species indicators may be of greater use compared to a single species when the target site group is widespread geographically resulting in low individual sensitivity as each indicator might end up occurring in only a small part of the broad geographical range. Thus one indicator can be used in one part of the geographical range while another indicator is used in another part of the geographical range for the same target site group. The important quantity of pooling the species indicators such that they complement each other to give a pooled coverage can give us a percentage of the sites within the target site group where at least one of the indicators is occurring (DeCa´ceres et al., 2012).

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2.4.3 Selecting candidate species

Selecting candidate species reduces the number of species to be explored during analysis. Species that have a low frequency of occurrence at the target site groups can be discarded. Additional characteristics such as rooting depth can also be used to discard candidate species (McGeoch 1998).

2.4.4 Setting a maximum number to the species forming a combination

Reducing the number of species indicators is necessary since combinations with a large number of species are not usually used as indicators; it also reduces computational requirements (DeCa´ceres et al., 2012).

2.4.5 Selecting valid indicators

Both confidence interval calculation and hypothesis testing can be done for permutation of species combinations for indicator purposes. However hypothesis testing as a strategy for determining the best indicators can be problematic as a large number of species can occur within a specific target site group especially if site groups are defined using species composition data. The best method is to determine those species restricted to target sites (DeCa´ceres et al., 2009).

It is recommended to set a threshold which sets the lowest allowable positive predictive value (At). This minimum threshold is a subtraction of the maximum allowable false positive a user will accept for future potential target sites. For example if At = 0.6, then all valid indicators will indicate a false positive in the target site group 40% of the time. A species or species combination is then considered a valid indicator if its lower bound of the 95% confidence interval is equal or higher than the lowest allowable positive predictive value (At). A minimum value for sensitivity can also be set so as to discard those indicators that might be powerful but occurring at too low a frequency (DeCa´ceres et al., 2012).

2.5 Use of indicator species biometric characteristics in groundwater prospecting

2.5.1 Rooting depth

It is important to understand both the maximal and typical rooting depth of phreatophytic species. Rooting depths enable hydrogeologists to estimate the depth to which roots have to grow

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in order for plant species to benefit from groundwater. However rooting depth is only a guideline to help determine water table depth due to the fact that they are affected by other factors such as shallow bedrock or the bulk density of soil (Canadell et al., 1996).

Phreatophytic plants experiencing water stress have been determined to have relatively deeper root systems (Schenk et al., 2002). Plants that are experiencing water stress usually send their roots deeper and can reach their threshold theoretical maximum rooting depth (Shafroth et al., 2000). Phreatophytes exhibiting signs of water stress show that the depth of the water table is close to the threshold depth of their rooting system. Signs of water stress can also show fluctuations in recent groundwater levels. Thriving phreatophytes on the other hand show accessible groundwater levels within easy access of their rooting system (DeCa´ceres et al., 2012).

Many savannah tree species are deep rooted with leguminous species such as Prosopis and Acacia being able to reach depths of up between 3 to 20 m or even up to more than 53 m. (Stone et al., 1991). Many shrub species can penetrate up to 10 m, while eucalyptus can reach up to 60 m (Dodd et al., 1984). View (Table 2.1).

2.5.2 Girth, crown width and height

When plants are exposed to groundwater their productivity goes up, they are able to produce more in terms of biomass i.e. to increase in size and numbers. Studies were conducted in Australia linking leaf area index to the availability of groundwater. The study went on further to show how trees grew bigger in areas were groundwater was available (National Centre for Groundwater Research and Training, 2014). Meinzer (1927) mentioned how plants growing where there is groundwater had a higher growth than plants that were not. Peggy et al. (1982) carried out a study to investigate the effects of an altered hydrologic regime on tree growth. The study showed that trees in uplands which retained less water had less growth than those in downlands which retained more water. Braun et al. (2004) conducted a study to investigate on the effects of water level variations on tree growth. The studied used the biometric characteristics tree height, canopy diameter, and trunk diameter to determine if water level variations had an

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effect on tree growth. Results from this study showed that a decrease in the groundwater level resulted in less growth and even mortality of trees.

A study was conducted in the savanna regions bordering the Sahel in Nigeria to determine the relationship between girth, crown width and height for trees growing in savanna zones. Arzai et al. (2010) showed that for trees growing in savanna climates, there existed a linear relationship between crown width, girth and height of trees. This is to say that for tree species growing in the savanna a regression equation can be used for each species to link crown width, girth and height. This means any variables affecting one biometric characteristic will automatically affect the other two in the same way whether they have been measured or not.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study area

The study area is the Midlands Province between $16^{0}30'$- 21^{0} $30'$ S, 28^{0} – 31^{0} E, in Zimbabwe concentrating more from the central to the south of the province (Figure 3.1).

Figure 3.1: The map highlighting the study site

The Midlands province mainly comprises of dry bush and tree savanna, with some areas being dry grassland savanna. The midlands province forms part of the Sanyati, Gwayi and Runde Catchments which form the major rivers with numerous smaller rivers supplying them. In terms of groundwater the province is characterized by limited groundwater resources, with occurrence of problem areas in this regard such as Tongogara Rural District Council (ZINWA, 2015).

The Midlands province covers Agricultural-Ecological regions III, IV and V, (Vincent et al., 1960). Region III with rainfall between 550 mm to 700 mm. Region IV having rainfall between 450 mm to 600 mm, while region V has rainfall less than 500 mm (Mugandani et al., 2012).

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The geology of the province is mainly comprised of an Archaean basement with metamorphic rock usually granite, some gneiss with remnants of piles of volcanic materials forming greenstone belts. However rock types such as basalt and dolerite do occur. A proterozoic intrusion of mafic to ultramafic layers of rock forms the Great Dyke whose craton is surrounded by three metamorphic belts rich in minerals, running generally from the north to the south of the province, (Shoko et al., 2014).

Figure 3.2 shows a general overview and distribution of the locations were observations were made. Some of these areas had more than one site being observed, for this illustration all sites were generalized according to areas for the purpose of visual representation.

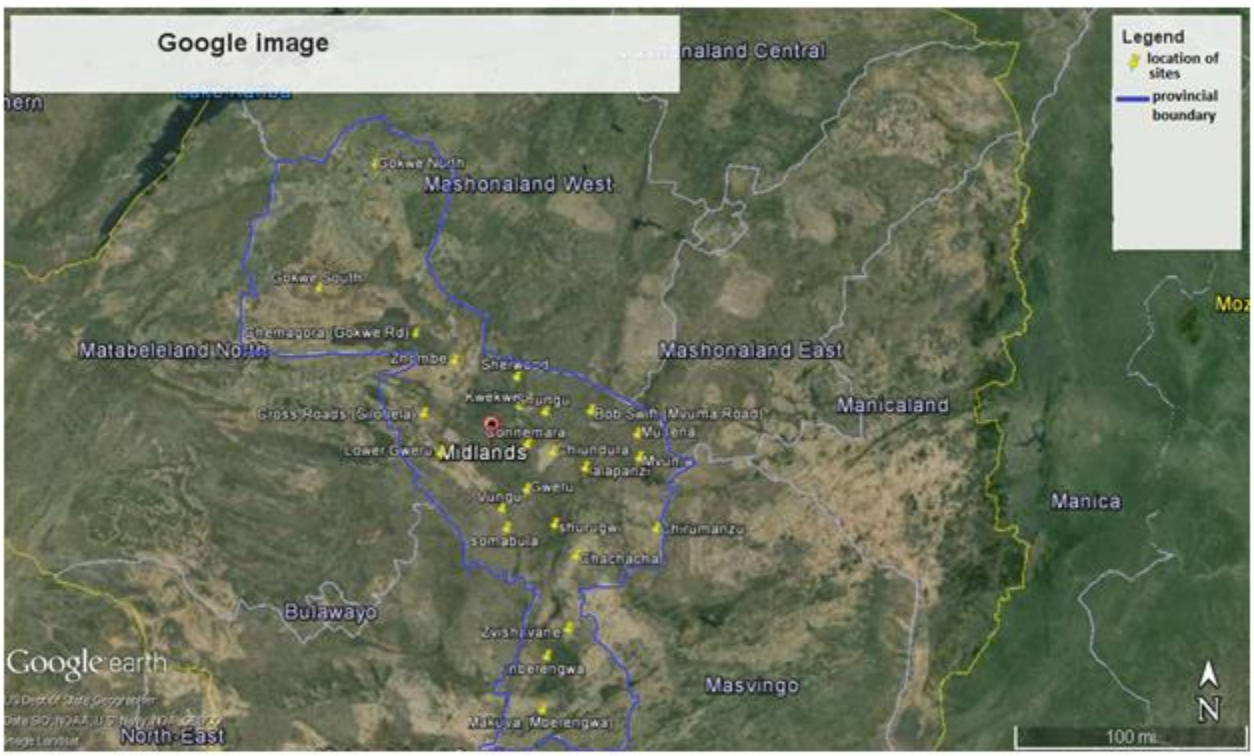

Figure 3.2: Google Earth Image highlighting distribution of areas visited. (Landsat, 04/09/2012)

3.2 Sampling

Data on existing boreholes was collected from Toramvura drilling company, data was obtained from this company because it drills extensively with in the province.

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Data included name of the client, depth of the borehole, depth of both plain and perforated casing, level of fractures, estimated yield of the borehole and location of the drilling site.

3.2.1 Sampling procedures

3.2.1.1 Convenience sampling

Data supplied from Toramvura Drilling consisted of 200 boreholes drilled from 2011 up to 2015 the length of the time frame is irrelevant because any potential relationships between groundwater and phreatophytes exists long before boreholes are drilled and is independent of them. The data was stratified in to two layers i.e. boreholes existing in urban areas and boreholes existing in rural areas. From these target sites, 69 were eliminated because they were in urban areas. Urban sites were eliminated because they are more likely to contain exotic tree species and trees planted artificially for landscaping purposes. Furthermore watering of trees usually occurs in urban areas, this disturbs the natural conditions that trees grow which is important for the study of phreatophytic species. 131 sites remained and of these sites 11 more were eliminated due to their remoteness, these would not be easy to access due to budget constraints. 120 sites were left for the purpose of selecting 100 sites for observations and measurements.

3.2.1.2 Random Sampling

The next step involved awarding a natural number for all remaining sites that had not been eliminated. The Random (RAN) function of a scientific calculator was used to determine a random probability sample. A total of 100 sites where chosen. 25 in Gweru, 3 in Lalapanzi, 24 in Kwekwe, 6 in Mvuma, 7 in Somabula, 3 in Gokwe, 4 in Silobela, 2 in Zvishavane, 9 in Shurugwi, 3 in Lower Gweru, 4 in Mberengwa, 6 in Chirumanzu, 4 in Chiundura.

3.3 Observation of tree species at target sites

A survey was conducted for each of 100 sites. At each borehole the vegetation within a100 m radius of the borehole site was inspected, a 100 m radius was chosen as the maximum so as to limit the probability that the indicators are being influenced by groundwater other than that at the observation site (actual borehole being observed). Of the 100 sites, 28 were condemned as they were in open fields and did not have any tree species within a 100 m radius; some were also

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located in homesteads. However some did have species, but these were also condemned due to the fact that the species existing around these boreholes were exotic species.

3.3.1 Establishment of baseline species

The base line species of each site of the target site group were established. The baseline species' were established because due to their unlimited abundance and low specificity, they are not limited to the target site group. Specificity of an indicator is important for it to be able to determine a target site in any target site group. (DeCa´ceres et al., 2012).

Since Zimbabwe has limited groundwater it is important to establish baseline species for areas because the growth of these species in abundance does not always mean good groundwater. Species such as Mutondo µ0XEHUQUGLDJORELIRUD¶ for example form large forests throughout Zimbabwe (Hyde et al, 2015), their existence in such abundance does not necessarily mean all these areas are full of groundwater since Zimbabwe is granite country and dry holes do occur in these heavily forested areas regardless of these tree species abundance. The baseline species were established by subjectively observing the relative abundance of tree species throughout the entire general area where the borehole is located not just the target site and its 100 m radius. Table 3.1 shows the baseline species' that were identified for elimination purposes.

Table 3.1: Baseline species' established

9HUQDFXODUQDPH	*/DWLQQDPH*
Mutondo	*-XOEHUQDUGLDJORELIORUD*
Mopane	*%UDFK\VWHJLDVSLFLIRUPLV*
Musasa	*&RORSKRVSHUPXPPRSDQH*
Mupfuti	*%UDFK\VWHJLDERHKPLL*
Muunga	*$FDFLDEHQDQDQ*

3.3.2 Identification of indicator species

After establishing the baseline species' of the general area, other tree species within a 100 m radius were investigated and identified.

Tree species other than the baseline species observed at target sites were assumed to be site specific (DeCa´ceres et al., 2012). 10 different tree species were identified as potential indicator

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species' because of their seeming restriction to the target site group. Table 3.2 shows identified indicators;

Table 3.2: Indicator species identified

Vernacular name	***Latin name***
Mukaya	***Acacia [illegible]***
Chinanga	***Acacia [illegible]***
Mupanda	***Lonchocarpus capassa***
Musekesa	***Piliostigma thonningii***
Mupfura	***Sclerocarya birrea caffra***
Muwonde	***Ficus sycomorus***
Mutsubvu	***Vitex payos***
Muunze	***Och[illegible]***
Mukamba	***Afzelia quanzensis***
Mugan'acha	***Lannea discolor***

(Hyde et al, 2015)

Highlighted species were eliminated from analysis because they had a low frequency, this is according to (McGeoch, 1998), and they occurred less than 5% of the time. Independent sample T-tests were used to determine (at 95% confidence level) which of the indicator species had significant differences in the means of the yields they represented. A T-test requires normally distributed data so non-numerical data such as those representing indicators was first transformed and re-coded so that it follows a normal distribution for each of the different variables.

The trend between the occurrence of indicator species' and depth was also observed and analysed. A one-way ANOVA was used (at 95% confidence level) to determine if there was any significant difference between the means of depths represented by the occurrence of all the indicator species'. For all purposes involving depth, the depth of the last fracture (commonly called breaks) was used instead of the actual depth of the borehole. This is because drilling after the last fracture is done for purposes of creating a sump for pumping purposes. Any further mention of depth refers to the depth to the last fracture.

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3.4 Determination of relationships between yield, depth and biometric characteristics

3.4.1 Measurement of girth

For the biometric characteristics of potential indicator tree species', girth was physically measured by way of a tape measure 1 m from the ground on the trunk of the tree. All potential indicator species at target sites were measured and the average recorded for each species. (Dufreˆ ne et al. (1997) had mentioned that indicator analysis can be done by way of correlation between the observed indicator and characteristics of the site from which it was observed. A regression analysis was done (at 95% confidence level), to determine whether the girth of any of the indicators was dependent on the quantity of the estimated yield of the boreholes.

3.4.2 Measurement of crown radius

The crown radius of the trees was measured from the ground level using a rod and tape measure. The rod was used to extrapolate the edge of the crown to the ground level. The rod was then drove into the ground and the tape measure used to measure the distance form 1 m height above ground from the trunk to any corresponding level above ground on the rod parallel to the 1 m level on the trunk. Two sides of the crown were recorded, the longest and the shortest. An average of the two sides was calculated and recorded as the crown radius. The averages for all the different indicators within the target site group was then calculated. A regression analysis was also used (at 95% confidence level), to determine if there was a correlation between estimated yield of boreholes and crown radius for the different indicators.

3.5 Determination of relationships between yield, depth and abundance

3.5.1 Determining abundance

Potential indicator species were counted within a 100 m radius around the borehole site for the purpose of determining their abundance around such target sites. Regression analysis was done (at 95% confidence level), again to determine if species' abundance was correlated to the estimated borehole yields. Regression was also done determine the relationship between species' abundance and depth of boreholes to the last fracture encountered during drilling.

3.6 Data analysis

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Analysis of the survey data was done using International Business Machines Corporation Statistical Packages for Social Sciences (IBM SPSS) statistics Version20 and Microsoft Excel 2010.

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CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Relationship of indicators to yield and depth of boreholes

4.1.1 Yield and indicator species interaction

The occurrence of the different potential indicators was plotted against the respective estimated yields of the boreholes at which they were occurring. Figure 4.1 shows the comparison;

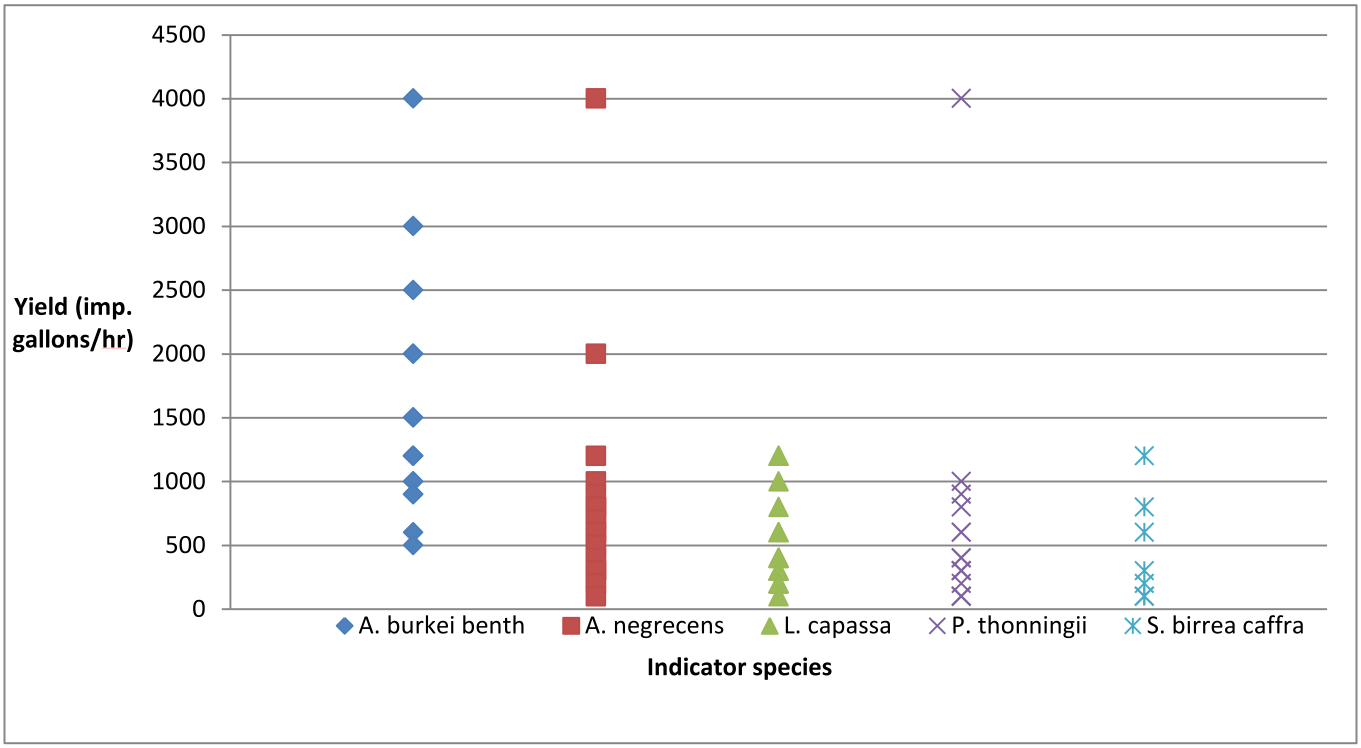

Figure 4.1: Typical borehole yields associated with indicator species'

The scatter plot clearly shows how the indicators were distributed amongst the various boreholes. The plot shows that *Acacia burkei benth* was mainly distributed amongst the highest yielding boreholes. It occurred at the highest yielding borehole of 4000 gallons/hr (imperial); it also shows that the same prior mention species also had an occurrence floor of 600 gallons/hr below which its occurrence stopped. It had a mean representation of yield 1477.27 gallons/hr. *Acacia negrecens* did occur at the highest yielding borehole; however its distribution was mainly limited to a range of between 1200-200 gallons/hr, with mean 692.31gallons/hr. *Lonchocarpus capassa* occurred mainly between estimated yields of 1200-200 gallons/hr, with mean 447.06 gallons/hr. *Piliostigma thonningii* occurred mainly between estimated yields of 1000-200gallons/hr;

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however it did have an occurrence at estimated yield 4000 gallons/hr, with mean 552.38 gallons/hr. *Sclerocarya birrea caffra* represented yields of between 1200-200 gallons/hr, with mean 395.109 gallons/hr. Meinzer (1927), had identified Acacia species as being indicators for the groundwater regimen in the US, he identified *Acacia horrida* (Sweet Thorn) as being a reliable indicator for the existence of groundwater. (FAO, 2015), in their corporate document repository identified *Lonchocarpus Capassa* as a reliable indicator of groundwater. An independent T-test was used to distinguish between the sensitivities of the different indicator species' to yield.

Table 4.1: Independent T-test to determine differences in yield between species combinations

Independent Sample T-test			
Indicator combinations	**N**	**Mean**	**P<0.05**
A. burkei benth	22	1477.27	
A. negrecens	39	692.31	0.000
A. burkei benth	22	1477.27	
L. capassa	34	447.06	0.000
A. burkei benth	22	1477.27	
P. thonningii	21	552.38	0.010
A. burkei benth	22	1477.27	
S. birrea caffra	9	388.89	0.000
A. negrecens	39	692.31	
L. capassa	34	447.06	0.037
A. negrecens	39	692.31	
P. thonningii	21	552.38	0.507
A. negrecens	39	692.31	
S. birrea caffra	9	388.89	0.850
L. capassa	34	447.06	
P. thonningii	21	552.38	0.582
L. capassa	34	447.06	
S. birrea caffra	9	388.89	0.689
P. thonningii	21	552.38	
S. birrea caffra	9	388.89	0.472

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Table 4.1 shows the results of the Independent T-test between any combinations of any 2 of the indicator species, done to determine there was any significance between the different the yield means of indicators.

The results showed that there was a significance difference between the mean estimated yield represented by *Acacia burkei benth* and the yields represented by all other species. *Acacia burkei benth* is representing its own high range of borehole yields exclusive of other indicator species as it has the highest mean of 1477.27 gallons/hr. There was also a significant difference between the mean yields represented by *Acacia negrecens* and *Lonchocarpus capassa*. Both indicators *Acacia negrecens* and *Lonchocarpus capassa* failed to have any significant difference with any of the remaining indicators *Piliostigma thonningii* and *Sclerocarya birrea caffra*.
Naturally one would expect a significant difference between indicator combinations (*Acacia negrecens* and *Piliostigma thonningii)* or (*Acacia negrecens* and *Sclerocarya birrea)*. Both indicators *Piliostigma thonningii* and *Sclerocarya birrea caffra* did not show any significant difference from the indicator *Lonchocarpus capassa* but *Lonchocarpus capassa* had shown a significant difference to *Acacia negrecens*.

This statistical phenomenon can be easily explained, is a classic example of indicator species combinations. These combinations can occur following this pattern due to the fact that some species can exhibit a tolerance to fluctuating groundwater conditions. (Wierda et al., 1997). *Piliostigma thonningii* and *Sclerocarya birrea caffra* are exhibiting tolerance characteristics; they are able to survive over a larger range of yields. All other indicators are yield sensitive, except *Piliostigma thonningii* and *Sclerocarya birrea caffra*. For indicator valuation, species combinations involving *Piliostigma thonningii* and/or *Sclerocarya birrea caffra* with any of the other 3 indicators within the target site group will most likely depend on the other 3 indicators for an estimated yield prediction. In other words, although *Piliostigma thonningii* and *Sclerocarya birrea caffra* might have specificity in terms of general prediction of groundwater they do not have sensitivity in terms of predicting quantity (DeCa´ceres et al., 2012). Furthermore their yield fluctuation tolerance does not overlap with the average of *Acacia burkei benth* so a species combination involving *Acacia burkei benth* with either *Piliostigma thonningii* or *Sclerocarya birrea caffra* for yields greater than 1477.27 is statistically unlikely to occur.

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4.1.2 Depth DQLQLFDWRUVSHFLHVLQWHUDFWLRQ

The indicator species' were analysed for their sensitivity to depth. The relationship between borehole depths and the presence of indicator species was represented graphically. Figure 4.2 shows the relationship between the range of borehole depths and indicator species.

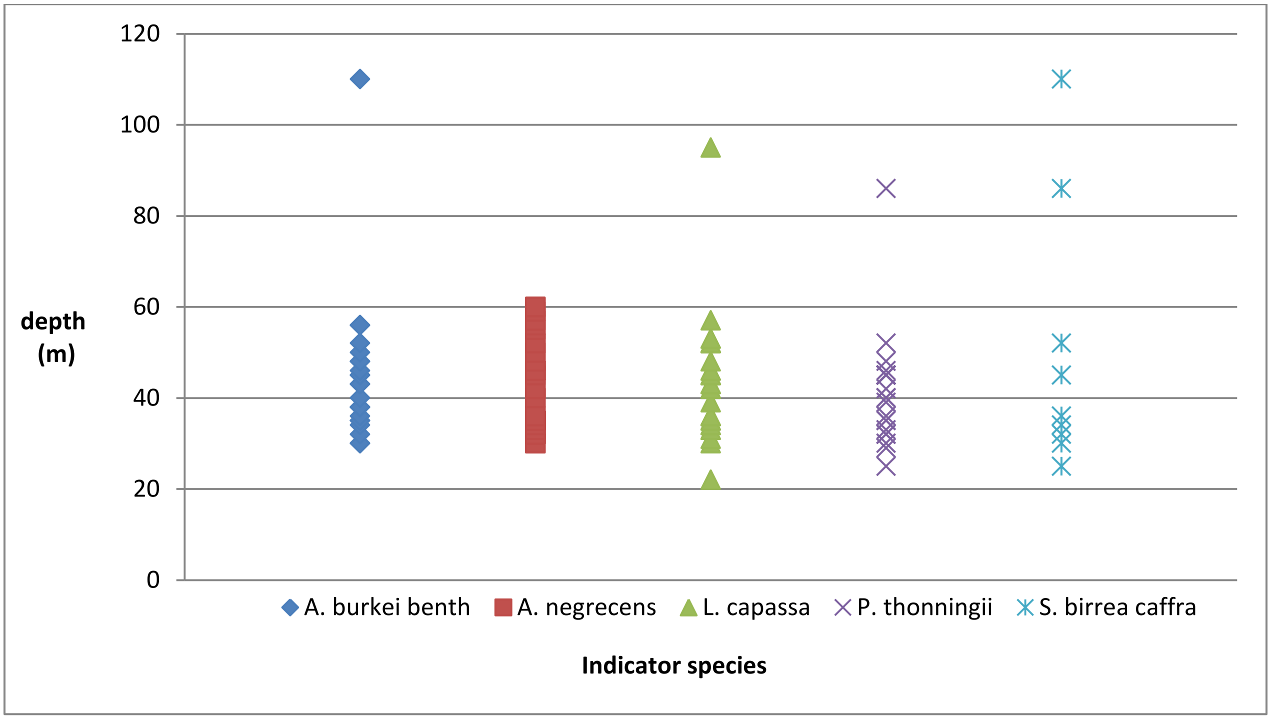

Figure 4.2: Range of borehole depths associated with indicator species

The results show that all the indicators were associated with borehole fractures mainly between 30m to 56m in depth. Generally; *Piliostigma thonningii* (mean = 40.57 m) and *Acacia negrecens* (mean = 41.47 m) are representing the shallower depths. Also, *Acacia burkei benth* (mean = 44.70 m) and *Lonchocarpus capassa* (mean = 43.15 m) are having their occurrence depths deeper than the first two. Finally *S. birrea caffra* (mean = 50 m) is occurring in conjunction with the deepest fractures. This pattern probably has a relationship with the ability of certain species being able to extract ground water from deeper levels than others (Stone et al., 1991).

However a one-way ANOVA (see appendix II), showed that there was no significant difference between the depths at which species' indicators were occurring. This showed that the occurrence of indicators was more depended on yield than depth.

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4.2 Relationships between indicator biometric characteristics and yield of boreholes

4.2.1 Girth and yield interaction

An analysis was done to test the effect of yield on species girth. Figure 4.3 is a graphical representation illustrating the relationship existing between girth and yield.

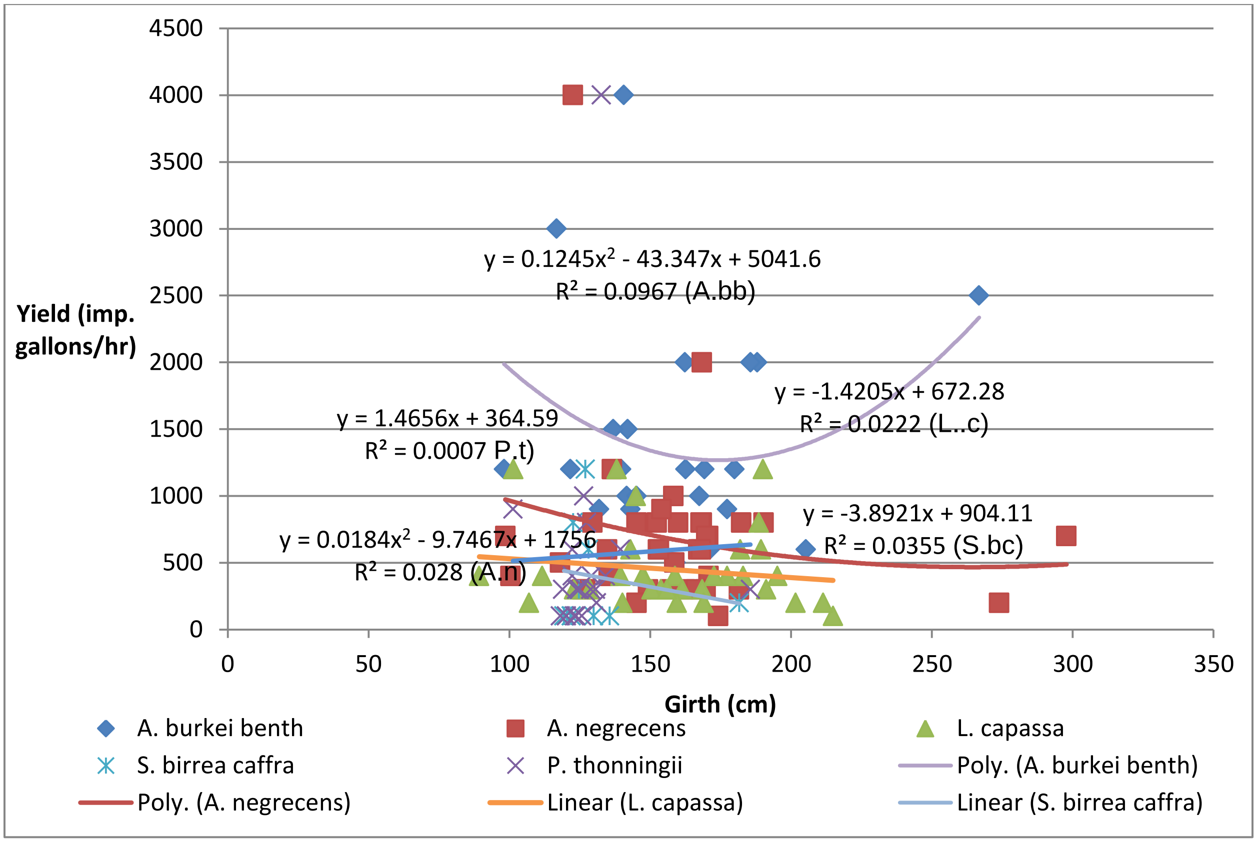

Figure 4.3: Relationships between indicator species' girth and borehole yields

The scatter plots clearly show a lot of clustering for all the indicators identified in this study, the majority of the indicators has their girth clustered between 100 cm to 200cm, representing yields of mostly between approximately 100 gallon/hr to 1200 gallons/hr. All species are described by a weak positive correlation. *Acacia burkei* benth has the best prediction rate, which can be described by a polynomial equation at 31%. A regression analysis was conducted to test for the significance of correlations.

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Table 4.2 shows the results of the regression analysis between girth of the indicators and borehole yields.

Table 4.2: Regression analysis between girth and yield

Regression Analysis		
Indicators	**R**	**P<0.05**
A. burkei benth	0.042	.851
A. negrecens	0.149	.372
L. capassa	0.149	.400
P. thonningii	0.027	.908
S. birrea caffra	0.188	.627

The regression analysis showed that there was no significant correlation between girth and estimated yield for any of the species'.

4.2.2 Crown radius and yield interaction

Figure 4.4 illustrates the relationship between crown radius and yield. There is some degree of clustering of as shown by the scatter, without any prominent trends occurring. All the scatter plots show a weak positive correlation. *Lonchocarpus capassa* and *Acacia negrecens* have their girth exhibiting a spread from both high to low girth values within a smaller range of yields (less clustered). This is probably a testament of their morphology. This shows that they are savanna species able to grow over a wide range of yields. They are exhibiting tolerance to yield fluctuations (Wierda et al., 1997). Table 4.3 shows the regression analysis between yield and crown radius.

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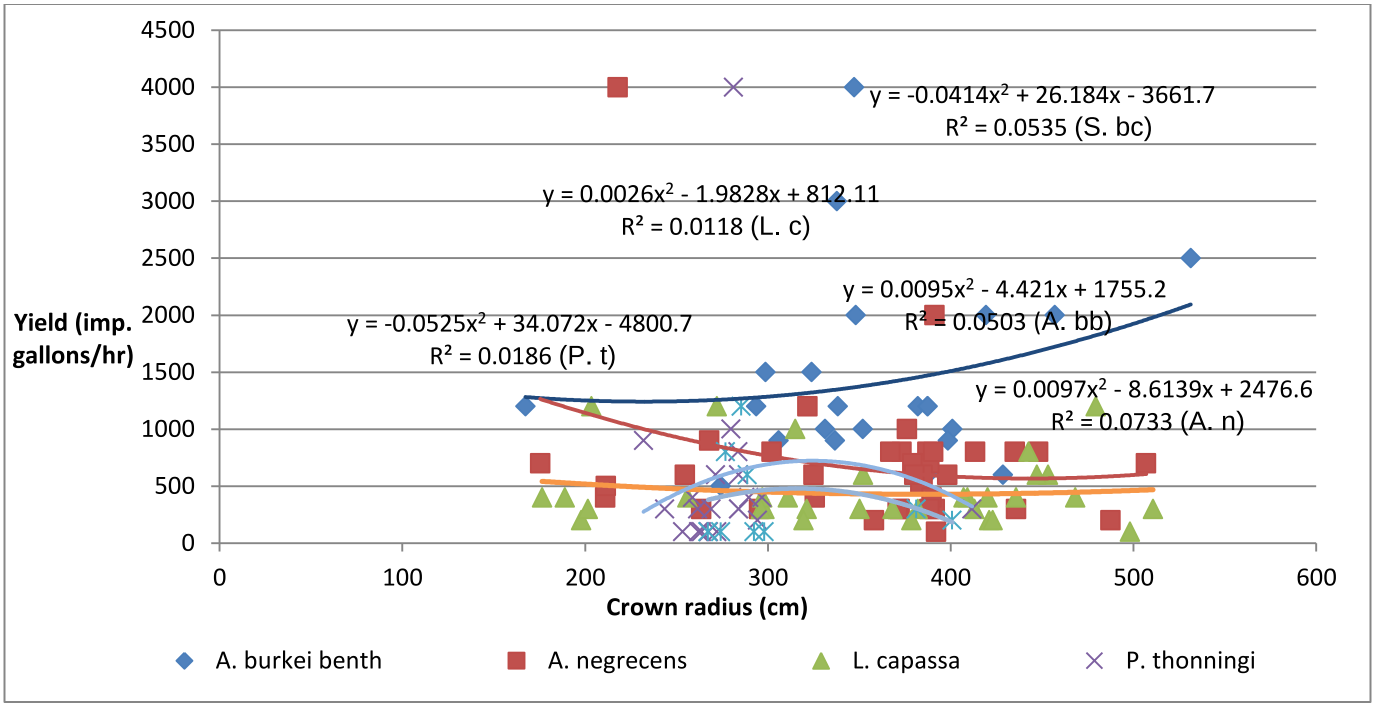

Figure 4.4: Relationships between indicator species' crown radius and borehole yields

Table 4.3: Regression analysis between yield and crown radius

Regression Analysis		
Indicators	**R**	**P<0.05**
A. burkei benth	0.197	0.367
A. negrecens	0.248	0.134
L. capassa	0.115	0.518
P. thonningii	0.000	0.999
S. birrea caffra	0.197	0.611

There is no significant correlation between crown radius and borehole yield.

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4.2.3 Discussion of relationship between borehole yield and biometric characteristics

Both yield and depth of aquifers affect the availability of groundwater to trees species. The biometric characteristics (girth and crown radius) of plants are not only affected by groundwater or moisture availability. Other environmental conditions such as nutrient availability (Zhao et al., 2005), toxicities, drainage, local climatic conditions etc., also affect biometric characteristics. This could explain why there is no positive correlation between biometric characteristics and yield for the observed sites.

Furthermore Midlands is in the savanna region, vegetation in the savanna is adapted to surviving in dry conditions and it able to tolerate fluctuating water availability conditions and maintain growth. It is possible that the yields of borehole might not be entirely related to water stress levels of the indicators, plant might still be extracting enough water to meet their physiological needs (Wierda et al., 1997).

Also the province is comprised of more than one Agro- Ecological regions (Vincent et al., 1960) meaning that the province has different mean annual rainfalls with different temporal distributions. This affects plant growth if they are not obligate phreatophytes (Preobrazhenskaya, 1965). Another factor to note is that the Great Dyke an extensive mineral belt passes through the Midlands province (Shoko et al, 2014), indicators located within it, or within its possible sphere of influence might be having their biometric characteristics not only being affected by the groundwater table but by toxicities of minerals such as chromium etc. It is also possible that some aquifers might be passing through the great dyke and distributing the effects of dyke mineral toxicities to other areas.

Finally the indicator species' were not separated by age within the group because cheaper methods such as ring counting required tree felling would have been environmentally destructive, more expensive methods such as carbon dating were financially unobtainable, so it is very possible that the trees could have been of different ages (affecting sample homogeneity), had they been classified according to age perhaps a significant correlation between yield and biometric characteristics might have been observed.

4.3 Relationship between biometric characteristics and depth

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The sensitivity of indicator species' biometric characteristics to borehole depth was also analysed.

4.3.1 Girth and depth interaction

The interaction between species girth and depth is illustrated in Figure 4.5. The scatter plots show a lot of clustering between girths 100 cm to 200 cm and depths of between 30 m to 60 m. *Lonchocarpus capassa* had the highest R^2 value of 0.1594 while *Sclerocarya birrea caffra* had the lowest R^2 value of 0.0111. Most relationships were best described by a polynomial equation. None of the relationships between species' girth and borehole depth were significant. All relationships were a weak positive correlation.

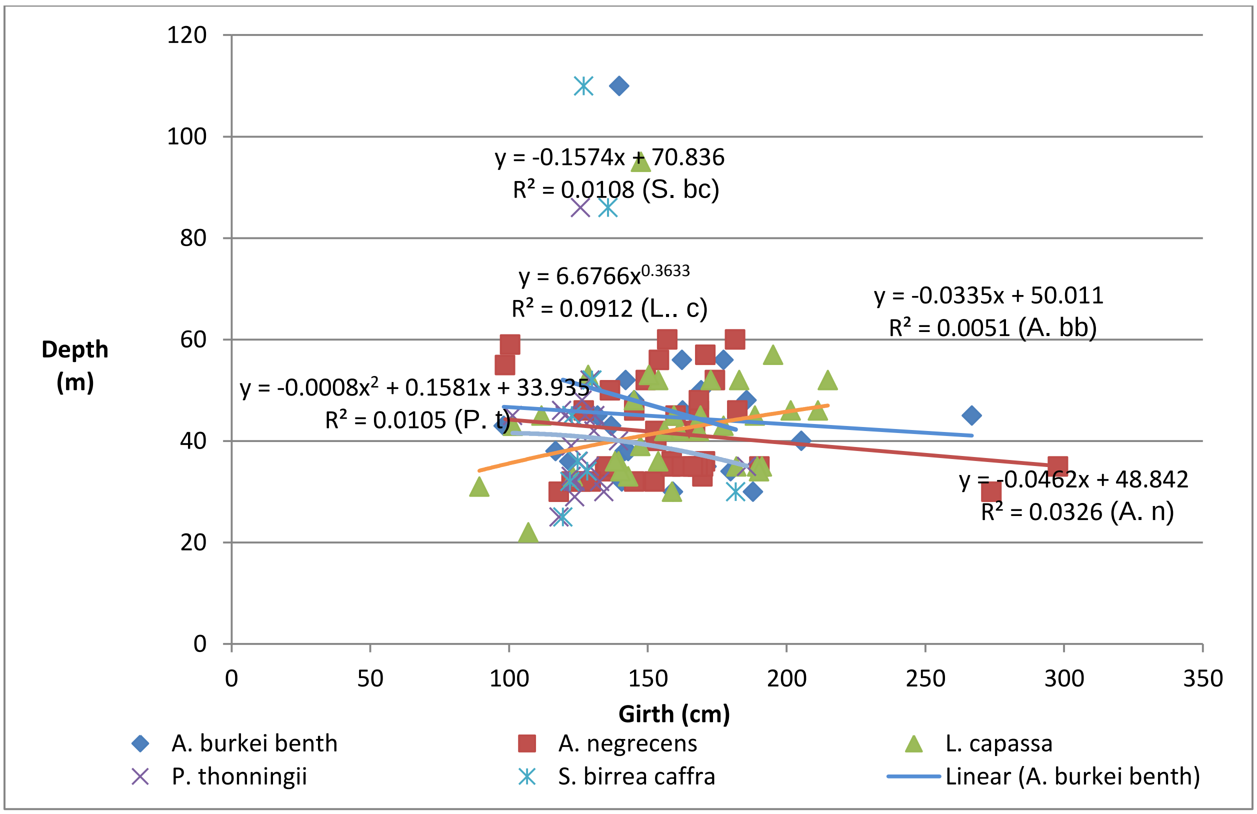

Figure 4.5: Relationships between indicator species' girth and depth

4.3.2 Crown radius and depth interaction

Figure 4.6 shows the relationship between crown radius and depth. The scatter plots show that a weak positive correlation relationship exists between the crown radius of species and the depth

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of boreholes. The scatter plot also shows a lot of clustering. However *L. capassa* does show to be represented at a wider range of crown radius. Acacia negrecens is also exhibiting a similar characteristic. However none of the correlations had any significance.

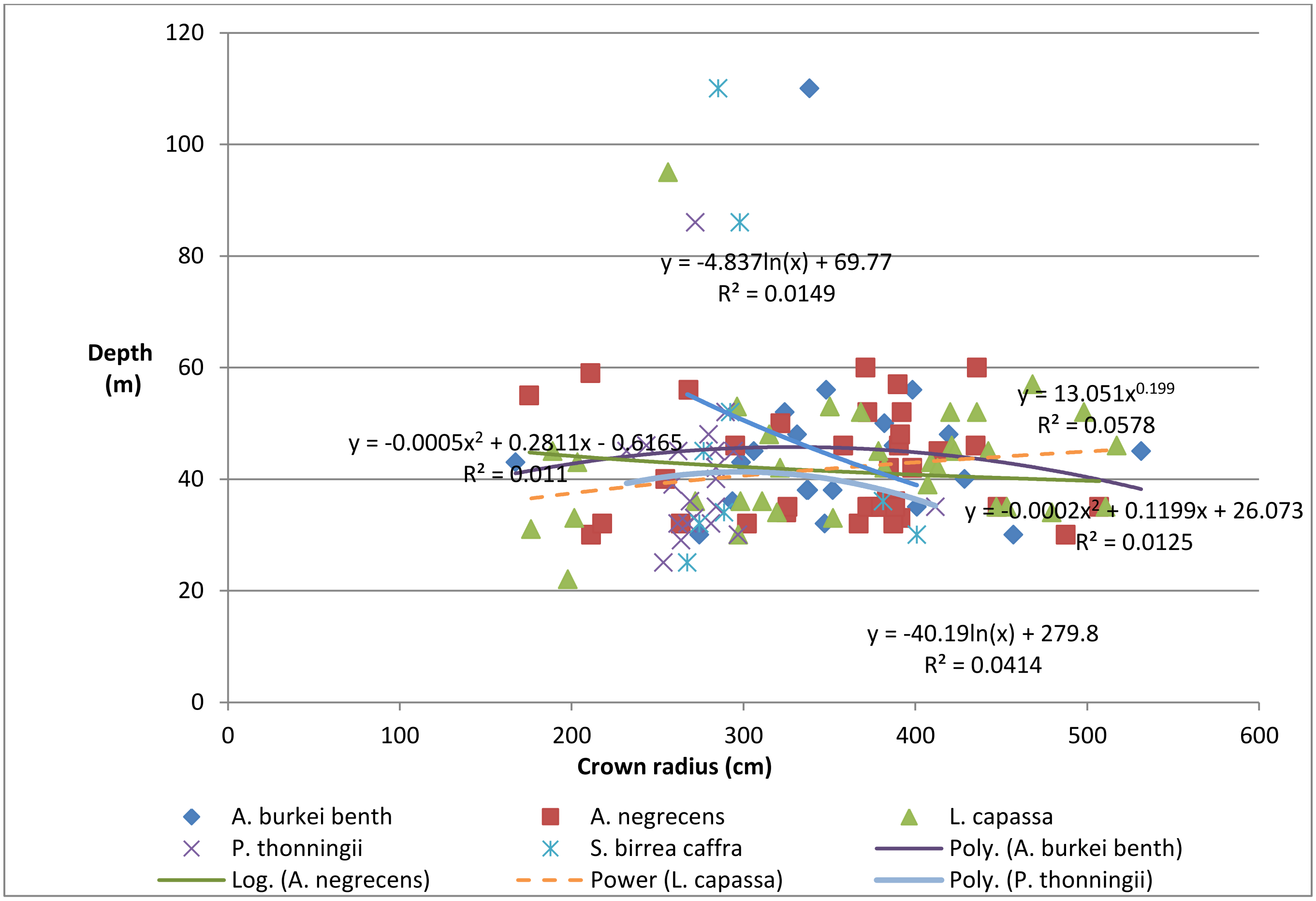

Figure 4.6: Relationships between indicator species' crown radius and borehole depth

4.3.3 Discussion of relationship between borehole depth and biometric characteristics

The indicator species might not be extracting water from the level of the last fracture used in the analyses but rather from higher up. It is important to note that these boreholes were not drilled for the purpose of research but rather for abstraction purposes. Clients have different water requirements independent of depth, thus it is possible that the depth to which they were drilled did not constitute all the potential aquifers at that site. They might have been depths of convenience due to either client abstraction needs, limitations in the finance or limitations due to difficulties encountered during drilling.

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4.4 Relationships between abundance and borehole yield and depth

4.4.1 Abundance and yield

Figure 4.7 illustrates the relationship between abundance and yield.

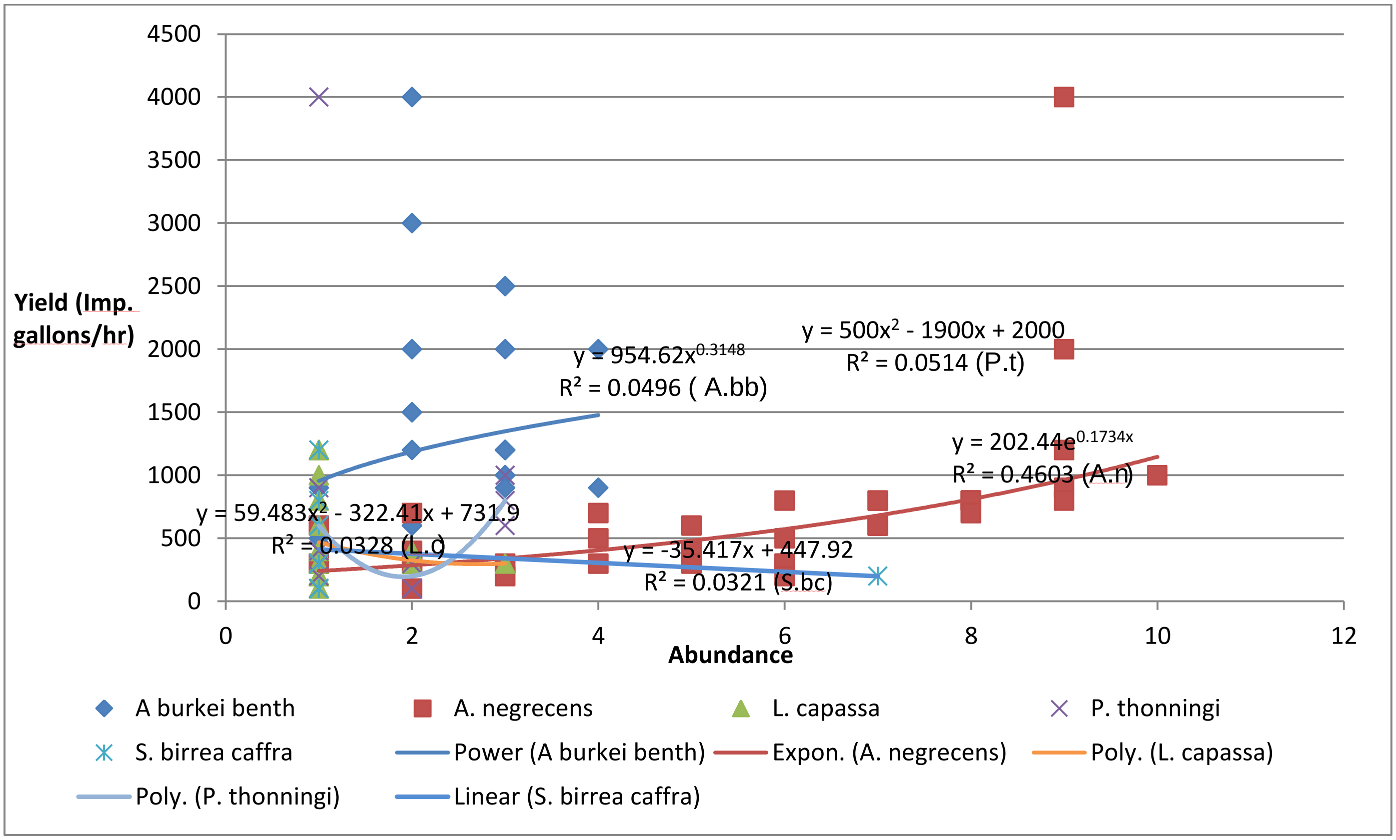

Figure 4.7: Range of borehole yields associated with indicator species' abundance

All indicators are showing a positive correlation between species abundance and borehole yield. The most powerful relationship is being exhibited by *Acacia negrecens*. This relationship is best described by an exponential equation. The other indicators show a weak positive correlation which has no significance. The species exhibiting a weak positive correlation have abundance's of mainly between 1 and 3. *Acacia burkei benth* is having a maximum abundance of 4. The species with the most powerful positive correlation, *Acacia negrecens* is exhibiting a range of 1 to 10 trees per site.

Table 4.4 shows results for the regression analysis between yield and abundance.

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Table 4.4: Regression analysis between yield and abundance

Regression Analysis		
Indicators	**R**	**P<0.05**
A. burkei benth	0.006	0.977
A. negrecens	0.678	0.001
L. capassa	0.204	0.247
P. thonningii	0.019	0.934
S. birrea caffra	0.179	0.644

The analysis shows that the abundance of *Acacia negrecens* has a significant positive correlation with estimated borehole yield. It is able to predict the yield with the best relationship being polynomial with a 67.8% prediction rate. The increase of groundwater with abundance for the indicator concurs with the idea that areas with more groundwater will have more trees growing (National Centre for Groundwater Research and Training, 2014).

Acacia negrecens is a leguminous plant (Stone et al., 1991) and is able to fixate nitrogen; this advantage might be giving it an advantage over other species allowing it to establish more easily increasing its abundance. It also has seeds that form inside a pod. Although animal seed dispersal does occur (Richardson et al., 2004), another form of seed dispersal for this species involves exploding of the pod dispersing seed away but in close proximity to the mother plant. Such dispersal methods ensure that the seed a placed away from the mother plant to reduce completion but not so far away as to terminate benefits from the existing environmental conditions were the mother plant is thriving. This mechanism can result in species being abundant with in a smaller radius. The significant correlation between the abundance of *Acacia*

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negrecens and borehole yield is indication of it being a potential obligate phreatophyte assuming that it is limited to the target site group.

However *Acacia burkei benth* is also leguminous but is no exhibiting any correlation between its abundance and yield, it might be a facultative phreatophyte such that is abundance does not solely need to be deepened on high groundwater quantities in a single area.

4.4.2 Abundance and depth

Figure 4.8 shows the relationship between depth of borehole and species' abundance.

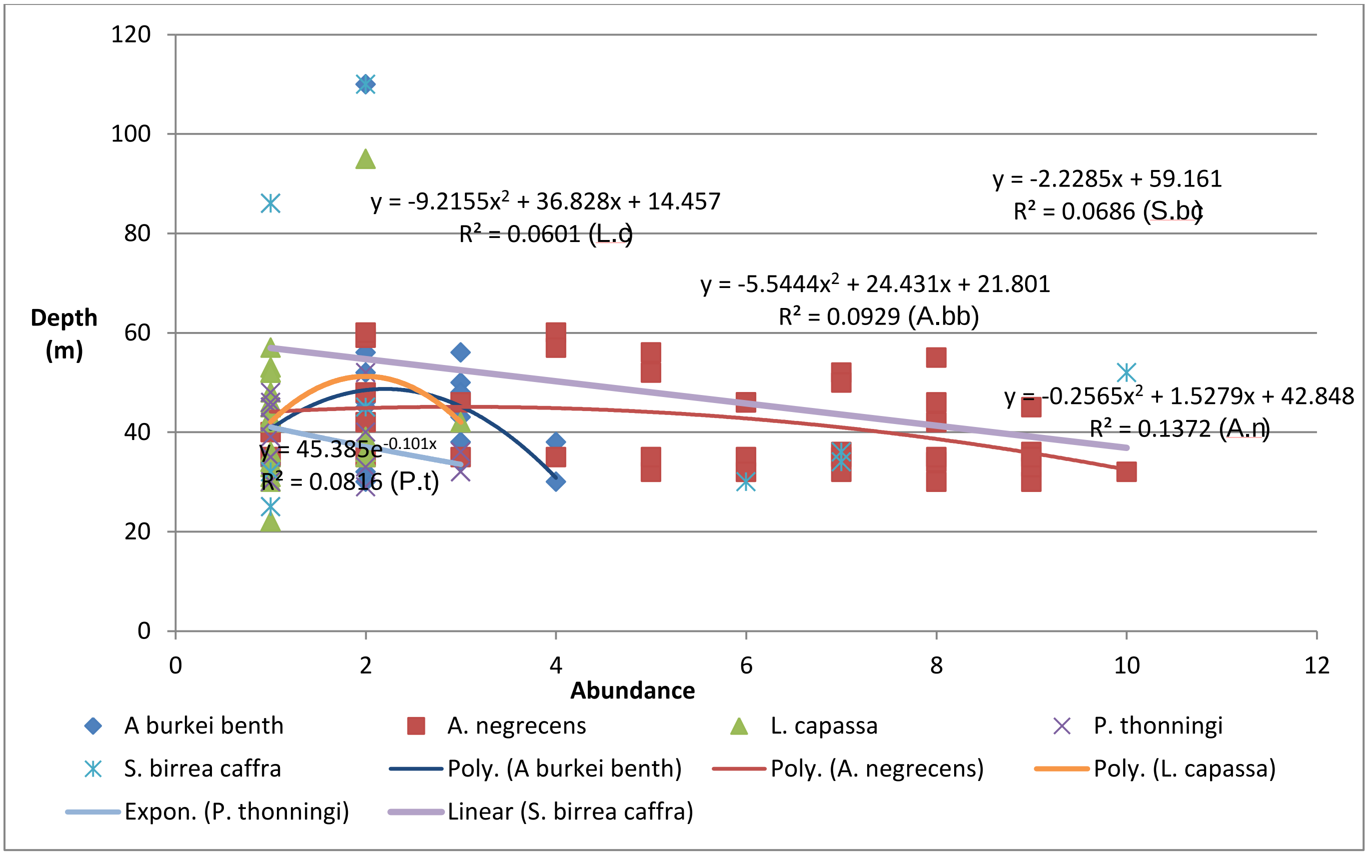

Figure 4.8: Range of borehole depths associated with indicator species' abundance

The borehole depths represented by the species mainly range between 30 m to 56m. All the species are exhibiting a positive correlation between abundance and depth. All the relationships are quite strong. However the strongest linear relationship is occurring between the abundance of *Sclerocarya birrea caffra* and the depths to the last fracture it represents. It has a prediction rate

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of 77.6% followed by *Acacia negrecens* at 33.2%. Table 4.5 shows the regression analysis between abundance and depth;

Table 4.5: Regression analysis between abundance and depth

Regression Analysis		
Indicators	**R**	**P<0.05**
A. burkei benth	0.150	.495
A. negrecens	0.332	0.231
L. capassa	0.162	0.359
P. thonningii	0.272	0.233
S. birrea caffra	0.776	0.014

During borehole drilling the deeper the unconsolidated material the deeper it will take to reach consolidated rock material were fracture determination can occur (Rowles, 1990). The positive correlation exhibited by species' abundance to yield is in all likelihood a preference for good drainage. Notably, *Sclerocarya birrea caffra* prefers well drained sandy soils and/or well fractured geological formations allowing good drainage, such as rocky hills (Orwa et al., 2009). Its site distribution in this study included areas such as Chemagora, an area with close geological similarity to Gokwe which has deep Kalahari sands and Pakami which also has sandy soils amongst others. Thus it is very possible that its abundance might be more of a function of drainage rather than depth to the last break.

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CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Five species were identified as indicators of groundwater. These were $DFLDEXNHL EHQWK $DFLDHQJUHFHQV/RQKRFDUSXFDSDV3LOLRVWLJPDWKRQQL and Sclerocarya birrea caffra . Of the five identified species three were linked to the yields of boreholes. These were Acacia burkei benth, Acacia negrecens and Lonchocarpus capassa . None of the species had any distinguishable relationship between biometric characteristics and the yield or depth of boreholes. There was however, a positive linear relationship between the abundance of Acacia negrecens and the yield of boreholes. Finally the abundance of Sclerocarya birrea caffra also showed a positive linear relationship with borehole depth.

5.2 Recommendations

From the results of the study, it is strongly recommend that the species identified as indicators be used in conjunction with existing groundwater prospecting methods in the Midlands Province. It can also be recommend that groundwater prospectors use and link *Acacia burkei benth, Acacia negrecens* and *Lonchocarpus capassa* in predicting the quantity of ground water during groundwater prospecting. Judging from the results of the study it is not recommended to use the biometric properties of indicators in determining depth or yield of boreholes in the Midlands province. However it can be recommend from the study, that groundwater prospectors use the abundance of *Acacia negrecens* in aiding borehole yield prediction and the abundance of *Sclerocarya birrea caffra* as an aid for predicting the depth of boreholes.

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APPENDIX I

Independent Samples T-test for the comparison of means of yields represented by the GLIIHUHQWLQLFDWRUVSHFLHV¶

Independent Sample T-test					
Indicator combinations	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**	**P<0.05**
A. burkei benth ***A. negrecens***	22 39	1477.27 692.31	828.614 640.47	176.661 102.557	0.000
A. burkei benth ***L. capassa***	22 34	1477.27 447.06	828.614 296.684	176.661 50.881	0.000
A. burkei benth ***P. thonningii***	22 21	1477.27 552.38	828.614 832.838	176.661 181.74	0.010
A. burkei benth ***S. birrea caffra***	22 9	1477.27 388.89	828.614 395.109	176.661 131.703	0.000
A. negrecens ***L. capassa***	39 34	692.31 447.06	640.47 296.684	102.557 50.881	0.037
A. negrecens ***P. thonningii***	39 21	692.31 552.38	640.47 832.838	102.557 181.74	0.507
A. negrecens ***S. birrea caffra***	39 9	692.31 388.89	640.47 395.109	102.557 131.703	0.850
L. capassa ***P. thonningii***	34 21	447.06 552.38	296.684 832.838	50.881 181.74	0.582
L. capassa ***S. birrea caffra***	34 9	447.06 388.89	296.684 395.109	50.881 131.703	0.689
P. thonningii ***S. birrea caffra***	21 9	552.38 388.89	832.838 395.109	181.74 131.703	0.472

APPENDIX II

One-way ANOVA comparing the means of depths represented by all indicators.

Notes

Output Created		24-OCT-2015 19:30:24
Comments		
Input	Active Dataset	DataSet8
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Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on cases with no missing data for any variable in the analysis.
Syntax		ONEWAY LASTBREAK BY INDICATOR
Resources	Processor Time	00:00:00.02
	Elapsed Time	00:00:00.02

ANOVA

LAST BREAK

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	720.217	4	180.054	.901	.466
Within Groups	23991.751	120	199.931		
Total	24711.968	124			

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APPENDIX III

Regression Analyses showing relationships between biometric characteristics and yield.

Girth and yield

Regression Analysis							
Indicators	**R**	**Std. Error**	**Mean Square**	**F**	**Adjusted R-Square**	**Std. Error of Estimate**	**P<0.05**
A. burkei benth	0.042	5.236	26153.196	.036	-.046	848.770	.851
A. negrecens	0.149	2.879	346420.173	.819	-.005	650.481	.372
L. capassa	0.149	1.666	64500.156	.727	-.008	297.920	.400
P. thonningii	0.027	12.569	9920.085	.014	-.052	854.168	.908
S. birrea caffra	0.188	7.671	44300.245	.257	-.102	414.830	.627

Crown radius and yield

Regression Analysis							
Indicators	**R**	**Std. Error**	**Mean Square**	**F**	**Adjusted R-Square**	**Std. Error of Estimate**	**P<0.05**
A. burkei benth	0.197	2.484	589951.192	0.851	-0.007	832.805	0.367
A. negrecens	0.248	1.392	954855.427	2.351	0.350	637.358	0.134
L. capassa	0.115	.531	38257.269	0.427	-0.018	299.293	0.518
P. thonningii	0.000	5.510	.580	0.000	-0.053	854.474	0.999
S. birrea caffra	0.197	3.005	48686.345	0.284	-0.098	414.074	0.611

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APPENDIX IV

Regression Analyses showing relationships between biometric characteristics and depth

Girth and depth

Regression Analysis							
Indicators	**R**	**Std. Error**	**Mean Square**	**F**	**Adjusted R-Square**	**Std. Error of Estimate**	**P<0.05**
A. burkei benth	.153	.101	135.344	.505	-.023	16.364	.485
A. negrecens	.114	.042	42.047	.472	-.014	9.440	.497
L. capassa	.218	.068	147.536	1.594	.018	12.146	.216
P. thonningii	.072	.189	164.143	.099	-.047	12.812	.757
S. birrea caffra	.374	.532	942.368	1.141	.017	28.744	.321

Crown radius and depth

Regression Analysis							
Indicators	**R**	**Std. Error**	**Mean Square**	**F**	**Adjusted R-Square**	**Std. Error of Estimate**	**P<0.05**
A. burkei benth	.039	.049	8.922	.033	-.046	16.547	.858
A. negrecens	.115	.021	44.172	.483	-.014	9.567	.492
L. capassa	.107	.022	56.343	.368	-.020	12.374	.548
P. thonningii	.067	.084	.580	.086	-.048	12.971	.773
S. birrea caffra	.225	.219	340.402	.373	-.085	30.203	.561

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APPENDIX V

Regression analyses showing relationships between abundance and yield or depth

Abundance and yield

Regression Analysis							
Indicators	**R**	**Std. Error**	**Mean Square**	**F**	**Adjusted R-Square**	**Std. Error of Estimate**	**P<0.05**
A. burkei benth	0.006	229.909	610.634	0.001	-0.048	849.486	0.977
A. negrecens	0.678	35.519	4162624.085	13.126	0.247	563.134	0.001
L. capassa	0.204	106.541	119396.887	1.392	0.012	292.917	0.247
P. thonningii	0.019	247.083	4877.345	0.007	-0.050	836.243	0.934
S. birrea caffra	0.179	73.459	40138.889	0.232	-0.106	415.546	0.644

Abundance and depth

Regression Analysis							
Indicators	**R**	**Std. Error**	**Mean Square**	**F**	**Adjusted R-Square**	**Std. Error of Estimate**	**P<0.05**
A. burkei benth	0.150	4.431	129.478	.483	-0.24	16.373	.495
A. negrecens	0.332	0.573	368.288	4.462	0.086	9.085	0.231
L. capassa	0.162	4.661	130.680	0.867	0.004	12.280	0.359
P. thonningii	0.272	3.732	237.973	1.521	0.025	12.509	0.233
S. birrea caffra	0.776	3.456	4050.000	10.594	0.545	19.552	0.014

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