SCALING IRRIGATION AND MALARIA RISK IN MALAWI

By

April Nicole Frake

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ABSTRACT

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A primary means of increasing agricultural productivity to reduce global food insecurity is through intensification, including scaling irrigation measures (USAID, 2014). Aid agencies have strongly promoted agricultural intensification efforts to increase productivity and improve overall livelihoods. While scaling of irrigated agriculture has demonstrated significant boosts in productivity (ADB, 2013; Melaine & Nonvide, 2017), agrarian transformation of the landscape through irrigated agricultural practices is associated with a number of water-related diseases (Hunter et al., 1993; Lacey & Lacey, 1990; Mather & That, 1984) including malaria (Ghebreyesus et al., 1999; Koudou et al., 2005; Oomen, De Wolf, & Jobin, 1988). The government of Malawi established through the Green Belt Initiative (GBI) a long-term program aimed at land use modifications for the development of small and large-scale irrigation. While Malawians continue to face challenges directly related to food insecurity, the country is simultaneously holoendemic for malaria, wherein the disease is found in essentially all members of the population.

This research investigates changes in disease dynamics of seasonal malaria cycles as a result of land transformation for irrigated agriculture using remote sensing and spatial analytical approaches. It is conducted against a backdrop of scaling up irrigated agricultural solutions across varying sectors, and myriad actors. To that end, the meaning of 'scaling up' is analyzed across Research and Development (R&D) institutions and a conceptual framework of scaling up was constructed to promote ontological agreement of scaling up from defining programs through to final evaluation of success. Three scenarios for estimated spatio-temporal distribution of suitable

area for mosquito breeding pool formation and persistence were produced for the Bwanje Valley Irrigation Scheme (BVIS) using remotely sensed and field-based data. In addition, an estimation of habitat suitability during the dry season was produced for the 8-km area surrounding BVIS, the Bwanje Valley. Potential malaria transmission at the national scale driven by the GBI is presented through analysis of the current extent of irrigated agriculture, proposed expansion, and historic malaria prevalence data assessed by the 2012, 2014, and 2017 Demographic Health Surveys (DHS) in combination with the results of a habitat suitability model generated in Google Earth Engine. The conclusions from this study provide a strong foundation for agricultural land use decision making with respect to malaria transmission across Malawi.

For Adam.

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1.1 Introduction

1.1.1 Food Insecurity

Food insecurity is a global phenomenon with a distinctly spatial character. Prior to 2016, the prevalence of undernourishment was declining, from 18.6% of the global population in 1990-1992 to 10.9% recorded from 2014-2016 (FAO, IFAD, & WFP, 2015). Recent reports show a potential reversal of trends: In 2018, 821 million people were undernourished (FAO, IFAD, UNICEF, WFP, and WHO 2018); an increase over the 777 million estimated in 2015 (FAO, IFAD, UNICEF, WFP, 2017). The Food and Agriculture Organization of the United Nations (FAO) defines food security as, "[existing] when all people, at all times, have physical, social, and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (FAO, 2003, p.29). Contrastingly, food insecurity, "(e)xists when people do not have adequate physical, social, or economic access to food" (FAO, 2003, p.29).

While access to sufficient food is considered a basic human right (United Nations, 1948), many remain hungry. Spatial trends of food insecurity reveal that populations with the greatest vulnerability to food insecurity live in developing countries (United Nations, 2016). At the regional scale, substantially larger shares of undernourishment are experienced in Southern Asia and sub-Saharan Africa (FAO et al., 2015). According to "The State of Food Security and Nutrition in the World 2018" report, the prevalence of undernourishment in sub-Saharan Africa was 23.2% in 2017; and 14.8% in Southern Asia (FAO, IFAD, UNICEF, WFP, 2018). By December 2018, FAO reported that across Africa 31 countries required external assistance for food: 11 countries were experiencing widespread lack of access to food, 19 faced severe localized food insecurity, and the Central African Republic had exceptional shortfalls in aggregate food production and supplies (FAO, 2018).

A related point to food insecurity pressures is population expansion: more people translates to the need for more food. By mid-2017 the global population totaled nearly 7.6 billion, with a projected increase to 9.7 billion by 2050 according to medium-variant projections (UN, 2017). Challenges to feeding the expanding population are considerable. While satisfying global food needs will require an increase in food production (FAO, 2017; Rockström et al., 2017), the demand for food is spatially uneven. Important shifts in population dynamics have occurred in the proceeding decades, including rural to urban migration and a growing number of live births. By mid-century, it is estimated that two-thirds of the global population will live in urban areas (FAO, 2017). Further, across regions, asymmetrical population growth is expected to continue: Africa and Asia are anticipated to be the largest contributors to population expansion between 2017 and 2050, increasing their populations by 1.7 billion and 750 million respectively (United Nations, 2017). Coupled with an expanding population, demand for food is further exacerbated by significant gains in life expectancy across regions. Estimated projections suggest that the global life expectancy at birth will rise from 71 years in 2010-2015 to 77 years by 2045-2050 (United Nations, 2017).

1.1.2 Agricultural Intensification

To meet the demands of an increasing population projected to live longer, food systems must continue to evolve. The problem of how to feed more people is not novel. Between the 1940's and late 1960's public investment in scientific research designed for agricultural development led to a revolution in practices that resulted in dramatic increases in yield. Ultimately the "Green Revolution" led to significant increases in calories produced per acre. Between 1960 and 2015, agricultural production has more than tripled (FAO, 2017). Yet, despite these tremendous strides, widespread hunger and malnutrition remain pervasive, exacerbating the need for continued innovation. In a speech delivered by FAO Director-General, José Graziano da Silva in 2015, Graziano da Silva remarked, "Business as usual would mean a huge and simultaneous increase in the need for food, energy, and water in the next decades: 60 percent more food, 50 percent more energy, and 40 percent more water by 2050" (FAO, 2015).

Addressing the challenge of feeding more people requires a multi-faceted approach. Only 11% of global land surface area is suitable for agriculture; Of this, poor natural resource management has already compromised 38% (USAID, 2017). With finite land resources, and an inability to expand, emphasis on doing more with less is paramount. Agricultural intensification is, "An increase in agricultural production per unit of inputs (which may be labor, land, time, fertilizer, seed, feed, or cash)" (FAO, 2004, p.3). A related response to agricultural intensification is sustainable intensification, where more food is produced from the same land area, but with the added emphases of reducing environmental impacts and increasing natural capital and flow of environmental services (FAO, 2011; Godfray et al., 2010). By design, intensification should occur over time, achieving increasing yields while subsequently using fewer resources. Approaches to intensification are considerable including, use of high-yield crop varieties, chemical pesticides and fertilizers, irrigation, and mechanization (Ringler et al., 2013).

1.1.3 Irrigation

Agriculture is the single largest driver of environmental change (Rockström et al., 2017) and irrigation has been shown to have substantial environmental impact (Dougherty & Hall, 1995). In irrigated systems, water is artificially applied to soil to assist with crop, tree, or pasture production (FAO, 2014). Surface irrigation involves the application of water by gravity flow to the field surface; sprinkler irrigation systems are typified by spraying water on to crops; and in drip irrigation systems, water is applied directly to the soil through emitters wetting the immediate root zone of each plant (Brouwer, Prins, Kay, & Heibloem, 1988). Globally, 40% of crop production is under irrigation (AQUASTAT, 2014) and in Africa, total land area used for irrigation is expected to increase from 11.9 million hectares (ha) in 1990 to 15.9 million ha in 2020 (Rosengrant & Perez, 2000).

Approximately 70% of the African population are smallholder famers (AGRA, 2017) who depend on rain-fed, staple crop production (Burney & Naylor, 2012). Subject to seasonal weather fluctuations, production constraints, and characteristically low yields, small-scale irrigation has been promoted as means to mitigate the effects of climate variability (Mango, Makate, Tamene, Mponela, & Ndengu, 2018), increase crop productivity (Kamwamba-Mtethiwa, Weatherhead, & Knox, 2015), and serve as a poverty alleviation tool (Burney & Naylor, 2012).

1.1.3.1 Irrigated Agriculture & Parasitic Disease

While increases in food production can be achieved through intensifying agricultural practices, the process of land conversion for intensified agriculture collectively alters natural biotic interactions within ecosystems. Previous literature has shown agrarian transformation of the landscape for irrigation is associated with a number of water related parasitic diseases, including schistosomiasis, filariasis, onchocerciasis, and malaria (Boelee & Madsen, 2006; Ijumba & Lindsay, 2001; J.M.Hunter, L.Rey, K.Y.Chu, E.O.Adekolu-John, 1993; Patz, Graczyk, Geller, & Vittor, 2000).

Water is a requisite for mosquito development. As such, land use and land cover changes that alter the distribution and flow of water across the landscape can have profound impacts on the epidemiology of malaria. Keiser et al. (2005) highlight that as much as 90% of the global malaria problem can be attributed to environmental factors including the establishment of irrigated schemes. Irrigation for crop production can encourage pathogen transmission through a number of pathways. First, through the development of vector habitat and the production of adult stage mosquitoes (Van Der Hoek 2004; Mutero et al. 2004). Intensification of agriculture involves a significant change to the natural landscape occurring across areas, altering vegetation and expanding surface water availability. Likewise, expanding irrigation can promote vector longevity by significantly increasing relative humidity over large areas (Secretariat & WHO, 1996). Collectively, landscape modifications for irrigated agriculture have the potential to both promote diversity of breeding sites and reduce predation of vectors (Sutherst, 2004). Further, environmental and ecological changes for irrigated agriculture can increase the frequency of human-vector contact thereby encouraging transmission (Secretariat & WHO, 1996).

The association between irrigated agriculture and malaria is well documented in the literature. In some studies, malaria prevalence increases (Yaw Asare Afrane et al., 2004; Ghebreyesus et al., 1999; Guthmann, Llanos-Cuentas, Palacios, & Hall, 2002; Jaleta et al., 2013; Keiser, Caldas, et al., 2005; Kibret et al., 2010; Kobayashi et al., 2000). Contrastingly, other studies have shown a decrease or no change in prevalence of infection (Assi et al., 2013; Diakité et al., 2015; Faye et al., 1995; Ijumba, Mosha, & Lindsay, 2002; Klinkenberg, Van Der Hoek, & Amerasinghe, 2004; Mutero et al., 2004). The contradictory nature of such studies suggests the necessity for further investigation on the impact of irrigated agriculture on malaria transmission particularly in light of continued emphasis on expansion throughout malaria endemic areas to meet crop production goals.

1.1.4 Malaria

Discovered by Laveran in Constantine, Algeria, in 1880, the malarial agent is a parasitic protozoan of the genus *Plasmodium* and the class Sporozoa (May, 1961). Only four types of *Plasmodium* infect humans- *Plasmodium malariae, P. ovale, P. vivax,* and *P. falciparum*. *P. falciparum* and *P. vivax* are the two most widespread malaria parasites (NIH, 2016). In sub-Saharan Africa, *P. falciparum* was responsible for an estimated 99% of infections in 2016 (WHO, 2017). Roughly 64% of malaria cases in the WHO Region of the Americas, over 30% in the WHO South East Asia, and 40% in the Eastern Mediterranean Region are attributable to *P. vivax* (WHO, 2017).

The life cycle of the malaria parasite occurs in three stages- sporozoites, merozoites, and gametocytes, and involves two hosts: humans and female *Anopheles* mosquitoes (CDC, 2016). In humans, transmission occurs during a blood meal when sporozoites are injected into the human host from an infected mosquito's salivary glands. Sporozoites rapidly make their way to the liver, asexually replicating in the liver cells (Klein, 2013) and maturing into schizonts (CDC, 2016): the human liver stage. After 6-15 days (Klein, 2013), the liver schizonts rupture, releasing merozoites into the bloodstream to invade red blood cells and beginning the human blood stages (CDC, 2016). Within the red blood cells, merozoites replicate asexually and progress through ring and trophozoite stages (Klein, 2013) to develop either a blood-stage schizont, or gametocyte (Crutcher & Hoffman, 1996). Blood-stage schizonts will eventually rupture, releasing on average 16 daughter merozoites into the blood stream to further infect red blood cells (Klein, 2013). Clinical manifestations of malaria including the characteristic fever cycle, are attributable to these blood stage parasites (CDC, 2016; Klein, 2013).

The sexual stage of the plasmodium, the gametocyte (Crutcher & Hoffman, 1996) in either male (microgametocytes) or female (macrogametocytes) form is ingested by *Anopheles* mosquitoes during blood meal (CDC, 2016). Gametocytes will mate within the gut of the mosquito, producing zygotes that penetrate the midgut wall of the mosquito and form an oocyst (CDC, 2016; Klein, 2013). As the oocyst develops, it produces thousands of sporozoites (Klein, 2013). These sporozoites are eventually released after the oocyst ruptures, making their way to the mosquito's salivary glands in preparation for perpetuating the malaria life cycle (CDC, 2016).

Populations that typically reside in malaria endemic areas often experience malnourishment in part due to lower socio-economic status. The relationship between malaria and malnutrition is complex (Almeida et al., 2015). Fillol et al. (2009) suggested that malnutrition may facilitate the development of protective anti-malarial immune response. Contrastingly, Friedman et al. (2005) demonstrated that stunting was significantly associated with increased odds of concurrent malaria and that wasting increased severe malaria anemia risk. Likewise, Pérez-Escamilla et al. (2009) showed that in Haitian children <5 years old, severe household food insecurity was associated with malaria risk, even after controlling for Body Mass Index (BMI). It is important to note that malnutrition is not simply a lack of sufficient calories, but also a lack or imbalance of essential vitamins and minerals (i.e.

micronutrients). Micronutrient deficiencies, in particular protein-energy malnutrition, vitamin A, zinc, and folate play a critical role in malaria morbidity and mortality (Caulfield, Richard, & Black, 2004; Shankar, 2000). Shankar (2000) provides a critical review of the relationship between malaria and nutritional status including vitamin A, B, and E, zinc, iron, folate, unsaturated fatty acids, amino acids, and selenium. Findings suggest that improvement in dietary intake may significantly reduce malaria morbidity and mortality, highlighting the need for integration of effective nutrient-based interventions to existing malaria intervention programs.

1.1.5 Malaria Transmission

Despite a long history of efforts to curb infection through emphasis on vector, parasite, and habitat modification, malaria remains one of the most significant challenges to global public health (CDC, 2018). In 2016, the World Health Organization (WHO) estimated that 216 million cases of malaria occurred worldwide; 445,000 cases resulted in death (WHO, 2017). These statistics reflect an increase in the overall number of cases in 2015 (211 million), but a slight reduction in the number of fatalities (446,000) (WHO, 2017). The WHO African Region carries the greatest disease burden accounting for 90% of all malaria cases (WHO, 2017). Malaria transmission and intensity are a byproduct of the complex interplay of a wide variety of biotic and abiotic factors. Herein specific consideration is given to factors related to the vector, environment, and humans.

1.1.5.1 Vector

Human malaria is caused by *plasmodium* parasites transmitted by mosquitoes of the genus *Anopheles*. Of the 475 formally recognized and 50 unnamed members of the species complex (Mosquito Taxonomic Inventory, 2018), approximately 70 have the capacity to vector malaria parasites (Service & Townson, 2002; Sinka et al., 2012). Sinka et al. (2012) characterize 41 of these species as dominant vector species/species complexes (DVS) based on their transmission capability and public health concern. In Africa, *An. gambiae, An. arabiensis, and An. funestus* are the primary vectors responsible for malaria transmission (Tonnang, Kangalawe, & Yanda, 2010).

The capacity of a given mosquito species to be an effective malarial vector is tied to a number of defining characteristics including: host selection preference, patterns of feeding and resting, longevity, biting rate, and vector competence. Mosquitoes more likely to transmit malaria are those whose behavior facilitate greater vector-human contact. If reasonably available, many species exhibit a predisposition for specific host types: human (anthropophilic) or animal (zoophilic) (Mcdonald, 1957). Both *An. gambiae* and *An. funestus* demonstrate strong anthropophilic feeding characteristics (CDC, 2015); *An. arabiensis*, while still exhibiting a preference for biting humans, is described as less anthropophilic (Foster & Walker, 2009; Sinka et al., 2010).

Mosquito feeding patterns are characterized by timing (nocturnal, diurnal, or crepuscular) and location of biting, indoors (endophagic) or outdoors (exophagic). While only female mosquitoes feed on vertebrate blood, both male and female mosquitoes regularly feed on plant sugars for nutrition and energy (Foster & Walker, 2009). Mosquito resting behavior has important implications for indoor residual spraying. Endophilic mosquitoes are females that preferentially rest indoors from the time of blood-feeding to the onset of searching for an oviposition site (Pates & Curtis, 2005). Exophilic mosquitoes rest outdoors after blood feeding (CDC, 2017).

Malaria transmission *intensity* is characterized by vectorial capacity , or the "daily reproductive rate" (Garrett-Jones, 1964; D. L. Smith et al., 2012). Smith et al. (2012) present a comprehensive synthesis of the historical development of vectorial capacity and its significance to public health. The metric VC is defined as, "The expected number of infective mosquito bites that would eventually arise from all the mosquitoes that would bite a single fully infectious person on a single day" (Smith et al., 2012, pg. 6) and is computed as:

$$V = \frac{ma^2p^n}{-\ln(p)} \tag{1}$$

where m is the ratio of adult mosquitoes to humans (vector density), a is human biting rates, n is the parasites Extrinsic Incubation Period (EIP), and p is daily probability of mosquito survival. While VC principally influences the transmission of malaria, vector competence too is essential (Cohuet, Harris, Robert, & Fontenille, 2010). Vector competence refers to the ability of an organism to become infected, maintain and replicate the pathogen, then transmit it (Fortuna et al., 2015). Thus, mosquito longevity is a critical function of malaria transmission: mosquitoes must survive long enough to become infected, get through the extrinsic incubation period, then deliver infectious bites (Cohuet et al., 2010; D. L. Smith et al., 2012). A related point to consider is abundance, both human and vector. For transmission to occur, mosquito species populations must be high enough to ensure an encounter with an infectious human carrier of the parasite. Spatio-temporal fluctuations in vector capacity are often a byproduct of differences in mosquito densities across space and time (D. L. Smith et al., 2012). In addition, each mosquito must carry enough malaria parasites within their salivary glands to ensure parasitic transmission.

1.1.5.2 Environment

Environmental factors that influence malaria transmission are Land Use and Land Cover (LULC), weather and climate. The association between LULC and malaria transmission is well established, in part because availability of breeding habitat strongly influences mosquito activity. As such, LULC can encourage or restrict vector populations through availability of breeding sites. Many mosquito species exhibit specific preferences in breeding habitats (Secretariat & WHO, 1996). For instance, *An. gambiae s.s.* prefer small, temporary, sunlit pools generally free from organic matter (Gimnig, Ombok, Kamau, & Hawley, 2001; Sinka et al., 2010) whereas *An. funestus s.s.* prefer breeding sites with emergent vegetation and large, permanent or semi-permanent fresh water bodies (Sinka et al., 2010). A related point is the influence of phenology and availability of sugar sources associated with various land cover types on mosquito population dynamics. (Gu et al., 2011).

The influence of land cover on microclimatic conditions is considerable given that temperature is an important determinant of malaria risk (K. P. Paaijmans, Read, & Thomas, 2009). Mosquito lifecycles are temperature sensitive. Warmer temperatures can promote faster development of some species, leading to smaller adults (Christiansen-Jucht, Parham, Saddler, Koella, & Basáñez, 2014). This is an important consideration as adult mosquito size influences longevity, biting rate, size of bloodmeal, and gonotrophic cycle (i.e., the length of time between a bloodmeal and oviposition of eggs) (Christiansen-Jucht et al., 2014). Further, Briegel (1990) showed that a positive correlation exists between body size and fecundity, which may feedback through density dependent competition and mortality in aquatic stages of development (M. T. White et al., 2011). Beyond body size, higher ambient temperatures are also associated with faster bloodmeal digestion, subsequently shortening the gonotrophic cycle, and increasing biting frequency (Yaw A Afrane, Lawson, Githeko, & Yan, 2005) Temperature is also an important determinant of parasite biology (Blanford et al., 2013). Extrinsic Incubation Period (EIP) refers to the amount of time between a mosquito taking an infectious bloodmeal and becoming infected. Models to predict the EIP of malaria parasites are based on assumptions of malaria parasite development in relationship to accumulated degree days above a lower temperature threshold for development (e.g., Detinova, Bertram, & Organization, 1962; Moshkovsky, 1946). For *P. falciparum*, as temperature decreases the number of days necessary for parasitic development increases (M. T. White et al., 2011) In the classic Detinova model, 16°C is the lowest developmental threshold for *P. falciparum* (Detinova et al., 1962).

Two additional meteorological variables besides temperature play an important role in vector population dynamics: precipitation and humidity. The availability of larval habitats is largely influenced by the frequency, duration, and intensity of rainfall. While precipitation works to create or expand breeding sites, rainfall has also been shown to contribute to high larval mortality rates through flooding and subsequent flushing out larvae (Krijn P Paaijmans, Wandago, Githeko, & Takken, 2007).

Precipitation may also indirectly influence malaria transmission through its effect on relative humidity. Relative humidity levels are associated with mosquito longevity; higher humidity levels enhance survival (Yamana & Eltahir, 2013). Likewise, *Anopheles* become active shortly after dusk, a behavior associated with higher humidity and minimized risk of desiccation (Rund, O'Donnell, Gentile, & Reece, 2016). It is important to note the critical distinction between weather and climate as they relate to malaria transmission. Weather is short-term and can have direct, immediate effects on vector distribution and the timing and intensity of outbreaks (Mayer & Pizer, 2011). Long-term climate conditions influence the spatial and seasonal limits of transmission.

1.1.5.3 Humans

Human immunity and behaviors influence malaria transmission both at the individual and community levels. Humans may possess three types of acquired or adaptive immunity to plasmodia: (1) antidisease immunity, providing protection against clinical disease; (2) antiparasite immunity, protection against parasitemia; and (3) premonition, the state of maintaining a low-grade and generally asymptomatic parasitemia that protects against new infections (Doolan, Dobaño, & Baird, 2009). A related point is human genetic resistance to malaria. For instance, structural variants of hemoglobin and the sickle-cell allele are associated with conferring resistance (Hedrick, 2011). For those living in malaria endemic regions, most do not experience overt disease as a result of Naturally Acquired Immunity (NAI) to falciparum infection. Exceptions include infants and young children, along with pregnant woman whose NAI is compromised during pregnancy (Doolan et al., 2009).

Human behavior contributes to the epidemiology of malaria substantially; social, political, and cultural factors collectively influence transmission, prevention, and control. From a spatial perspective, human movement increases plasmodium dispersal beyond what would be possible for mosquitoes alone (Wesolowski et al., 2012). Likewise, the movement of people from malaria-endemic to malaria-eradicated areas can lead to resurgence of disease (Martens & Hall, 2000). Myriad efforts to prevent and control malaria have emerged over time (Gachelin, Garner, Ferroni, Verhave, & Opinel, 2018; Packard, 2007), notably insecticide treated bed nets, antimalarial drugs, and insecticides. An additional vector management approach is environmental modification, specifically the use of engineering or water-management activities to prevent the spread of malaria (i.e., Utzinger, Tozan, & Singer, 2001). Ironically, environmental modification of landscapes is also associated with the proliferation of vectors and change in malaria disease dynamics through multiple pathways including, land use changes (Paul, Kangalawe, & Mboera, 2018), deforestation (Yasuoka & Levins, 2007; Yomiko Vittor et al., 2006), agricultural development (Packard, 1986), and, as is considered directly in this body of work, irrigated agriculture.

1.2 Research Design

The primary goal of this research is to investigate change in temporal disease dynamics of malaria driven by irrigated agriculture and subsequent land use modifications. Given the complexity of this relationship, this work draws on several theoretical frameworks namely, medical geography, ecological and species distribution modeling, the triangle of human ecology, and political ecology. It is the intention that study outcomes advance the theory of disease systems. The study design for this body of research considers the relationship between land transformation for irrigated agriculture and malaria risk explored at varying scales of analysis: country, site, and area.

1.2.1 Study Country

Malawi is a landlocked country in southern Africa with a strongly agrarian society and a long-standing history of chronic food insecurity. From October 2018 to March 2019, FAO (2018) estimated that 3.3 million people were food insecure. Simultaneously, Malawi faces a significant malaria burden despite more than a decade of increased intervention implementation in rural areas (Roca-Feltrer et al., 2012; Wilson, Walker, Mzilahowa, Mathanga, & Taylor, 2012). A total of 4,901,344 confirmed cases of malaria were reported to the WHO in 2017; 3,613 deaths were reported (WHO, 2018). In

Malawi, *P. falciparum* accounts for 100% of infection with *An. arabiensis, An. funestus,* and *An. gambiae* as the dominant vectors of transmission (WHO, 2016).

1.2.2 Study Site

The Bwanje Valley Irrigation Scheme is located in the central region of Malawi within the Dedza district and Mtakataka Extension Planning Area (Figure 1.1). Situated along the Lake Malawi lakeshore, the scheme spans 800 hectares; the country's largest, single block, small-scale irrigation scheme and benefits more than 2,000 smallholder farmers from 14 surrounding villages (GoM, 2015).

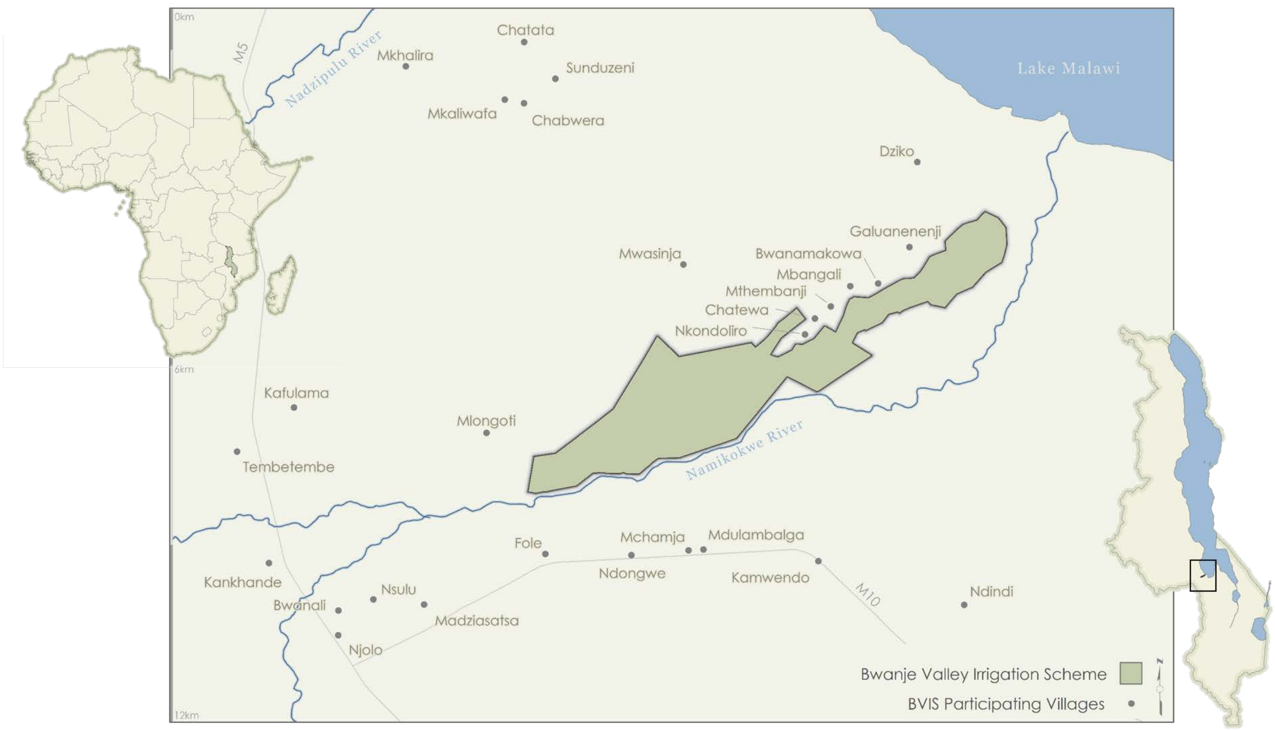

Figure 1.1: The Bwanje Valley Irrigation Scheme (BVIS) located in the central region Malawi and the study area, defined as the 8km surrounding BVIS.

1.2.3 Study Area

The study area is defined as the 8km area surrounding BVIS. An 8km value was selected in order to consider the influence of mosquitoes and their immediate progenies developing through the aquatic stage at BVIS, and those produced outside. The flight distance for the *Anopheles gambiae s.s.* mosquito, one of the primary vectors of the study area, has been documented from less than 1.0km (Costantini et al., 1996) to a maximum flight distance of 1.7km (Thomas, Nall, Cross, & Bøgh, 2013). Given the uncertainty of flight distance, the decision was made to conservatively estimate the 4.0km surrounding area to BVIS as the area where mosquitoes and their immediate progenies produced at BVIS would dwell. By doubling the 4km distance to 8km, the study aimed to adequately estimate the land use and land cover besides that attributed to BVIS that may contribute to mosquito development within the area.

1.2.4 Specific Aims

Aim 1: Address LULC decisions and their impact on the spatio-temporal structure of agricultural growth and mosquito development by:

1. Describing LULC of BVIS and the Bwanje Valley and its impact on breeding pool formation through development of a land classification system for irrigated agriculture in rainy and dry seasons

Aim 2: Demonstrate the influence of irrigation schemes for agriculture on mosquito breeding pool formation and persistence by:

1. Modeling breeding pool scenarios based on spatio-temporal, environmental and anthropogenic characteristics at BVIS under three scenarios
2. Describing the association between LULC and breeding potential at BVIS contrasted with the 8-km area surrounding the scheme

Aim 3: Assess the impact of dynamic changes in irrigated agriculture on malaria vulnerability in Malawi by:

1. Examining spatio-temporal changes in irrigated agriculture at the national scale
2. Describe habitat suitability for *Anopheles gambiae s.s.* mosquitoes in Malawi through construction of a habitat suitability model in Google Earth Engine
3. Addressing the historic and plausible future impact on malaria vulnerability driven by the expansion of irrigated agriculture

1.3 Outline of the Dissertation

Chapter 2 describes the lack of ontological agreement on the meaning of 'scaling up' in development literature. Findings suggest that definitions fall into three distinct categories: Interventions, Mechanisms, and Outcomes. Further, that 'scale' is often applied in two fashions: as a noun (outcome) and verb (process). A conceptual framework for scaling up is presented that gives greater emphasis on separating the noun scale, from the verb, to scale.

Chapter 3 reports the results of a characterization study at BVIS to explore the influence of the scheme's spatial distribution on breeding pool formation. Environmental characteristics and anthropogenic influences pertinent to breeding distribution are used to generate three spatio-temporal breeding scenarios across the scheme. Results illustrate how perturbations to irrigated systems in the form of water availability, water management, and crop cover can influence the distribution of aggregated water bodies and thereby influence disease ecology for the local area.

Chapter 4 considers the association between LULC and mosquito breeding potential within the Bwanje Valley Irrigation Scheme, contrasted with the 8km area surrounding the scheme during Malawi's dry season. Results are discussed in relationship to malaria epidemiology and the impact of LULCC for irrigated agriculture on spatio-temporal disease dynamics of malaria.

Chapter 5 addresses the impact of expansion of irrigated agriculture on malaria vulnerability at the national scale in Malawi through examination of spatio-temporal changes of irrigated agriculture in relationship to historical malaria prevalence.

Chapter 6 summarizes the key findings and future research as a byproduct of this body of work.

CHAPTER 2

2.1 Introduction

Food security is a complex mix of production and supply constraints as well as access to nutritious food. With a distinctly spatial character, food security solutions often take ungeneralizable forms. Scaling up development interventions within the agricultural sector specifically targeting food security challenges is frequently proposed as a solution to the global hunger crisis (e.g. Linn, 2012)). While the phrase 'scaling up' is extensively used across Research and Development (R&D) institutions and in Natural Resource Management (NRM) literature, experience has shown that the term lacks ontological agreement (Hartmann & Linn, 2007; Menter, Kaaria, Johnson, & Ashby, 2004; Uvin, 1995). Further, scaling up is often used broadly to refer to a variety of processes (Menter et al., 2004), or occurs concurrently with discussions on innovation, particularly agricultural innovation, and concepts related to spatial diffusion when there are in fact important distinctions.

Approaches and viewpoints on scaling exist across a range of disciplines (Wu & Li, 2006). Further, interpretations of scaling are often driven by perspective and perceptual bias (Levin, 1992). One view of scaling is results-based, increasing impact to reach a greater number of people (e.g. Linn, 2012). How impact is achieved involves additional perspectives on scaling up including the expansion of programs, technologies, or projects from pilot experiences to larger enterprises. To deliver multiplier impacts, scaling up investment too, is critical. An added dimension relates to policy and governance: what is appropriate at one level may not be suitable at another (Veldkamp, Polman, Reinhard, & Slingerland, 2011; Wu & Li, 2006). Spatially-based perspectives often involve the expansion of a technology or intervention's geographic reach (e.g. Noordin, Niang, Jama, & Nyasimi, 2001), or estimating impact at larger scales from small, field or plot sized experiments (e.g. Zhang et al., 2007). Wigboldus et al. (2016) present a considerable literature review on scaling perspectives exercised

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through a wide range of approaches, notably: agricultural systems, interdisciplinary, transdisciplinary, research, innovation systems, value chain, landscape, socio-ecological systems, transitions to sustainability, and the multi-level perspective on socio-technical transitions. Other relevant perspectives are those held directly by the observers or actors involved in the scaling up process: developers, donors, extension agents, and farmers. In this analysis, we approach scaling up from a development perspective giving particular consideration to scaling up interventions targeting food security challenges. We accept that while scaling up is not always a positive force, or the only pathway for development (Pitt & Jones, 2016), effective scaling up of development interventions is often cited as a measure of success in reducing food insecurity.

Working towards food security solutions involves a wide range of actors embedded within myriad social and environmental systems. Given this inherent complexity, the number of actors, and often necessity for collaboration between development partners to achieve sustainable impacts, a clear, ontological understanding of what scaling up means is essential. Herein, ontological disagreement refers to the varied meanings of scaling up inherent within institutional definitions. Imprecision of definitions across institutions and actors creates ambiguity in defining and measuring outcomes of scaling programs. In turn, uncertainty of scaling up from the onset of development programs contributes not only to inflated reports of success, but failure of programs to actually scale as either a product or process.

The purpose of this article is not to call for improved definitions, but given scales' widespread application, we argue for precision of definitions where scale is considered both as a function of outcome (noun) and process (verb). To explore the varied meanings of scaling up across institutions, a text analysis is presented of adopted definitions across institutions, pointing to a conflation of scaling up operating as an Intervention, Mechanism, or Outcome. The article concludes with the introduction of a conceptual framework that gives greater consideration to separating scales' functions, as an outcome or process, along with the necessary role of monitoring and evaluation on both innovation and development scaling up efforts.

2.2 Scaling

In recent years aid agencies have increasingly begun to recognize the the importance of scaling up to achieve widespread impacts (e.g. Hartmann et al., 2013). For instance, the International Fund for Agricultural Development (IFAD) has declared scaling up as "mission critical" across the agency, embedding it throughout corporate strategy (Hartmann et al., 2013). Given the significance of scaling up across the development sector, clarity on what scaling, rooted in the noun 'scale,' means is critical.

2.3 What is Scale?

The concept of scale is complex, stemming from the noun, 'scale' possessing varying definitions. Even in Geography, a discipline where scale is intrinsic to all inquiry, across the sub disciplines meanings vary (Sheppard & McMaster, 2008). When describing scale, Goodchild (Goodchild, 2001) uses the phrase "heavily overloaded," and later points to not one precise definition, but four distinct meanings of scale: level of spatial detail, representative fraction, spatial extent, and process scale. Likewise, scale is applied in varying contexts including geographic, temporal, and spectral (Goodchild, 2001; Quattrochi & Goodchild, 1997). Further, Smelser and Baltes, (Smelser & Baltes, 2001) contend that in science, scale takes three distinct forms: cartographic, analysis, and phenomenon scale. Cartographic scale refers to features represented on a map and those features' relationship to actual size. Analysis scale is the extent of a given study area, and phenomenon scale describes the size at which human or physical structures or processes exist (Smelser & Baltes, 2001).

For geographers, scale in diffusion research typically is conducted as functional, which reflects decisions made by varying aggregations of individuals, or spatial, directly reflecting the manifestations of these decisions within a spatial context (Brown, 1981). Beer (1968) describes the differentiation between scales, regularly conducted in scientific investigation, as the Cones of Resolution problem. Beerian Cones of Resolution examine spatial processes beginning at the micro scale and gradually work up towards a larger, macro scale perspective. Beer argues that since complex systems comprise a wide variety of subsystems, each operating with their own distinct attributes, a pivotal mark in scientific research is identifying meaningful scales of analysis to properly address the research question at hand. Extending this idea, Manson (Manson, 2008) questions whether a single definition of scale actually exists. Rather, he presents a scale continuum for human-environment systems to assist in framing researching methodologies. Given the existence of such a continuum, rather than searching for one widely accepted theory of scale it becomes prudent to understand of how epistemological contexts work to define scale.

2.4 Scaling Up

There exists a long literature on the uncertainty of scaling terminology. In April 2000, participants of the Consultative Group on International Agricultural Research (CGIAR)-nongovernmental organization (NGO) committee met in the Philippines and defined the objective of scaling up as, "lead[ing] to more quality benefits to more people over a wider geographic area more quickly, more equitably, and more lastingly" (Menter et al., 2004). As illustrated by Menter et al. (Menter et al., 2004), a number of issues surround this definition beginning with it defining the objective rather than the definition of scaling up itself. According to this definition, scaling up reflects two critical, impact-centered factors: extent and quality (Menter et al., 2004). Menter et al. (2004) go on to introduce 'vertical' and 'horizontal'; terms initially proposed by the participants of the Going to Scale Workshop (Gonsalves, 2000). Vertical scaling up is institutional, it involves institutions accepting and internalizing the fundamental principles of an innovation and allowing them to guide practice. Horizontal scaling up refers to geographical spread, whereby more people are impacted through replication and adaptation (Menter et al., 2004).

Uvin (1995) provides a rich literature review that engenders consideration of not only the variety of definitions of the term across the literature, but a suggestion that there are several forms of scaling up: Quantitative, Functional, Political, and Organizational. Yet, Menter et al. (2004) highlight that this reference to scaling up as a catch-all term for a variety of processes has in part led to the confusion of its meaning. Adding to the conversation, Hartmann and Linn (2008) in working to develop a framework for effective scaling up of development interventions, begin their analysis by highlighting the "scaling up debate" and drawing attention to the many definitions of the term across sectors. Building on the previous literature, Hartmann and Linn's (2008) proposed definition of scaling up, adapted from the one used by the World Bank (Mundial, 2004) considers quality of impact, scale, and sustainability across projects, programs, and policies. Further, Wigboldus and Brouwers (2016) posit whether the term scaling itself is in fact the appropriate terminology where alternative verbs or their related nouns, including institutionalism, mainstreaming, expansion, or spreading would provide more clarity.

2.4.1 Pathways to Scaling

Beyond the varying interpretations of scaling up are the number of interpretations of how direct, positive impacts in the agricultural sector can be effectively scaled. The historical approach to scaling methods was top-down: researchers influencing extension agents who then directed farmers on the adoption of new practices. Over time this model evolved to one that emphasizes a more circular flow of information between each of the parties involved in the extension process (Chester, 2005). This new method allowed for a feedback mechanism for each of the stakeholders and actors involved, facilitating greater communication with one another. Since 2003, a number of new efforts have addressed the issue of taking agricultural innovation to scale including the World Bank's Community Driven Development (CDD) Plan (Chester, 2005). The CDD model highlighted both strengths and priorities for taking programs to scale through three distinct stages: initiation, scaling up, and consolidation (Binswanger & Aiyar, 2003). Extending the ideas of CDD, the World Agroforestry Center (ICRAF) and the Food and Agriculture Organization (FAO) later worked to build scaling up initiatives where farmers became central figures in the extension process, and where education institutions and service providers were tasked with the role of meeting farmers' demands for services (Chester, 2005). Understanding the need for implementers to be provided with a mechanism for achieving scale, the Academy for Educational Development developed the System-wide Collaborative Action for Livelihoods and the Environment (SCALE) program. SCALE emphasized the necessity for increasing the number of individual and group stakeholders along with the linkages between them (Chester, 2005).

Today, two of the most common approaches to scaling up within the international development community are the Management Systems International (MSI) Framework and IFAD Framework (Cooley & Linn, 2014). The MSI Framework provides practitioners with specific tools geared at designing effective management frameworks. In contrast, the IFAD framework aims at providing high-level policy and direction on scaling up (Cooley & Linn, 2014). Cooley and Linn (2014) present a review of both frameworks. Most recently, a five-fold strategy for achieving impact at scale was presented by CGIAR as a part of the CGIAR Strategy and Results Framework 2016-2030 (CGIAR, 2015). This strategy includes 1) Deliberate prioritization of research efforts; 2) Close alignment of efforts by centers and center research programs in selected areas; 3) Coordinated planning with implementation partners; 4) Commitments from clients and national partners to make complementary investments and policy reforms where CGIAR is investing; and 5) Institutionalization of a culture of regular monitoring and evaluation.

2.5 A Visual Analysis of Scaling Up

To explore the varying interpretations of scaling up in development literature, definitions (when available) from the 15 CGIAR Centers, United States Agency for International Development (USAID), and IFAD, were illustrated in a TagCrowd™ word cloud in order to visually analyze the text. Definitions included in this analysis from the CG Consortium were from the following institutions: International Center for Agricultural Research in the Dry Areas (ICARDA), International Center for Tropical Agriculture (CIAT), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Food Policy Research Institute (IFPRI), International Livestock Research Institute (ILRI), International Maize and Wheat Improvement Center (CIMMYT), and World Agroforestry Center (ICRAF).

Analysis began by creating a text file containing all available definitions across institutions of 'scaling up.' Where multiple definitions were presented from one institution, all definitions were included in analysis. For study purposes the terms, 'scaling', 'projects,' 'successful' and 'agriculture' were removed from each definition. The file was uploaded to TagCrowd™ where a maximum number of words to display was set to twenty-five; minimum frequency was set to 1. The result is presented in Figure 2.1 where for each word in the word cloud, its size is proportional to the frequency it is found in institutions' definitions.

Figure 2.1: Visual analysis of 'Scaling Up' definitions across CG Consortium, USAID, and IFAD.

The word cloud contained twenty-four terms. One term, 'sustainable', dominates the rest as the most frequently applied term, followed by nine terms of relative importance given their similar size: 'people', 'process', 'technologies', 'impact', 'environment', 'adapting', 'expanding', 'policies' and,

’programs.’ Given the similar frequency of the remaining words, we elected to use only the top ten terms in the remainder of our analysis.

Across the institutions considered in this study, analysis of the ten words most commonly used in the definitions of scaling up reveal a distinct categorization of terms emphasizing individually or a combination of, Interventions, Mechanisms, or Outcomes. We arrived at this categorization by considering the terms through the lens of the formalized components to scaling: innovation, scaling, and monitoring an evaluation; or more directly, what is being scaled, how is scaling occurring, and ultimately to what end? Interventions refers to the ‘whats’ of scaling: what is being scaled up to meet the end goal of developing sustainable food security solutions? Interventions often take the form of new or adapted, existing innovations. Here, definitions across institutions point to technologies, policies, or programs; interventions which are suspected to have long-standing, positive impacts. The International Food Policy Research Institute (IFPRI) definition highlights these specifically: “Scaling up means expanding, replicating, adapting, and sustaining successful policies, programs, or projects to reach a greater number of people” (Linn, 2012). The United States Agency for International Development (USAID) echoes this sentiment in their emphasis on scaling referring to access and effective use of agricultural technologies by poor farmers: “[Scaling up] means that more poor farmers benefit from access to an effective use of agricultural technology” (Linn, 2014). It is worth noting the profound difference between an explicit measure of numbers and broadly defined access. Finally, IFAD, in choosing to define scaling up adopts similar verbiage to IFPRI where scaling again means, “Expanding, replicating, adapting and sustaining successful policies, programs, or projects in geographic space and time to reach a greater number of rural poor” (IFAD, 2011). Mechanisms refers to the “how tos” of scaling up: how is scaling up being conducted? Adapting and expanding both function as mechanisms of scaling up. Likewise, the term ‘process’ alludes to the mechanics of working on and accomplishing a scaling up program. Uvin (1995) introduced the concept of scaling as a process, which, despite Menter et al.'s (Menter et al., 2004) dissention, is a term still frequently applied in the literature. The International Livestock Research Institute (ILRI) gives particular attention to process: "Scaling is the act of increasing the size, amount, or importance of something, usually an organization or process" (Hendrickx, Ballantyne, Duncan, Teufel, & Ravichandran, 2015). Expanding on the idea of scaling up as a process, most recently Wigboldus and Brouwers (2016) moved beyond the processes described by Uvin to further include scaling up as quantitative, spatial, kinematic, or physical. The advantage of calling scaling up a process is that it is binary - a yes or no proposition. From a development perspective you can declare success by meeting an indicator of process rather than outcome. It sets a low bar. An added dimension is management. Writing for the International Center for Tropical Agriculture (CIAT) Menter et al. (2004, p.9) state, "Scaling up is a management issue. It us about how to manage projects to ensure that positive impact is maximized."

Beyond the Interventions and Mechanisms are the Outcomes of scaling up: what is the end result? Here we come to the most often applied term in the description of scaling up, sustainable. Closely related is impact. Both terms not only apply to end results but to intentions. The World Agroforestry Center (ICRAF) places particular emphasis on outcomes: "[Scaling up means] to bring more benefits to more people, more quickly and more lastingly" (Simons et al., 2011). For many, at the center of scaling up development interventions is the idea of reducing food security challenges for smallholder farmers; impactful programs are successful at working towards or meeting this end goal. Likewise, sustainable programs are those that work at maintaining success in reducing the burden of hunger over time. A related point to consider is resiliency; the ability to recover after disaster or unforeseen circumstances. The mission of the CG Consortium emphasizes improvement in resiliency directly, however when considering the visual analysis of scaling definitions presented, it is worth noting that the term 'resilient' is absent altogether. Yet, both an emphasis on sustainability and resiliency are necessary to meeting long term food security challenges. These two terms are not interchangeable, nor should the idea of resiliency be absorbed by sustainability entirely; the approaches to sustainable versus resilient programs and their scaling can have distinct differences.

Many of the definitions included in this analysis emphasize not one, but a combination of Interventions, Mechanisms, or Outcomes in their definition of scaling up, leading to ambiguity in their meaning. Returning to USAID's definition, emphasis is placed both on Mechanisms through agricultural technologies and Outcomes: that more poor farmers have access to and effectively utilize aforementioned technologies. The International Maize and Wheat Improvement Center (CIMMYT) combines all three where through scaling up strategies, "development practitioners expect to implement successful interventions and expand, adapt, and sustain them in different ways over time for greater developmental impact" (Roett & O'Leary, 2017). The International Food Policy Research Institute (IFPRI)'s definition provides an excellent example too. Scaling up is, "…Expanding, replicating, adapting, and sustaining successful policies, programs, or projects to reach a greater number of people (Linn, 2012, p.46)." Given this definition- is scaling up about policies, programs, or projects, their expansion, replication, or adaptation, or their sustainability in reaching a wider audience?

2.6 Discussion

The phrases, 'scaling up' and 'going to scale' are used extensively throughout the R&D and NRM literature. Yet, as several studies have highlighted, they lack ontological agreement. Uvin (1995, p. 928) argues that the, "variety of definitions is important. It allows us to look at the phenomenon in a number of different ways, giving us some insight into the complexity of the associative sector itself." We disagree as ultimately, the answer to the question, "what is scaling?" impacts both how scaling up is operationalized (ie: the intervention and/or the pathways to scaling), influences M&E, and affects program success. Likewise, how scaling up is defined will influence how funding is allocated, and in turn how project development progresses - which projects are made a priority and which are neglected. Given the varying definitions and interpretations of scaling up, Wigboldus and Leeuwis (2013, p.6) caution that, "we always need to verify how different people interpret the overall concept of scaling (up) and related concepts" in order to promote shared learning and efforts across actors. The generic nature of scaling up the authors contend does little to aid in knowing what scaling measures may best apply in a particular situation.

As we have highlighted in this paper, how scaling up is defined is rooted in the interpretation of scale itself. When considering the categorization of terms presented in our earlier analysis (Interventions, Mechanisms, Outcomes), it becomes apparent that scale is applied in two forms: as a verb and a noun. Where scale functions as a verb is demonstrated directly in the mechanics of scaling up with emphasis on adaptation and expansion of innovations. Innovations are a critical component to achieving widespread impacts in reducing food insecurity, either through new innovation or scaling up existing, successful innovations. As a noun, an innovation taken to scale implies meeting a specified end goal; project outcomes. Likewise, in the evaluation of project results in relation to its predefined, intended outcomes that were determined at the onset. Existing definitions of scaling up often conflate ideas related to interventions (innovations), the process of their expansion or replication, or their intended outcome; we contend this occurs in part due to the application of scale both as a noun and verb. To illustrate the application of scale as either (or both) a *noun* and <u>verb</u>, we return to IFPRI, USAID, ILRI, and ICRAF's definitions of scaling up:

"<u>Expanding, replicating, adapting, and sustaining</u> successful *policies, programs, or projects to reach a greater number of people*."-IFPRI (Linn, 2012, p.46)

"*More poor farmers benefit from access to an effective use of agricultural technology*" –USAID (Linn, 2014)

"Scaling is the act of <u>increasing the size, amount, or importance</u> *of something, usually an organization or process*." –ILRI (Hendrickx et al., 2015)

"*Bring more benefits to more people, more quickly and more lastingly*." –ICRAF (Simons et al., 2011)

To separate scaling up and its associated actions based on the process (verb) and outcomes (noun), we present a conceptual framework for defining scaling up and putting it into practice for development activities (Figure 2.2). Further, we emphasize the necessary role of Monitoring and Evaluation (M&E) on both the innovation and scaling up efforts.

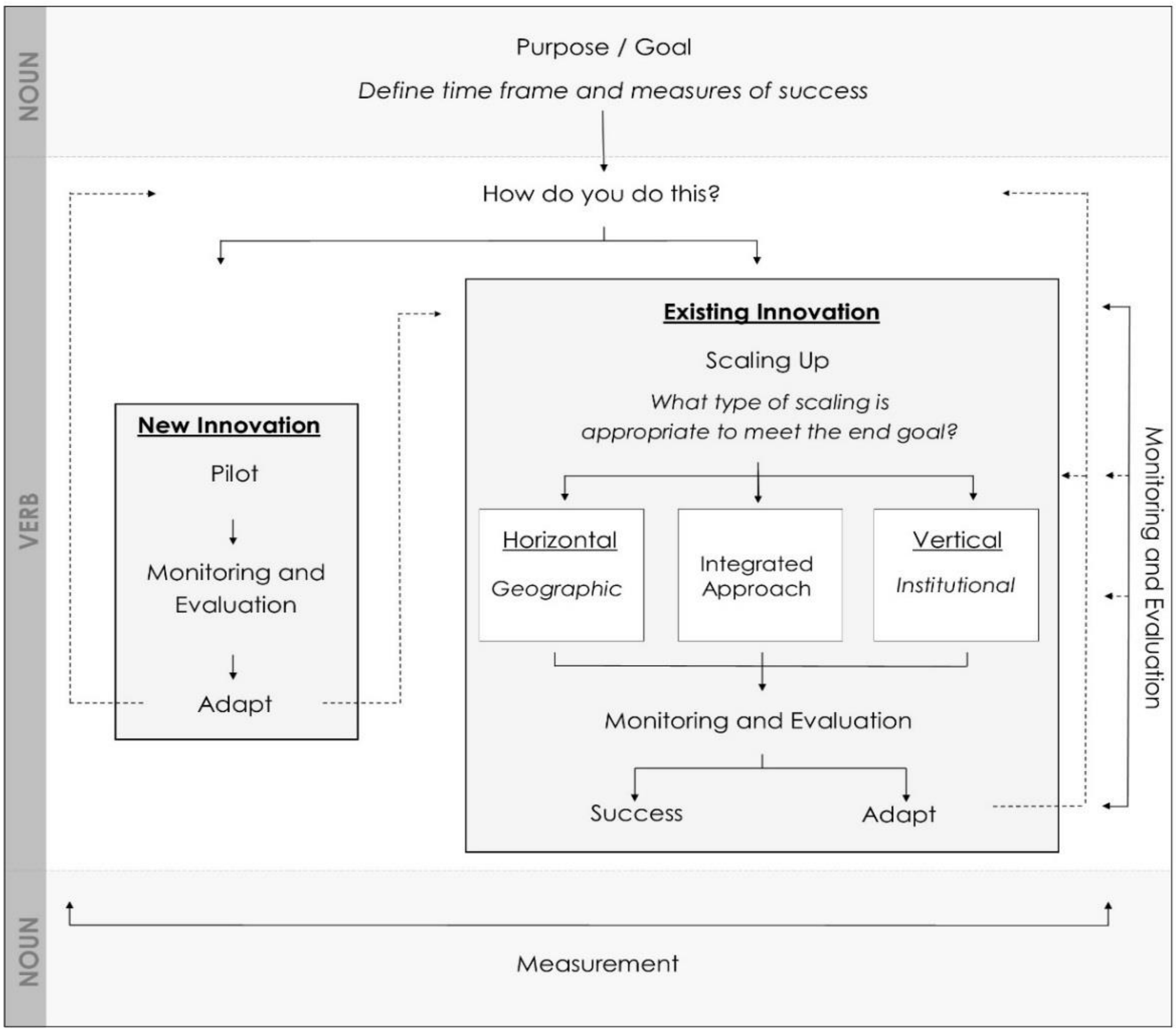


Figure 2.2: A framework for conceptually defining scaling and putting it into practice for development activities

During the initial stage, scale functions as a noun: a specific purpose or program goal is agreed upon, followed by defining its measures of success and the overall timeframe for the project or program completion. Measures of success are quantifiable outcomes of the innovation or scaling that serve to evaluate program performance. How to achieve these outcomes varies by either developing a new innovation or scaling an existing innovation. Here too, the question of whether scaling an existing innovation is even appropriate to the context should be addressed (Hartmann & Linn, 2007). It is at this stage that scale begins to function as a verb. After development, new innovations follow a pathway through piloting, monitoring and evaluation, then, adaptation. It should be noted that it is often this necessity for adaptation, coupled with imprecise definitions of scaling up that work to declare every program a success.

Scaling up existing innovations starts with careful consideration of which type of scaling is appropriate to meet the end goal. Vertical scaling up is institutional; innovations are meant to guide principles of practice. Horizontal scaling up is geographic, where the spatial reach of an innovation expands. Scaling up efforts do not occur in isolation; Vertical scaling up efforts spillover to geographic diffusion across space, likewise geographic expansion can influence uptake of institutional practice. Often scaling up requires an integrated approach (Hartmann & Linn, 2007). Giving consideration to an integral pathway aims at scaling up along both an institutional and geographic pathway from the onset. An integrated approach can be either sequential or simultaneous depending on the context.

Regular M&E of scaling up pathways provides important feedback and creates opportunities for adaptation from onset to completion. Rather than evaluating what went right or wrong at the conclusion of a project, effective M&E strategies attempt to gauge performance through a series of indicators throughout a project's lifespan (Crawford & Bryce, 2003). Monitoring and Evaluation is a requirement for effective scaling up (Mansuri & Rao, 2004). Yet historically, scaling up efforts and evaluation were often viewed as conflicting objectives for most international development agencies (Duflo, 2004), despite the value of reliable program evaluations at every stage of scaling up efforts. In this model, the M&E process occurs both for new and existing innovations; likewise, on the scaling up efforts to bring an innovation to scale. M&E specific to scaling up efforts is conducted during several stages: 1) The choice of existing innovation to be brought to scale; 2) The type of scaling up pathway selected- vertical, horizontal, or integrated; 3) On horizontal, vertical, or integral scaling up efforts; and 4) On the declaration of success or choice to adapt.

The final stage returns to scale, the noun. It is at this point that measurement between the stated indicators for success and actual outcomes are evaluated. Here, overall program performance is analyzed, and through careful consideration of program shortcomings, new initiatives developed to meet remaining unmet needs of communities.

2.7 Conclusions

It is trite to call for improved definitions, particularly given the outcomes of this paper; here, we argue for the careful consideration of the precision of definitions used. The imprecision of definitions, in part the product of uncertainty, contributes not only to the reported regular success of development programs, but also the failure of these programs to scale as both product and process. Literature is replete with examples of attempts to address the scaling up debate, many of which are highlighted herein. Often these discussions include an attempt to redefine or reinvent the terminology to better describe the meaning of scaling up to fit a particular development program rather than stressing the precision of terms already in use. Yet, regular redefinition only leads to the perpetuation of uncertainty particularly where adoption of these improved definitions are asynchronous across institutions. Given the importance of scaling up to development, ontological agreement of scaling up across institutions is vital not only to measurement but to meeting the needs addressed through sustainable development interventions. Ontological ambiguity devalues scaling up; by defining a clear pathway for success, value judgements regarding development as outcome can be examined.

Our analysis on the interpretations of scaling up showed that across the different agencies considered, definitions were dissimilar despite some commonalities in etiology and occasionally authorship. The issue here is not alternative phrasing, but rather the lack of ontological agreement among definitions. The categorization of terms highlighted when analyzing the descriptions of scaling up are a byproduct of the varied meanings behind the definitions themselves. In some cases, emphasis is placed primarily on the innovation being scaled (Interventions). Other interpretations give priority to the structure of the scaling up process itself including institutional or geographical expansion (Mechanisms). Still others underscore the end results (Outcomes) and notably the sustainability, with strikingly no mention of resiliency, of the product or process brought to scale. Finally, many definitions in our analysis revealed an emphasis on not one, but a combination of Interventions, Mechanisms, or Outcomes, leading to further ambiguity.

In light of the literature and above categorization of terms, we contend that the continued uncertainty of scaling up is in part often related to the conflation of the noun, scale, and verb, to scale. Interpretation of scaling up that stresses product or process success, or outcomes is a function of the noun, scale. By contrast, where scaling up emphases reside in adaptation, expansion, geographical spread, or process, these descriptions are rooted in the meaning of the verb, to scale. Working to emphasize and separate the critical functions of scaling, we have presented a conceptual framework that operates in three stages: 1) Defining objectives and creating indicators; 2) Scaling efforts either by a new or existing innovation; and 3) Final measurement of outcomes. The novelty of this model lies in both its separation of scaling up and its associated actions based on the process (verb) and outcomes (noun). Where scaling up has traditionally occurred irrespective of M&E, our model works to showcase the critical role of M&E for both the innovation and development scaling up efforts. Scaling up and M&E are inextricably linked. Given this relationship and the evolution of M&E, future work could consider critically analyzing the variation in meaning of scale, by institution over time. Further, presenting commonalities and discrepancies in meaning between institutions and consideration on how these conceptions of scale influence development interventions.

Scaling up product or processes in targeting food security challenges is a vital component to developing sustainable solutions to the global hunger crisis across geographical scales. As such, a consensus on the ontological meaning of scaling up across institutions working towards these solutions is critical. Our aim in developing this model is to engender further consideration on the precision of scaling up terminology when working to bring a product or process to scale. Uncertainty on the meaning of scaling up should not be a barrier to meeting the critical needs being addressed through development interventions. Where there is ontological agreement on scaling up within and across R&D and NRM institutions, there is a higher likelihood for project success.

CHAPTER 3

3.1 Introduction

The association between irrigation, mosquito production, and malaria transmission is well documented in the literature (see e.g. Ijumba & Lindsay, 2001; Kibret et al., 2010) However, irrigated schemes are treated as homogenous spatio-temporal units with little consideration for how breeding potential varies across the space and time. Irrigated schemes may change seasonally in crop production and distribution and not every irrigated scheme receives sufficient water resources to operate on an annual, but rather only seasonal basis. In addition, some land covers found in irrigated schemes are not agricultural, but engineered structures including concrete canal networks. The heterogeneity of irrigated schemes spatio-temporal distribution results in asymmetrical breeding risk. The structure of heterogeneity is the product of environmental and anthropogenic factors, including, but not limited to, soil type, timing and intensity of irrigation, drainage, and crops type(s) being cultivated. Each of these factors, independently and in combination, influence the amount and duration of pooled surface water available to mosquitoes for breeding.

This chapter reports the results of a characterization study at the Bwanje Valley Irrigation Scheme (BVIS) to explore the influence of the scheme's spatial distribution on breeding pool formation. Environmental characteristics and anthropogenic influences pertinent to breeding distribution are used to generate three spatio-temporal breeding scenarios across the scheme. Results illustrate how perturbations to irrigated systems in the form of water availability, water management, and crop cover can influence the distribution of aggregated water bodies and thereby influence disease ecology for the local area.

3.2 Methods

3.2.1 Study Site

The Bwanje Valley Irrigation Scheme is an example of a typical smallholder irrigation scheme in Malawi. Established in 2000 through cooperation of the Japanese and Malawi governments, the BVIS is a gravity-fed scheme located in the Shire watershed of central Malawi where annual rainfall is approximately 867mm and temperatures range from 17.2°C to 27.3°C (Adhikari & Nejadhashemi, 2016). Spanning 800 hectares, the scheme diverts water from the Namikokwe River to ~30X30 meter agricultural plots via a series of concrete, main and branching canals, and earthen, tertiary canals. Grant aid of $15 million USD was provided by Japan, mediated through the Japanese International Cooperation Agency (JICA) (Veldwisch, Bolding, & Wester, 2009). During the 2016 growing season, 2067 farmers participated at BVIS from 14 surrounding villages; 1089 farmers were women (M. Tarsizio, personal communication, March 17, 2016). Veldwisch et al. (2009) provide a comprehensive commentary on BVIS including the schemes' historical development and subsequent 'travails.'

3.2.2 Study Design

Land use and land cover decisions and their impact on the spatio-temporal structure of agricultural growth and mosquito development were assessed using four sources of information: (1) Satellite imagery from the SPOT-6 sensor at two time periods; (2) Spatial structure and land cover information derived through field sampling during rainy and dry seasons at BVIS; (3) soils data taken from JICA's "Feasibility study on Bwanje Valley smallholder irrigation development project" (JICA, 1994) and (4) Onsite interviews with BVIS scheme personnel conducted in 2016, 2017, and 2019. The 2016 interview was conducted with the scheme manager, who was often present during field surveys to provide insight and commentary. In 2017, an interview with the BVIS board chairman was performed in the absence of a permanent scheme manager. The 2019 interview was conducted with the former BVIS manager interviewed in 2016. For survey questions see (Frake, 2019a, 2019b, 2019c). The conceptual framework for this study is presented in Figure 3.1.

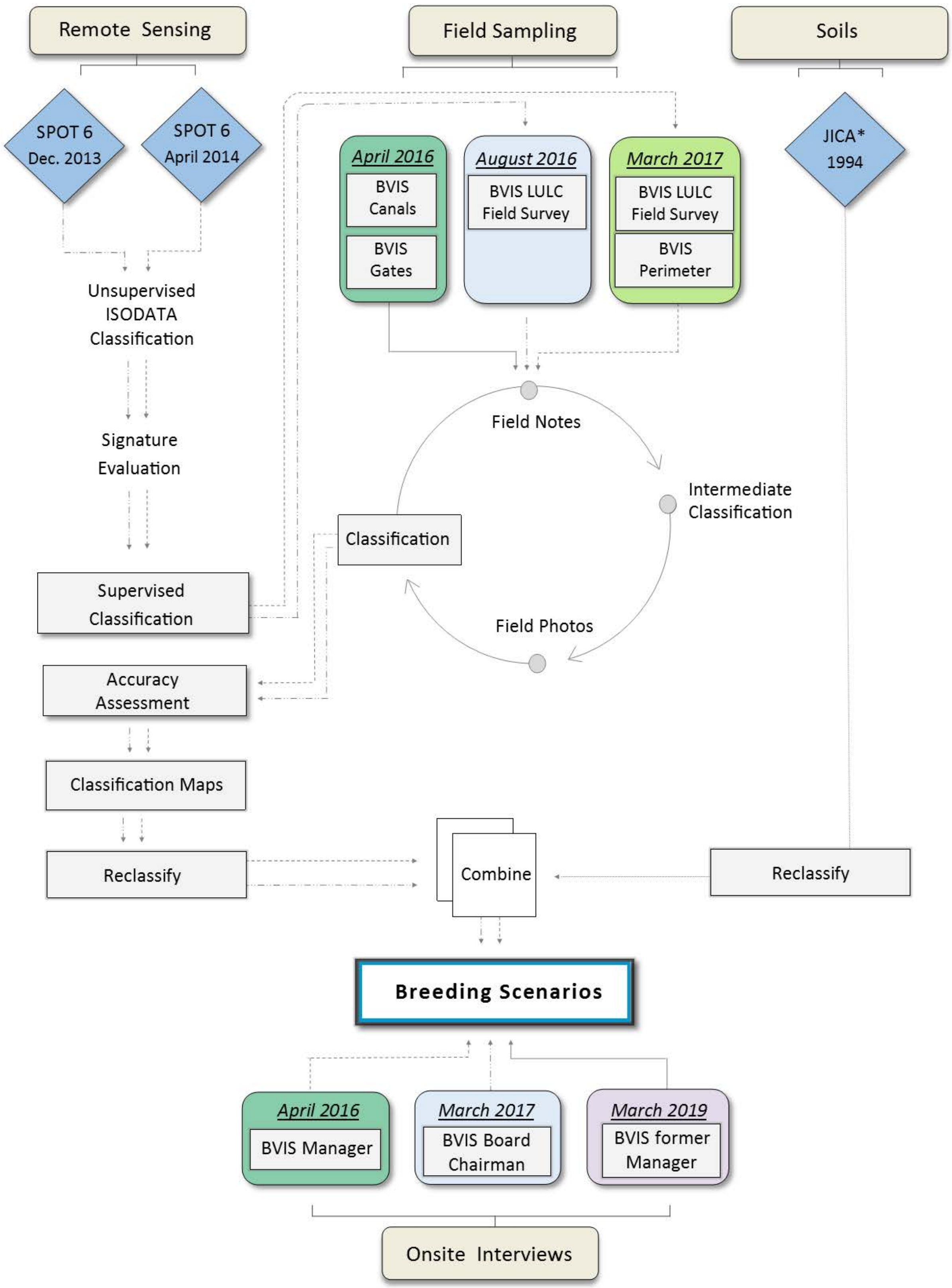
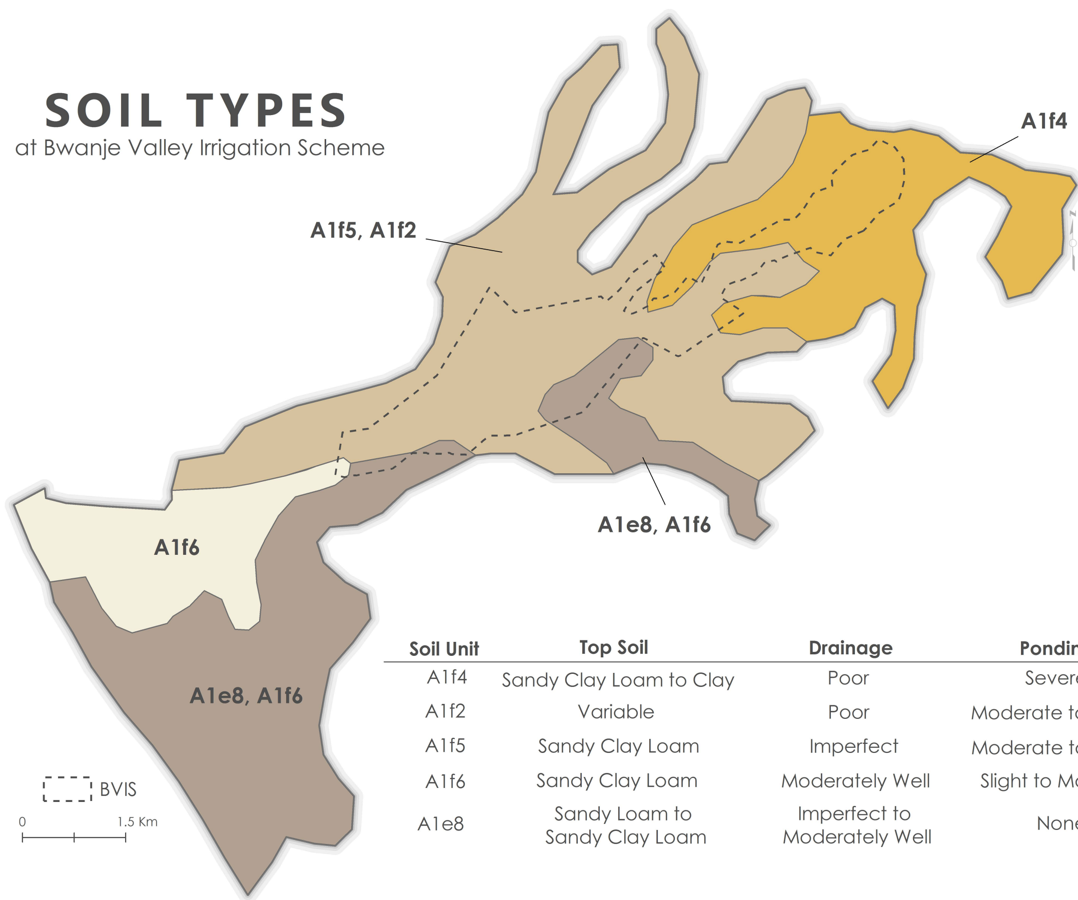


Figure 3.1: Conceptual framework for the study. Soils data are taken from JICA (1994)

3.2.3 Environmental Characteristics

3.2.3.1 Soils

There are five primary soils at BVIS whose parent materials are fluvial, colluvial, and/or lacustrine sediments. Top soil (0-30cm) types are sandy loam, sand clay loam, and sandy clay loam to clay. A notable consideration for our study is the drainage capacity for each soil. The dominant soil units at BVIS are A1f5, A1f2, and A1f4. Data from JICA (1994) does not include specific bulk density measurements (i.e. indicators of soil compaction) for each soil type. However, drainage and ponding potential are available and were utilized for this study. Soil units at BVIS are typified by poor to imperfect drainage, and moderate to severe ponding potential (Figure 3.2).



Soil Unit	Top Soil	Drainage	Ponding
A1f4	Sandy Clay Loam to Clay	Poor	Severe
A1f2	Variable	Poor	Moderate to Severe
A1f5	Sandy Clay Loam	Imperfect	Moderate to Severe
A1f6	Sandy Clay Loam	Moderately Well	Slight to Moderate
A1e8	Sandy Loam to Sandy Clay Loam	Imperfect to Moderately Well	None

Figure 3.2: Soil types at BVIS. Data and soil characteristics are taken from JICA (1994)

3.2.3.2 Land Cover

3.2.3.2.1 Data preparation

Multispectral SPOT-6 images of the study area were acquired on December 4, 2013 and April 1, 2014 at a spatial resolution of 6.0m for four spectral bands: Blue (0.455 µm — 0.525 µm), Green (0.530 µm — 0.590 µm), Red (0.625 µm — 0.695 µm), and Near-Infrared (0.760 µm — 0.890 µm). Geometric correction to ensure positional accuracy of the imagery was performed using ground control points prior to analysis and a 30m DEM from the Shuttle Radar Topography Mission (SRTM). Sensor calibration and conversion of digital numbers (DNs) to radiance was performed following a solar correction to top of atmosphere (TOA) reflectance using ERDAS IMAGINE™ 2014.

Image classification was performed using an unsupervised ISODATA classification where 255 classes were selected at .98 convergence (see e.g, Messina et al. 1998). Signature evaluation was conducted using the Transformed Divergence measure with separability markers of >1975 deemed acceptable. Using the edited signature set, a Maximum Likelihood supervised classification was performed. Data preparation and image classifications were processed in ERDAS IMAGINE™ 2014.

Field sample sites were selected by stratified random sampling of land cover classes from the supervised classification for each image: 11 classes in the dry season and 9 in the rainy season at BVIS. A total of 242 points were selected for sampling during the dry season and 72 during the wet season. Fewer sample sites were selected during the rainy season given that there were fewer classes to sample and previous fieldwork had shown that rice was the predominant crop grown across the scheme.

3.2.3.2.2 Land Cover Data Collection

Field based surveys of LULC were carried out during the 2016 dry season and 2017 rainy season. A total of 235 dry season samples were collected over a fourteen-day period in mid-August 2016 by a field team of three researchers. These samples included 185 of the sites selected from the random stratified sample, and 50 additional 'accuracy assessment' points collected at random to further assist with classification. Rainy season samples included 68 sample sites and 36 accuracy assessment sites sampled over a nine-day period in early April 2017 by a field team of two researchers. At each site, the location and elevation, along with geotagged photographs were captured using a handheld Garmin™ Monterra GPS unit. In addition, field notes describing the LULC at each sample site along with descriptions of LULC in all directions were recorded. Where land cover of surrounding areas differed from that recorded at the sample site, the direction of these areas along with approximate distances were included within field notes. Field note transcriptions and associated GPS data collected at each sample site were combined for classification analysis.

3.2.3.2.3 Land Cover Classification

Classification of LULC followed a two-step process: (1) Sites were categorized by land use, land cover type, and feature (e.g. maize, rice, bare earth); (2) Field notes were used to include information on stage of agricultural growth, appearance of soils, density of plantings, presence of water within irrigation canals, and locations of trees relative to agricultural growth for each feature identified in step 1. Descriptions of LULC including the number of samples within each class are presented in Tables 3.1 and 3.2. Point shapefiles of all sample sites, by season, and their respective LULC descriptions were generated in ArcMap™ 10.5.1, then overlaid with supervised classification imagery.

3.2.3.2.3.1 BVIS: Rainy Season

Maximum Likelihood classification for the rainy season yielded 9 classes of land cover, of which 7 were classified as 'Rice', 1 as 'Maize' and 1 as 'Non-Agricultural' (Figure 3.3). The number of supervised classes assigned as 'Rice' is attributable to the variations in growth stages observed during sampling. While rice plants in some plots were in panicle formation stage, other plants had begun flowering, or were mature. Rice on other plots had been harvested, releasing the plots to renewed planting. The Non-Agricultural class included irrigation canals, concrete and earthen, along with roads and pathways.

One particular challenge of the rainy season classification was presence of maize grown in single or double rows, in the narrow spaces immediately adjacent to irrigation canals. These areas are situated at a slightly higher elevation (~2ft) than the plots, owing to the gravity-fed design of the scheme. The proximity of maize in relationship to the structures within the 'Non-Agricultural' class is the cause for the mixing of pixels observed in areas immediately adjacent to roadways and irrigation canals.

The combination of water availability from seasonal rains and the Namikokwe River during the rainy season allows for the predominant cultivation of rice at BVIS occurring across 87.9% of the scheme. The primary rice varieties are kilombero, a long-grain aromatic rice, and faya (M. Mafosha, personal communication, March 27, 2019). BVIS personnel direct farmers to begin planting in mid-December, with harvesting around mid-February (M. Mafosha, personal communication, August 19, 2016). However, the varied stages of rice growth observed during land cover analysis from this study suggests that farmers are able to practice governance over their plots' cropping timeline. Besides growing in areas immediately adjacent to irrigation canals, two concentrated areas of maize are cultivated during the rainy season along the southern boundary of the scheme. Rehabilitation plans for BVIS were prepared in 2005 by JICA and included fine leveling for plots (JICA, 2005; Veldwisch et al., 2009). However, according to our interviews with BVIS management, the plots in these areas were not leveled as well as in other areas. As a result, these areas are situated at a slightly higher elevation than those immediately surrounding them preventing efficient water flow and cultivation of rice (M. Mafosha, personal communication, March 27, 2019).

Table 3.1: Rainy season land cover class descriptions for BVIS

Class Descriptions	BVIS Sample	BVIS AA	TOTAL
I. AGRICULTURAL LAND			
I. ACTIVE			
Rice			
Flooded Field	2	0	**2**
Flooded Field w/ Dried Grasses	2	0	**2**
Early Growth w/ Visible Water & Grasses	2	1	**3**
Early Growth w/ Visible Light Standing Water	1	0	**1**
Early Growth w/ Visible Dark Standing Water	0	2	**2**
Mid-Growth w/ Visible Light Standing Water	1	0	**1**
Mid-Growth w/ Visible Dark Standing Water	0	2	**2**
Panicle	14	8	**22**
Panicle w/ Dried Grasses	3	1	**4**
Panicle & Grasses: Tall	8	1	**9**
Varied Growth Stages	2	1	**3**
Maize			
Mature	7	0	**7**
Past Maturity	5	2	**7**
Sweet Potato			
Mature	1	1	**2**
Young	2	0	**2**
Sweet Potato & Grasses	0	1	**1**
Sweet Potato & Emergent Shrubbery	1	0	**1**
Pumpkin			
Intermediate Growth Stage & Grasses	1	0	**1**
Mixed Cropping			
Sweet Potato: Young & Panicle Rice	1	1	**1**
Sweet Potato: Mature, Maize: Mature, & Rice: Panicle	0	1	**1**
Rice: Panicle & Maize: Mature	3	2	**5**
II. FALLOW			
Grasses			
Tall	3	1	**4**
Tall and Standing Water	1	1	**2**
Human Influence			
Road	1	0	**1**
Straw Structure on Bare Soil	1	1	**2**
III. IRRIGATION INFRASTRUCTURE			
Concrete Canal w/ Flowing Water, Bare Earth & Dried Grasses	1	0	**1**
Concrete Canal w/ Flowing Water & Emergent Grasses	2	1	**2**
Concrete Canal w/ Flowing Water, Emergent Grasses & Maize	0	1	**1**
Concrete Canal w/ Flowing Water, Emergent Grasses & Dried Grasses	0	3	**3**
Concrete Bridge Over Dirt Canal w/ Emergent Grasses	0	1	**1**
Dirt Canal w/ Standing Water & Dried Grasses	0	1	**1**
Dirt Canal w/ Standing Water & Panicle Rice	0	1	**1**
IV. TREES			
Banana Trees	1	1	**2**
Green foliage on flooded rice plot	1	0	**1**
Trees: Roadway Adjacent	1	0	**1**

Table 3.2: Dry season land cover class descriptions for BVIS

	BVIS		TOTAL
Class Descriptions	***Sample***	***AA***	
I. AGRICULTURAL LAND			
I. ACTIVE			
Maize			
Mature	9	7	**16**
Young	4	0	**4**
Young & Dense Shrubbery	3	0	**3**
Beans			
Mature	2	2	**4**
Mature & Emergent Weeds	2	0	**2**
Young	5	0	**5**
Cowpea			
Mature	2	1	**3**
Cowpea & Shrubbery	2	1	**3**
Young	3	0	**3**
General Agriculture			
Intercrop: Young Maize & Beans	1	1	**2**
Mature Maize & Beans	1	0	**1**
Mustard Greens	0	1	**1**
II. FALLOW			
Bare Earth			
Dark Soil	10	0	**10**
Dark Soil w/ Straw	12	2	**14**
Dark Soil w/ Straw & Ridging	0	2	**2**
Light Soil	2	1	**3**
Light Soil w/ Straw & Ridging	3	0	**3**
Medium Soil w/ Straw & Ridging	3	0	**3**
Charred Ground			
Charred Ground w/ Beans	1	0	**1**
Charred Ground w/ Cowpea	2	0	**2**
Charred Ground w/ Emergent Weeds	3	2	**5**
Charred Ground w/ Shrubbery	1	0	**1**
Charred Ground on Bare Earth	1	4	**5**
Dried Fields			
Dried Grass	4	1	**5**
Dried Grass & Emergent c3 Vegetation	6	0	**6**
Vertical Rice Straw w/ Little Vegetation	4	0	**4**
Vertical Rice Straw w/ Emergent Weeds	7	10	**17**
Vertical Rice Straw w/ Green Tops	1	1	**2**
Horizontal Rice Straw w/ Emergent Weeds	30	0	**30**
Straw & Dried Grass	6	2	**8**
Shrubbery			
Dense	28	5	**33**
Sparse	14	2	**16**
Dense & Emergent Red Weeds	2	2	**4**
Blackjack w/ Emergent Weeds	1	1	**2**
Dense Shrubbery w/ Medium Soil & Straw	1	0	**1**
III. AGRICULTURAL INFRASTRUCTURE			
Irrigation Canal			
Concrete	1	2	**3**
Dirt	0	2	**2**
Tertiary canal w/ Shrubbery	1	0	**1**

Table 3.2 (cont'd)

Human Influence			
Road	0	3	**3**
IV. TREES			
Banana Trees & Dried Grass	2	0	**2**
Banana Trees & Dense Shrubbery	0	1	**1**
Green Foliage on Active Agricultural Land	1	0	**1**
Green Foliage on Fallow Field	3	1	**4**
Green Foliage on Fallow Land w/ Green Vegetation	0	1	**1**

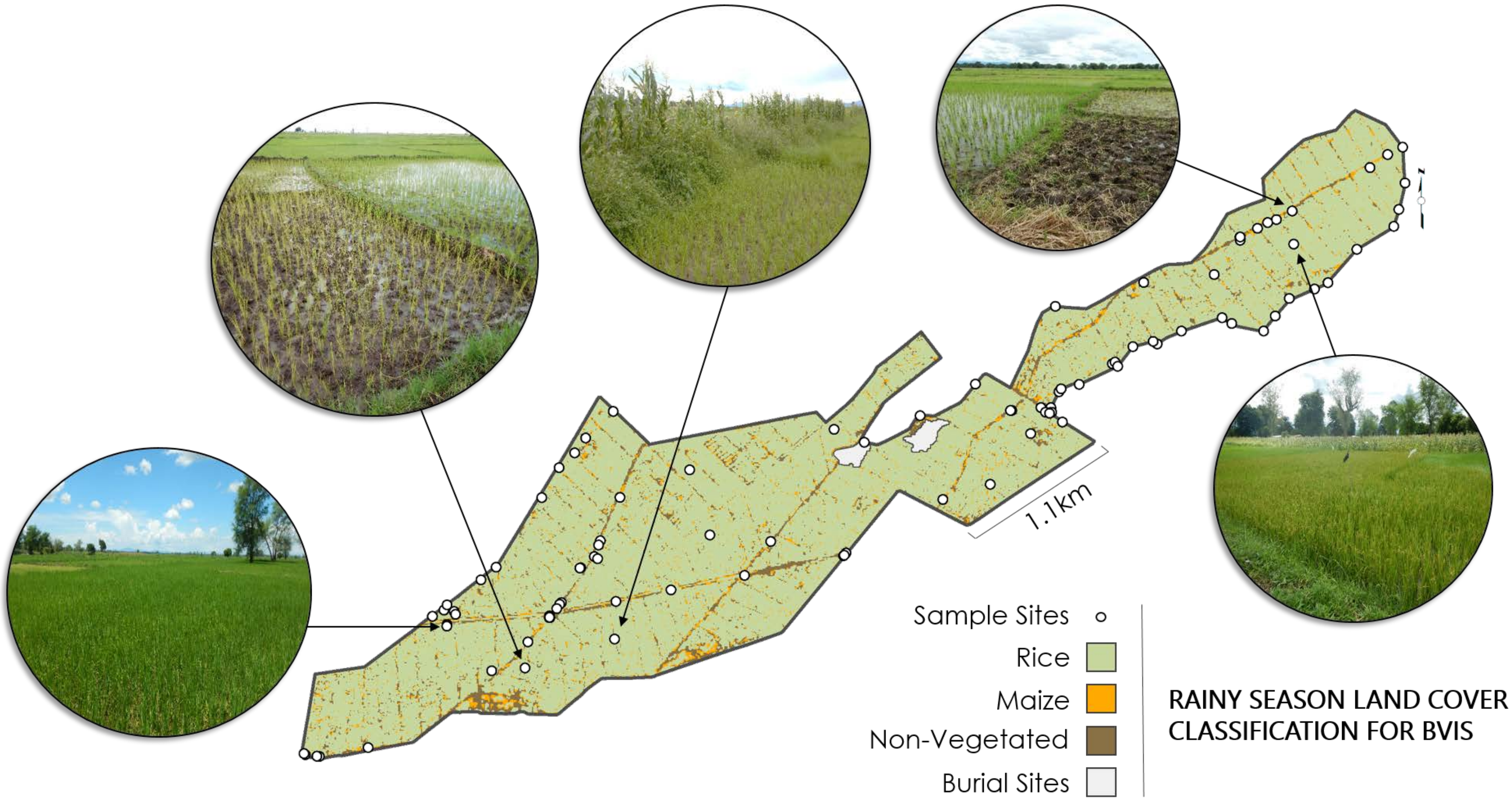


Figure 3.3: Rainy season land cover classification for BVIS including field photos depicting varied stages of rice growth within the scheme.

3.2.3.2.3.2 BVIS: Dry Season

To assist in differentiating between active and fallow vegetation in the dry season at BVIS, the Normalized Difference Vegetation Index (NDVI) was used to assess agricultural growth. The NDVI index is sensitive to live, green plants, elucidating difference between the near-infrared and visible red owing to chlorophyll's absorption of visible light, and the cell structure of leaves reflectance of near-infrared light (NASA, 2000). Of the 207 sample sites across BVIS, we sampled active agriculture at 46. These 46 points were combined with the NDVI scene, their range of values (0.14 to 0.48) assessed, then, visually inspected for variations of NDVI in relation to the supervised land cover classes. This analysis in combination with consideration of feature descriptions of each sample point determined meaningful class assignment of LULC.

Developing a classification system for the dry season presented a number of challenges: (1) Cultivation was widely dispersed throughout the scheme; (2) Bare fields spectrally resembled earthen roadways and tertiary canals; and (3) Maize and other unmanaged grasses were observed growing immediately adjacent to and often overhanging irrigation canals. The maximum likelihood classification analysis showed eleven significant classes of land cover of which, 5 were classified as 'Fallow', 4 as 'Non-Vegetated', and 2 as 'Active Agriculture' (Figure 3.4).

Dry season land cover was also more diverse than initially expected. The appearance of fallow fields varied significantly, attributable to farmer decision-making on the method of field clearing: burning, hand weeding, or no clearing. The 'Fallow' land cover category included observations of 'Charred Ground' from burning at the completion of cultivation, 'Dried Fields' were predominately characterized by dry, harvested rice, and 'Shrubbery' a term used to describe various forms unmanaged grasses and weeds. The 'Non-Vegetated' class is typified by irrigation structure's including dirt roadways, concrete and earthen canals. However, pixels in this class are also located within agricultural fields. These mixed pixel effects are attributable to the complexity of mapping *land use* versus *land cover* in an irrigated scheme. In this case, even within an over-arching 'Agricultural Land' land use classification, a portion of the land functions as agricultural plots while the remainder serves as infrastructure for agricultural growth. Dirt roadways and earthen canals at BVIS are constructed from native soils. Thus, spectrally they resemble bare fields where farmers have cleared their plots post-harvest.

The 'Active Agriculture' class included observations of 'Maize,' 'Beans,' 'Cowpea' and in rare cases, intercropping of maize and beans. The majority of observations of maize sampled were mature (72%). Whereas observations of beans' and cowpeas' stage of growth were evenly distributed between young and mature. Additional information on the specific crop varieties and cropping calendar for these varieties would assist in further characterizing the spatio-temporal structure of agricultural growth throughout the scheme during the dry season.

The extent of dry season cultivation at BVIS is determined by water availability; typical cultivation occurs over ~300 hectares (ha) (M. Tarsizio, personal communication, March 17, 2016). The crop types and hectarage cultivated during typical dry seasons are: Maize (200-250ha), Beans (50-60ha), Cowpea (5-10ha), and Soya (50ha) (M. Tarsizio, personal communication, March 17, 2016). Management reported that water scarcity in 2016 limited cultivation to 180ha: 50ha were allocated to maize, 120ha to cowpea, and 10ha to beans. The decision to forego growing soya and expand cowpea cultivation during the 2016 season was in an effort to mitigate the impacts of drought (M. Tarsizio, personal communication, March 17, 2016). The intended areas of the scheme for cultivation of cowpea, maize, and beans by scheme management for the 2016 dry season are presented in Figure 3.5. However, field sampling showed that actual occurrence of these crops varied considerably, including maize being grown in an area previously considered 'too dry' for cultivation. Field sampling also revealed sporadic, and rare, plantings of sweet potato along the southern border of the scheme in plots not allocated or under the governance of the board. These findings have considerable impact as the intended spatial arrangement of crop types by the farmer cooperative directly influences irrigation distribution and scheduling throughout the scheme during the dry season.

3.2.3.2.4 Validation of Classification Results

Classification accuracies for each image were assessed with confusion matrices created in ArcMap™ 10.5.1. Confusion matrices are a cross tabulation procedure that reflect the agreement between the produced land cover raster and ground truth (Foody, 2002). Test pixels were evenly distributed across the study areas. The number of test pixels for each class were selected to ensure that at least 10-times the number of test pixels were selected per class, as there were classes (see e.g. Jensen, 2005). Four accuracy tests were applied for each classification: (1) producer's accuracy; (2) user's accuracy; (3) kappa coefficient; and (4) overall accuracy.

Producer's accuracy and omission (exclusion) errors are inversely related. Similarly, user's accuracy is inversely related to errors of commission (inclusion). Kappa (ϰ) analysis is a discrete multivariate technique, commonly used for assessing classification accuracy. The ϰ statistic is an estimation of the agreement between the classification map and reference (test pixels) data (Jensen, 2005) where both the correctly classified and misclassified test pixels are considered. ϰ is computed as:

$$\widehat{K} = \frac{N\sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{k}(x_{i+} \times x_{+i})} \tag{2}$$

Landis and Koch (1977) consider values >.80 as strong agreement, values between .40 and .80 as moderate agreement, and <.40 as poor agreement. The ϰ coefficient value is .70 for the rainy season classification, an indication of satisfactory agreement between classified imagery and reality. The dry season ϰ coefficient value .88 for the dry season; strong agreement. The overall accuracy is the product of the correctly classified test pixels in each class, divided by the total number of test pixels. The overall accuracy for the rainy season classification is 80%; the dry season classification is 93%. Results of classification accuracy assessments are summarized in tables 3.3 and 3.4.

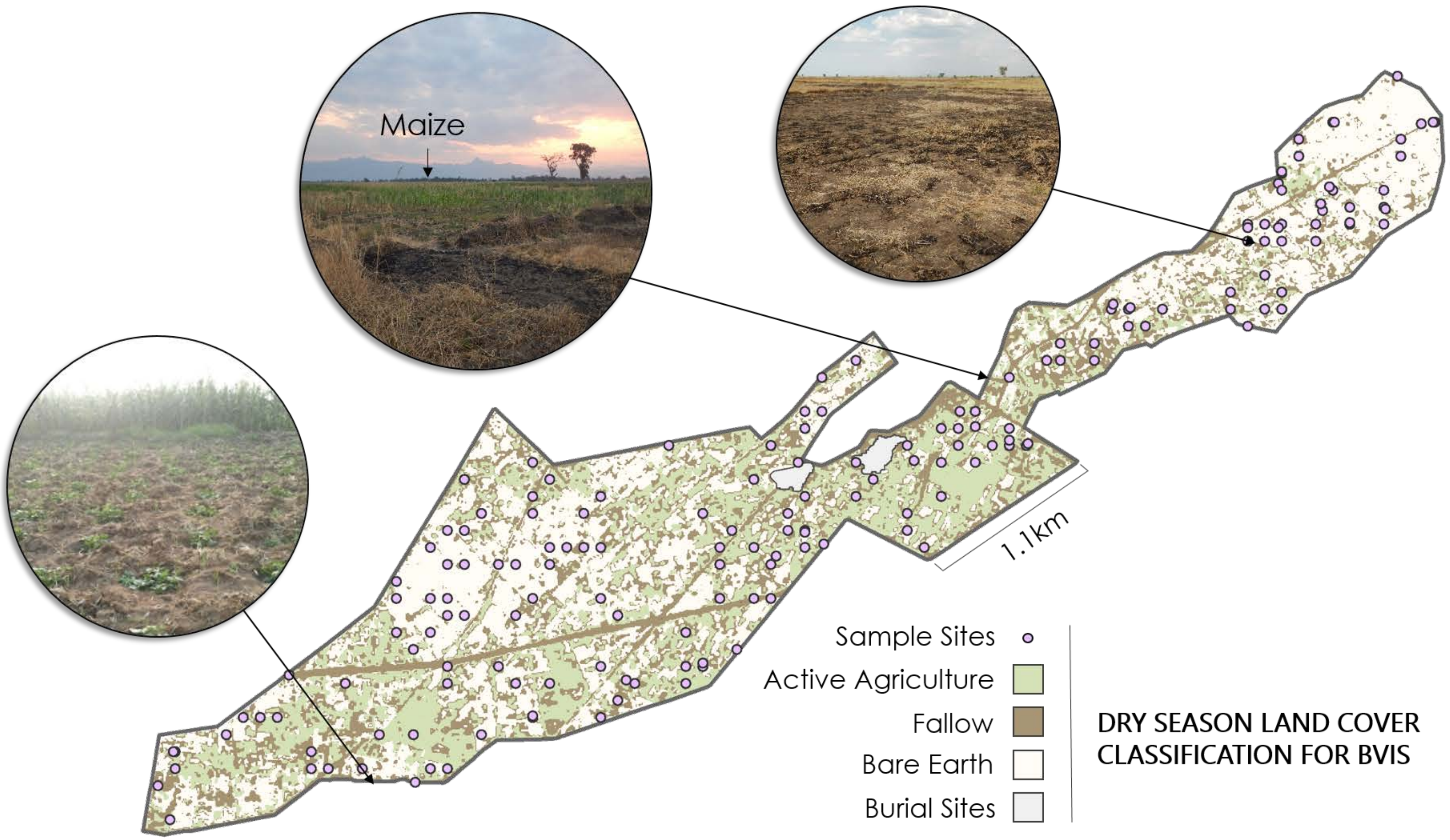


Figure 3.4: Dry season land cover classification for BVIS including field photos of varied land covers surveyed.

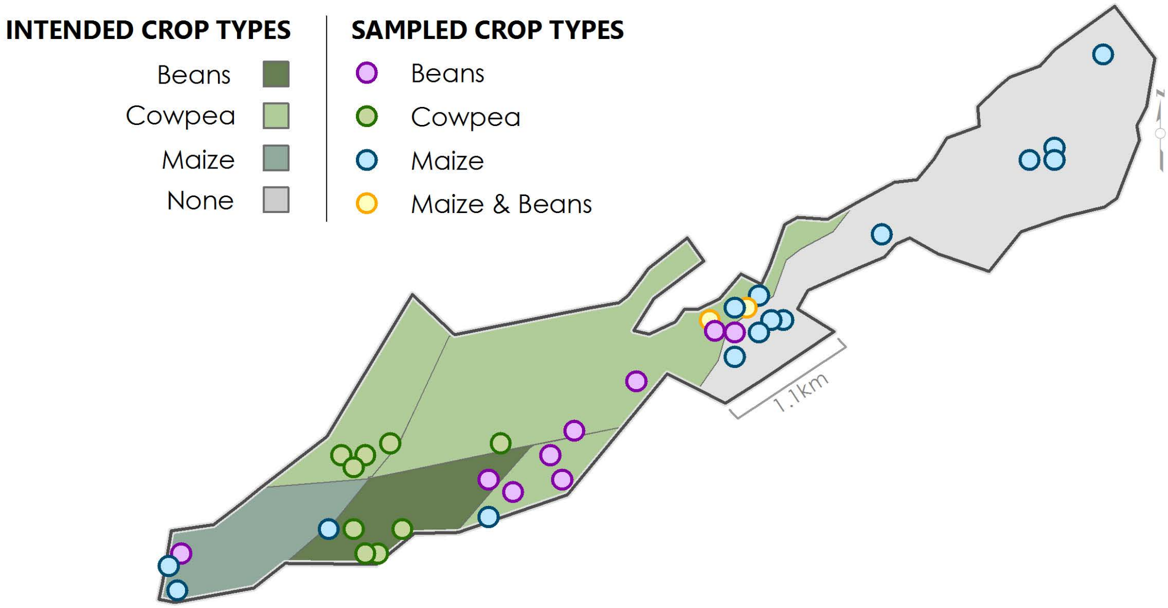


Figure 3.5: Variations between BVIS farmer cooperative intended distribution of crop types in relationship to where crops were sampled during field surveys.

Table 3.3: Rainy season classification accuracy assessment. P.ac., producer's accuracy; U.ac., user's accuracy; E.O., omission errors; C.O., commission errors

	Rice	Maize	Non-Agricultural	Total	P.ac (%)	O.E. (%)
Rice	29	3	4	36	96.6	3.3
Maize	1	21	4	26	70	19.23
Non-Agricultural	0	6	22	28	73.3	26.6
Total	30	30	30	90		
U.ac (%)	80.5	80.76	78.57			
C.O. (%)	19.4	19.23	21.42			
Overall Accuracy	.80					
Kappa	.70					

Table 3.4: Dry season classification accuracy assessment. P.ac, producer's accuracy; U.ac, user's accuracy; E.O., omission errors; C.O., commission errors

	Fallow	Vegetated	Non-Vegetated	Total	P.ac (%)	O.E. (%)
Fallow	38	0	4	42	95	5
Vegetated	0	37	0	37	92.5	7.5
Bare Earth	2	3	36	41	90	10
Total	40	40	40	120		
U.ac (%)	90.5	100	87.8			
C.O. (%)	9.5	0	12.2			
Overall Accuracy	93%					
Kappa	.88					

3.2.4 Anthropogenic Influence

3.2.4.1 BVIS Structure and Irrigation

Crop distribution and growth in an irrigated scheme are heavily influenced by the scheme's engineering. As such, the scheme's perimeter, main and branching canals, and water distribution control structures were mapped throughout the scheme. Throughout the literature, the actual perimeter of BVIS is ambiguous, particularly in the southeastern portion of the scheme (e.g. Chidanti-Malunga, 2009; JICA, n.d., 1994, 2005; Johnstone, 2011). Analysis was initially based off a perimeter georeferenced from (JICA, 2005) and verified through visual inspection of Google Earth Pro v. 7.3.1 imagery. However, it became increasingly apparent during field surveys conducted in 2016 that this working perimeter did not accurately reflect managements' operational boundary of the scheme.

A field survey delineating the positional accuracy of BVIS's perimeter was conducted in March 2017. The perimeter was mapped by walking along the operational boundary of the scheme with GPS tracking enabled on a Garmin™ Monterra GPS device; location coordinates were recorded at 3-second intervals. Surveying took approximately 2.5 days. To ensure the boundary's positional accuracy, a member of BVIS management was present for the duration of the survey. Results of this survey in relationship to the original georeferenced perimeter are presented in Figure 3.6.

The Bwanje Valley Irrigation Scheme is gravity fed system. The scheme's main intake directs water from the Namikokwe River and channels it through a series of main, branching, and tertiary canals. The main intake weir has a maximum discharge rate of 1.14 m^3/s (JICA, 2005). Since the scheme was established in 1999, irrigation canals have undergone significant rehabilitation due in part to catastrophic flooding in 2002 and 2003 (Veldwisch et al., 2009). Prior to rehabilitation the scheme was serviced by 1 main and 3 branching canals (Johnstone, 2011). At present, two main canals, six branching canals and 132 tertiary canals service the scheme (Figure 3.7). Bifurcation structures allow for the flow of water from main to secondary canals; 2 structures are located on main canal 1, and 3 on main canal 2 (Johnstone, 2011). There are five drainage canals located throughout the scheme (Chidanti-Malunga, 2009) totaling 17.3km (JICA, 2005). Ten drainage canals facilitate the collection and redirection of excess water to either other parts of the scheme or the outside area.

The location of main and branching canals were recorded in March 2016 over the course of two consecutive. Locations were mapped by driving the length of service roads immediate adjacent to canals with a tracking enabled on a handheld, Garmin™ Monterra GPS unit. Tracking was set to record location at 3-second intervals. When necessary, the locations of canals were tracked on foot. In both cases, the estimated offset distance of the canals to the position of the GPS unit was recorded. These data were uploaded to ArcMap 10.5.1 and the estimated offset distance were used to adjust the locations of canal transects. Results were verified in two ways: (1) by visual inspection Google Earth v. 7.3.1™ imagery; and (2) use of surveyed locations of slide gates located along each canal.

The engineering of BVIS includes turnouts that manage water distribution from branching to tertiary canals. Turnouts are equipped with manually operated, steel slide gates that control the amount of water permitted to move through the branching canal. Operation decks allow for access and control of slide gates. Turnouts are also equipped with hand gates that afford movement of water from the branching to tertiary canals located on either one, or both sides of the division structure. Surveying of slide and hand gates, and thereby the beginning of each tertiary canal, was performed in March 2016 in conjunction with the survey of irrigation canals. Locations of gates were recorded from the operation deck. A total of 142 hand gates and 90 slide gates were recorded across the scheme. The location of culverts were unmeasured.

Irrigation scheduling is the responsibility of the Water Use Association (WUA) at BVIS (M. Tarsizio, personal communication, March 17, 2016). During the rainy season, scheme management practices a 3-day irrigation schedule: water is directed along one branch canal for three days, then redirected to another branch canal. No specific irrigation schedule is followed during the dry season; water is directed along branching canals based on the appearance of crop stress (M. Tarsizio, personal communication, August 19, 2016). Regulatory precision and proportional water distribution at each turnout are limited in two ways. First, hand gates were constructed at a fixed width rather than a width proportional to the service area. In addition, these gates can only be opened at 5, 10, or 15cm. (Veldwisch et al., 2009). It was observed during surveying that water flow was further restricted by mounded grass placed across slide and hand gates in an effort to maximize water flow to tertiary canals upstream (Figure 3.8). In addition, two farmers were observed during sampling re-routing tertiary canal flow direction by removing silt preventing water access to their field, only to mound it further down the canal in order to halt the flow of water. Previous research has highlighted conflict between scheme management and farmers on the basis of water regulation including the appointment of water guards who control the allocation of water to each branch canal, and annual water fees (Chidanti-Malunga, 2009).

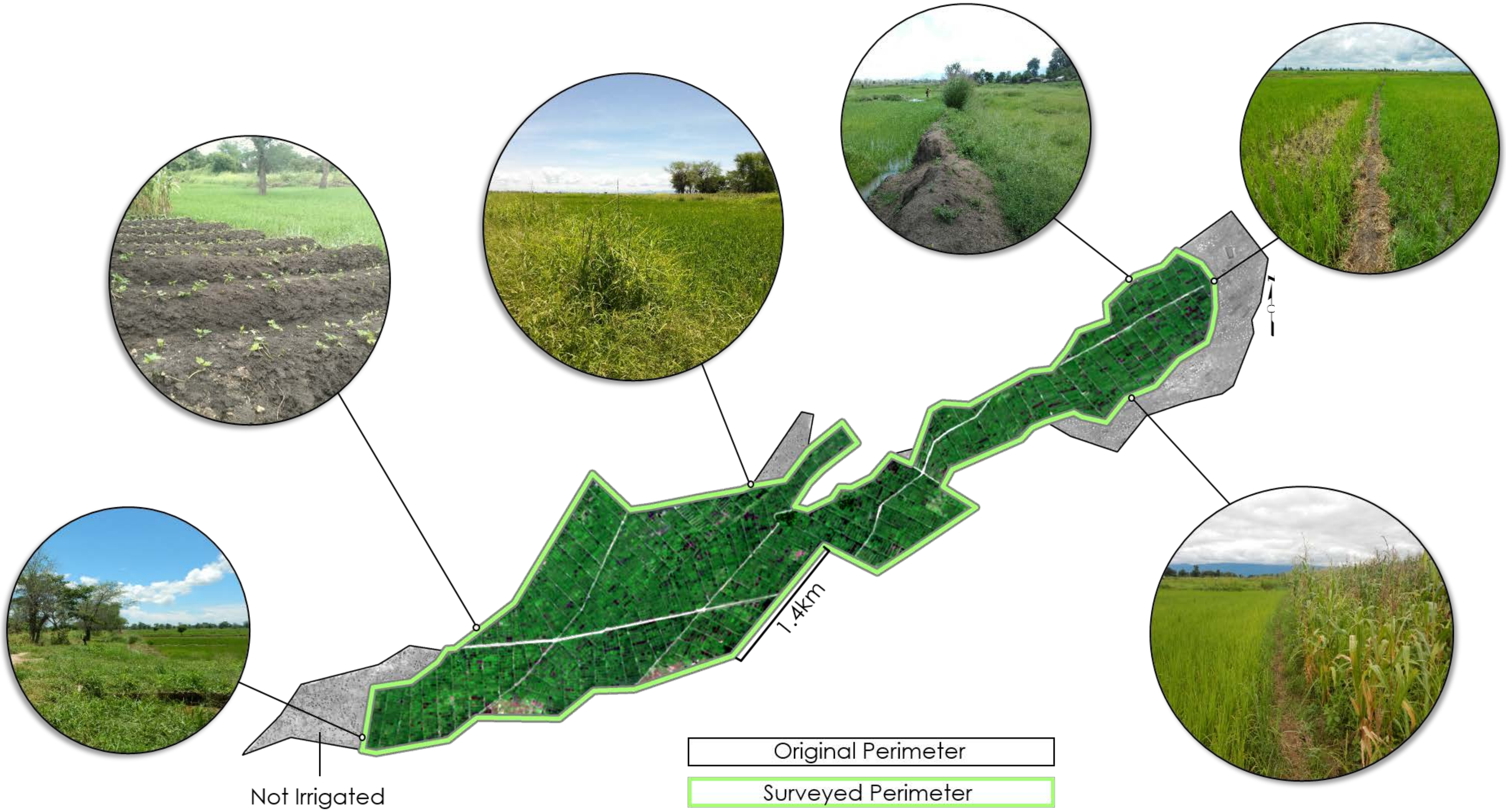


Figure 3.6: Bwanje Valley Irrigation Scheme (BVIS) 2017 surveyed perimeter (green). Digitized perimeter of BVIS from JICA's Basic Design and Study Report (2005) and visual inspection of Google Earth v. 7.3.1 imagery (black) initially used for data analysis and field collection.

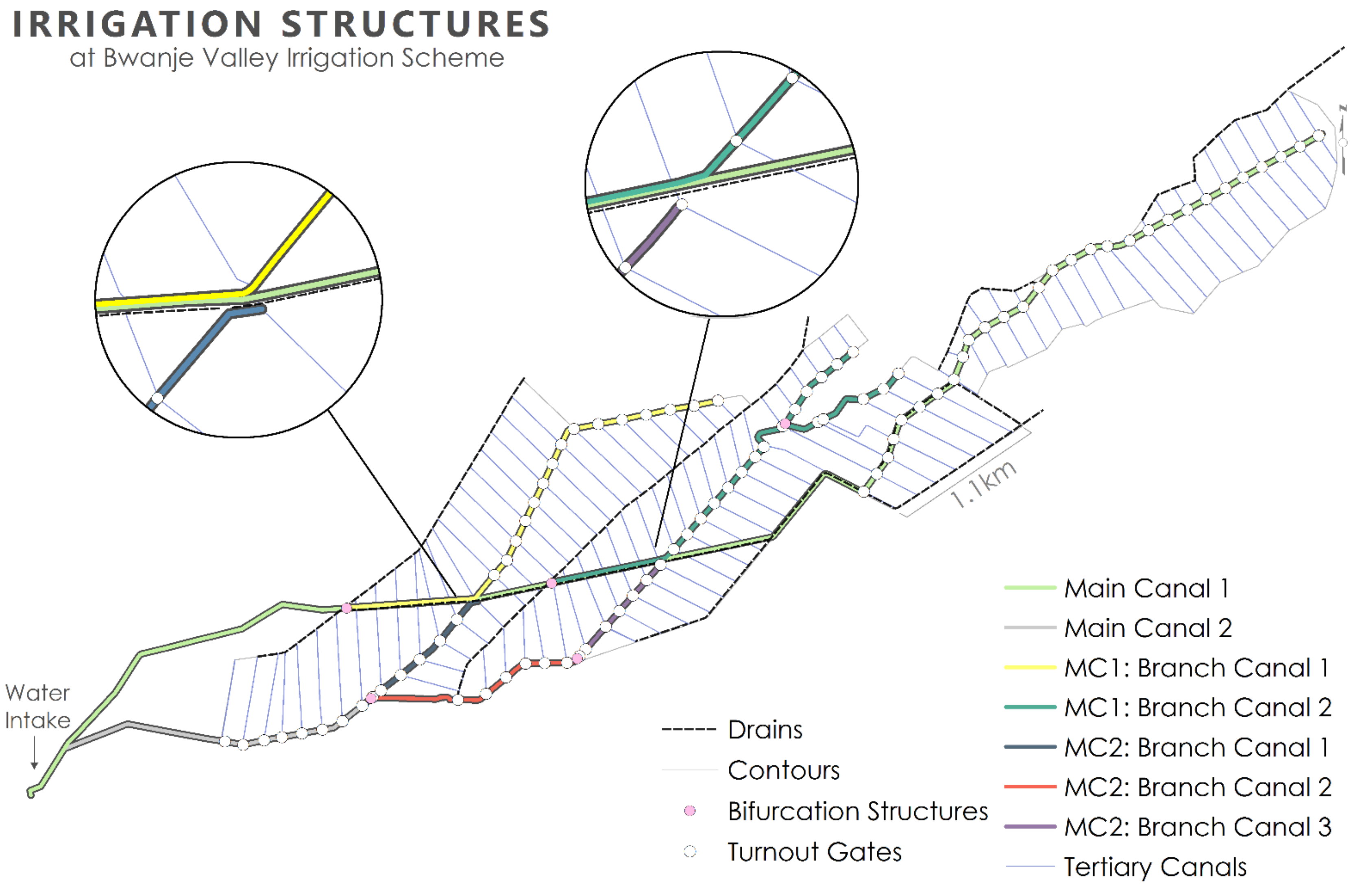


Figure 3.7: Irrigation water control structures at BVIS

Figure 3.8: Mounded grass and debris are placed in front of a branching canal slide gate at BVIS to prohibit water flow.

Figure 3.9: A farmer's name written along a branching canal denoting the farmer's specified maintenance area of the canal

3.2.4.2 Drainage

While attempts were made to map the drainage system at BVIS during field surveys, many drainage canals were indiscernible as a result of either unmanaged grasses or rice plants allowed to grow within the drainage areas. As such, drain locations were georeferenced from the 'Basic Design Study Report on the Project for the Rehabilitation of Bwanje Valley Irrigation System in the Republic of Malawi' (JICA, 2005).

Surface drains facilitate the movement of excess water caused by either rainfall or the application of too much water (Brouwer, Goffeau, & Heibloem, 1985). Improperly functioning surface drains can lead to waterlogging, allowing for pooling of water at the soil surface (Brouwer et al., 1985). Drainage at BVIS occurs in two distinct fashions: tail water is either collected, then redirected through a series of surface drains from one area of the scheme to another or is uncontrolled once leaving the tertiary canals and permitted to move naturally beyond the scheme's boundaries. The scheme has four main drains that total 17.3km (JICA, 2005). These trapezoidal earth canals have a maximum allowable velocity of 0.75 m/s, with an allowable unit area of drainage discharge of 7.64 l/s/ha (JICA, 2005).

Drains at BVIS are susceptible to many of the same ongoing maintenance issues as those found in tertiary canals: portions of drains were choked with weeds and silt during surveying. De-silting and weed management of drains (and branching canals) are shared responsibilities among the farmers and WUA. Farmer names are written along a portion of the branching canal adjacent to their plot(s) at which point drain and branching canal maintenance for this area becomes their responsibility (Figure 3.9). Failure to maintain these areas may result in a fine from the WUA, though scheme management admits there is often a lack of enforcement resulting in untidy irrigation structures (M. Mafosha, personal communication, March 27, 2019). Figure 3.10 shows a section of a main drainage canal that has been cleared in the foreground. Yet, poor management practices on the part of the farmer operating the adjoining plot has allowed for the proliferation of tall grasses to grow. These grasses restrict water flow and redistribution of resources to other parts of the scheme. The variability of drainage maintenance has considerable influence on the area(s) of BVIS that favor mosquito breeding pool formation.

Figure 3.10: Examples of improper drain management capture during field surveys. Surface drains are meant to be free of weeds and grasses in order to facilitate the flow and redirection of water to other portions of the scheme. Drain maintenance is the shared responsibility of farmers and the BVIS cooperative

3.2.4.3 BVIS Operations and Governance

At the onset of the scheme's operation, BVIS was managed by the Malawi government, but by 2003 power dynamics shifted and farmers organized into a cooperative. In 2004, the Cooperative was registered with the Ministry of Industry and Trade (Johnstone, 2011). The capital to form the Cooperative was secured through a "One Village One Product" loan; a Japanese regional development program that aimed to develop one local product for trade on both domestic and local markets (Johnstone, 2011). At BVIS, this product is rice. Rice is produced largely by smallholders in Malawi and is grown as a secondary cereal crop to maize (AICC, 2016). In 2017, Malawi's rice production was 15.2 million tons with farmers averaging 1500-2000 kilograms per hectare (AICC, 2017).

The BVIS Cooperative includes thirty-six farmers elected by scheme participants who serve on either the executive committee (27 members), general committee (9 members), or subcommittees.

Twelve farmers are elected from each of the three branch canals to ensure equal representation across the scheme (M. Tarsizio, personal communication, March 17, 2016). Subcommittee membership is held by members of the general committee and includes discipline, health, auditing, finance, marketing, and production. A scheme manager works in cooperation with the farmer cooperative to oversee daily scheme operation.

The types, quantity, and location of agricultural crops grown at BVIS are governed by the farmer cooperative. Farmers apply seasonally to grow specific crop types. Across the scheme, farmers practice monocropping; intercropping is discouraged (M. Tarsizio, personal communication, August 19, 2016). Each season, farmers pay a water fee of Malawi Kwacha (MK) 1000 (~1.20USD) per ~30X30m plot of land. In addition, farmers are required to pay an annual K5000 participation fee (M. Mafosha, personal communication, March 27, 2019). Farmers cultivate an average of five plots per season (M. Mafosha, personal communication, March 27, 2019). Though rare, farmers have the option of operating a plot 'not allocated' by the farmer cooperative. In these types of arrangements, farmers are provided with a plot of land at the standard participation fee rate. However, they are not provided with water access in exchange for their ability to exercise total governance over the crop type(s) under cultivation. In these situations, tertiary canal direction is rerouted to inhibit water access. If found to have tampered with the system so as to obtain water on an unallocated plot, farmers face a fine of MK5000 (M. Tarsizio, personal communication, March 17, 2016).

During dry season field surveys, very few unallocated plots were observed, and all were located along the southwestern border of the scheme adjacent to the Namikokwe River. The most obvious feature was the presence of intercropped maize and beans. It is these plots' location in relation to the Namikokwe River that allows farmers to more easily cultivate them in an unallocated manner. Irrigation is conducted by watering can, a widely practiced method of irrigation for smallholder farmers (Smith et al., 2014). While watering can irrigation is a simple and effective means of irrigating, carrying water is labor intensive and regular watering is required, limiting areas that can be effectively irrigated.

3.3 Results

3.3.1 Breeding Distribution Scenarios

The spatial distribution of water bodies at BVIS is influenced by seasonality, soil properties, timing and intensity of irrigation, drainage, land cover, crop water requirements, and management. It would be misleading to present a single maximum estimate of breeding potential at BVIS given the variable nature of the factors influencing their spatio-temporal distribution. Rather, projected distributions of breeding under three scenarios are presented: rainy season, dry season with limited water resources, and a dry season with abundant water resources. For each scenario, projected distributions represent the seasonal peak period.

To assist in this analysis, two breeding pool suitability models (rainy season and dry season) were developed by categorizing individual pixels relative to the soil's propensity for ponding (very low, low, moderate, or high) and seasonal land cover produced from this study. Soil properties were taken from JICA's "Feasibility study on Bwanje Valley smallholder irrigation development project" (JICA, 1994). Categorical ranking of breeding area was done by first considering the likelihood of ponding based on soil properties, then land cover. In each model, less breeding will occur in Non-Vegetated areas given their makeup: roadways and irrigation canals. In the dry season, active agriculture presents a greater likelihood for breeding over fallow areas given the intermittent presence of water either by traditional irrigation or alternative methods (i.e. watering can). Modeled outputs consider how the availability of water resources, drainage, and crop water requirements would affect the distribution of breeding pool formation and persistence. The influence of drainage in all scenarios was approached from an understanding of the scheme's irrigation engineering. As such, the structure of the scheme was divided into three Water Service Areas (WSA) based on the design of irrigation canals, their flow direction, and the location of drains across the scheme.

3.3.1.1 Mid-Rainy Season

In this scenario, ubiquitous pooling of surface water occurs across BVIS as a product of: 1) abundant water resources both through precipitation and irrigation; 2) the soil's susceptibility to ponding; and 3) regular irrigation following BVIS' standard rainy season schedule (Figure 3.11). The dominant crop is rice, at varied stages of development, consistent with field survey results. In this scenario, pervasive breeding within plots is expected across the scheme. Modeled environmental characteristics (land cover and soil ponding) show that maximum suitability occurs within the northeastern section of WSA3. Here the ponding potential in combination with rice cultivation and regular flooding create an environment conducive for mosquito breeding. Yet, environmental characteristics alone do not effectively describe water distribution and persistence as a function of irrigation management for BVIS. In fact, WSA3 receives less water than WSA1 and WSA2 by virtue of 1) its situation to the headworks (water intake) of the scheme and the necessary diversion of water upstream to branching canals; and 2) backlogging of water in WSA1 & WSA2 as a result of inefficient drainage and re-direction of tail water. It is both the combination of regular irrigation and inefficiency of tail water drainage that makes the western most portion of BVIS the area of highest breeding potential during the rainy season.

3.3.1.2 Dry Season: Limited Water Resources

The opportunity for breeding during the dry season at BVIS is directly affected by insufficient water resources. This is evident in the reduction of cultivated land area from 800ha in the rainy season to <300ha in the dry. Crop types include horticultural crops, namely maize, beans, and cowpea. In this scenario it is expected that breeding opportunity is limited only to active agricultural areas given the intermittent presence of water either through traditional irrigation or alternative methods including watering cans and treadle pumps; one instance of treadle pump use was recorded during the 2017 dry season survey. The influence of drainage and redirection of tail water has less of an influence on the aggregation of water bodies as often water resources are limited to the point that entire tertiary canals are unable to be serviced with water.

Agricultural crop types and their distributions are governed by the BVIS Cooperative. When water resources are limited, distinct spatial arrangements of crop types are valuable for irrigation planning and allocation of water resources. During the dry season irrigation scheduling is governed by the appearance of crop stress, a function of the crops fundamental water requirements. Crop types that require more water are irrigated more frequently than others. In our scenario, crop types under cultivation are maize, common bean, and cowpeas. Maize and common bean require on average 500-800mm and 300-500mm of water per growing period, respectively (FAO, 1991). Cowpeas are most often grown under dryland, not irrigated conditions given their ability to withstand drought conditions. Annual rainfall for geographical areas producing cowpeas averages 400-750mm (Republic of South Africa, 2011). Therefore, areas of greatest concentration of breeding potential are expected to be in the westernmost area of WSA1 based on the historical spatial arrangement of crop types dictated by the BVIS Cooperative (Figure 3.12). This area is historically allocated to maize cultivation. In addition, its location nearest to the scheme's headworks ensures that even in spite of limited water resources, irrigation water is supplied to these tertiary canals. This projection assumes that the majority of farmers adhere to the cooperatives crop distribution guidelines.

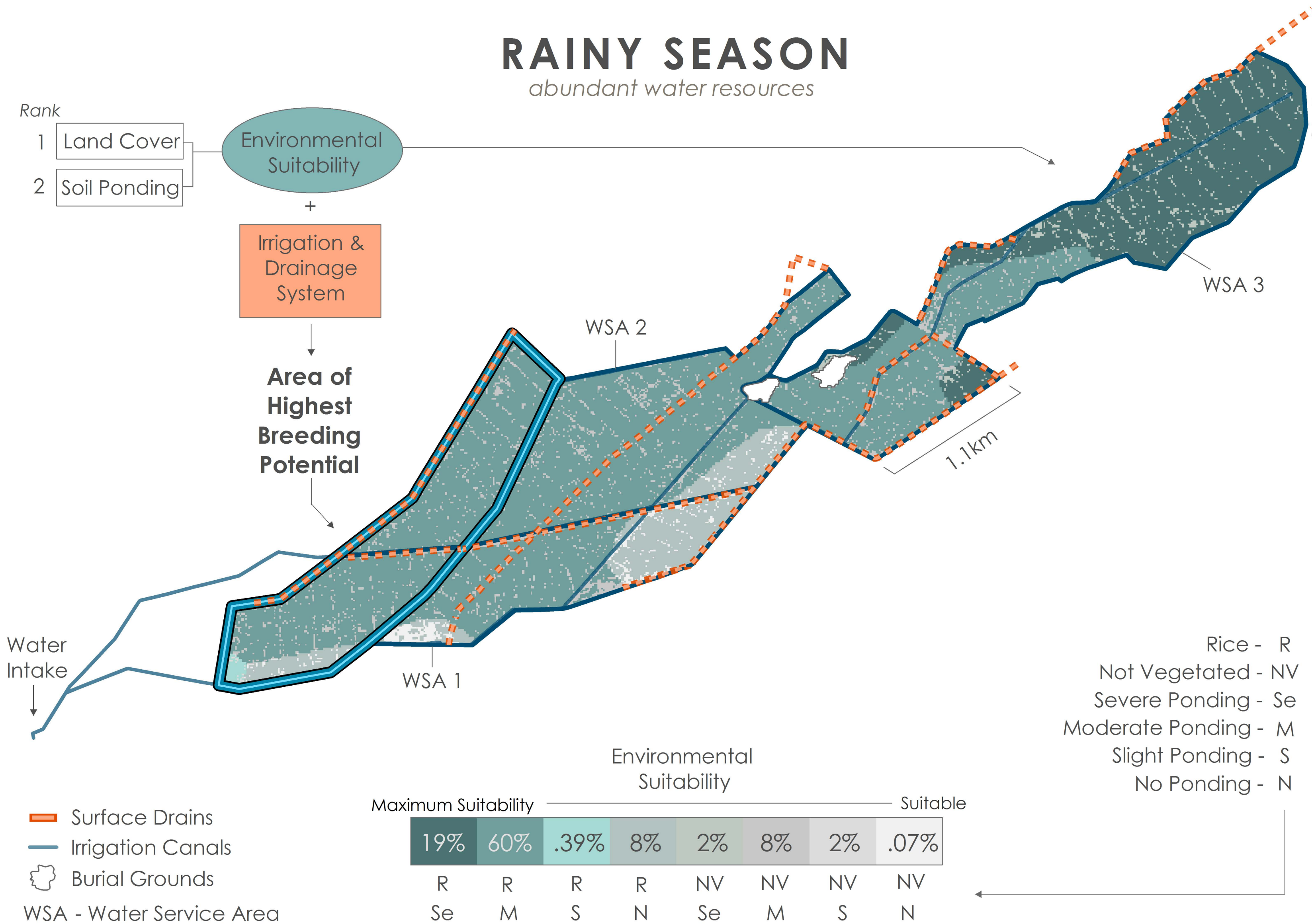


Figure 3.11: Rainy season breeding scenario under abundant water resource conditions at BVIS.

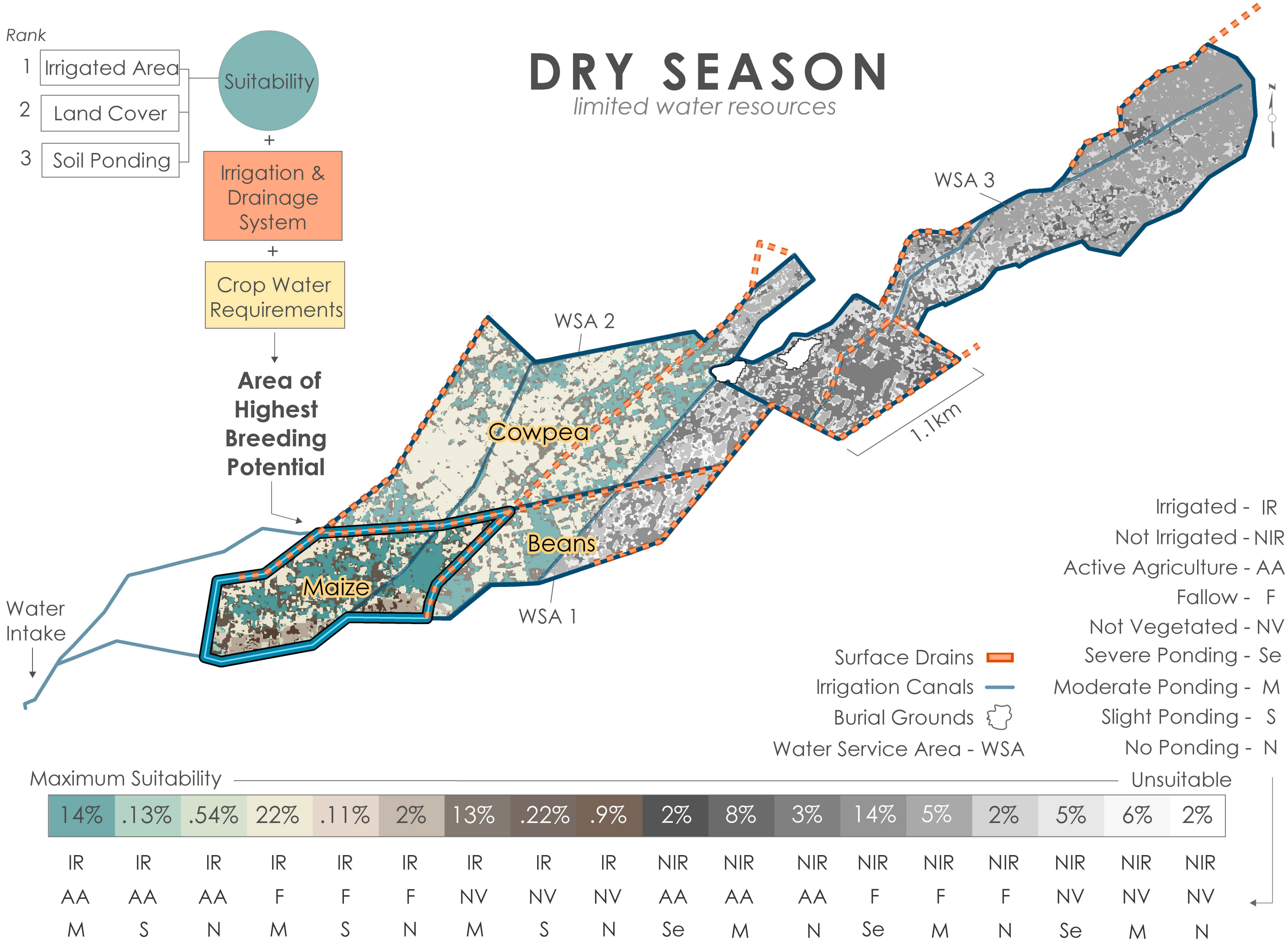


Figure 3.12: Breeding scenario under limited water resource conditions during the dry season

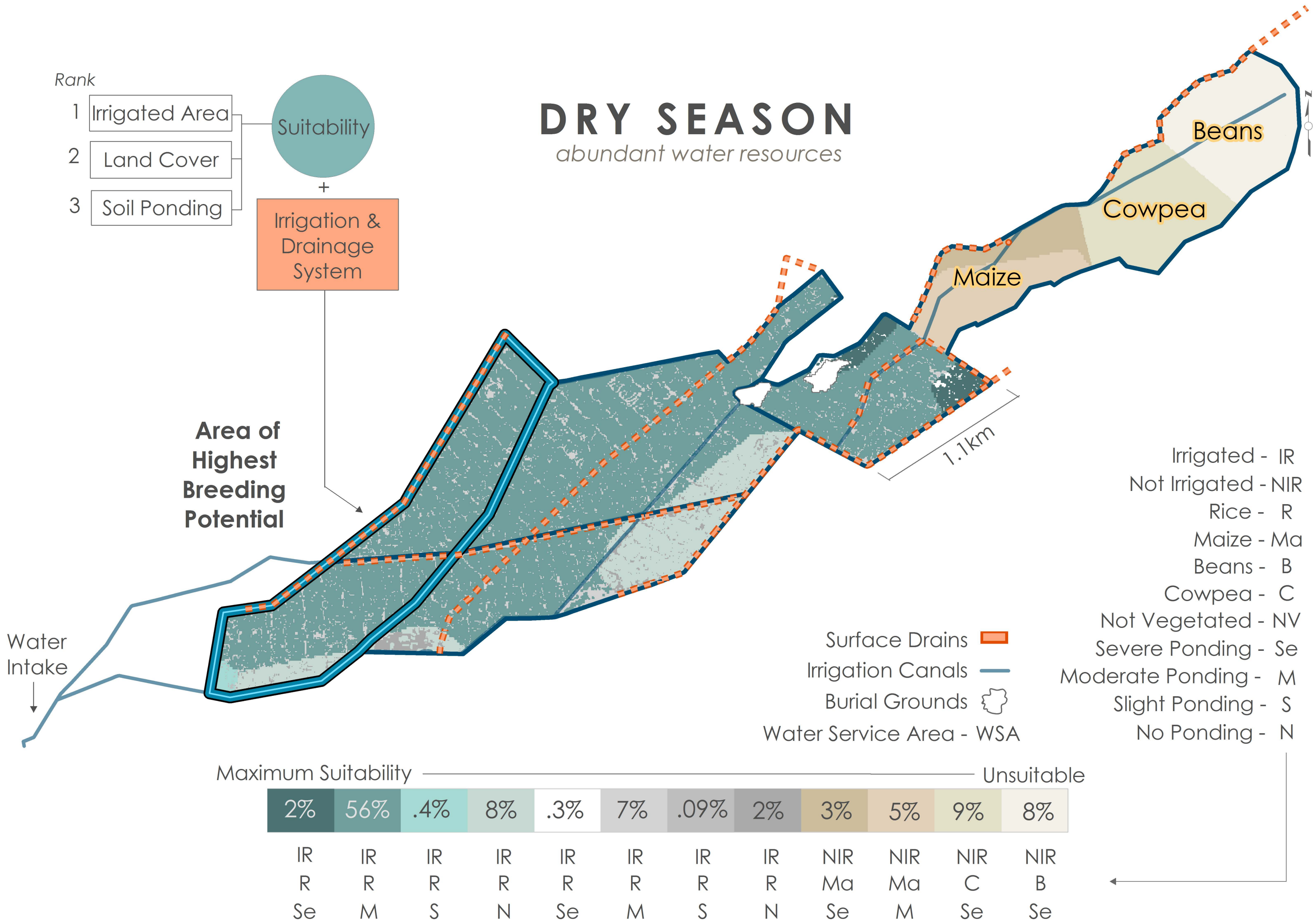


Figure 3.13: Breeding scenario under abundant water resource conditions during the dry season as a result of the construction of the Bwanje dam

3.3.1.3 Dry Season: Abundant Water Resources

A considerable limitation to the success of BVIS is the availability of water resources, either rain fed or from the Namikokwe River. As designed, the Japanese estimated that BVIS could only support roughly 150 hectares of dry season crops (Veldwisch et al., 2009). Though, Veldwisch et al. (2009) reports that the information that BVIS was not meant to supply water year-round came as a surprise to farmers during the first dry season. As a result, Malawi's Department of Irrigation sought to construct a dam in an effort to improve water availability and expand dry season cultivation at the scheme. Funded by the European Union ("Mutharika launches K6 billion dam project," 2017), the project began in June 2016 (Moyo-Mana, 2018). The rockfill dam is the largest in the South African Development Community at 40m high and approximately 150m long with a storage capacity of 500 million cubic liters ("Mutharika launches K6 billion dam project," 2017). Construction was completed in October 2018 and the dam later launched in December 2018 (News, 2018). The dam is expected to provide BVIS with sufficient water resources to cultivate 600ha of rice during the dry season and additional horticultural crops (maize, common bean, cowpea, and soya). Future plans include expanding irrigable are to 2000ha (M. Mafosha, personal communication, March 27, 2019).

Given the significant hydrological changes expected at BVIS, the impact to breeding pool distribution during the dry season where abundant water resources are present, coupled with a primary change to rice agriculture as intended is considerable (Figure 3.13). The projected 600ha of irrigable area at BVIS will be located closest to the schemes headworks. As such, rice cultivation will be limited to these areas. The remaining 200ha area is expected to be cultivated by horticultural crops given the presence of residual soil moisture and sloping topography owing to the gravity-fed design of the scheme. Irrigation scheduling will follow a 3-day schedule and drainage should function in a similar fashion to that of typical rainy seasons. Under these conditions, pervasive breeding is expected throughout the 600ha area of irrigated rice with areas of greatest concentration located in the western portion of the scheme, as a function of water availability, ponding potential of soils, and inefficient drainage. Rather than limited breeding opportunity as a function of water resources, the availability of continuous irrigation from the Bwanje dam has the potential to change breeding distribution from that expected during a prototypical dry season, to the expected distribution more typical of rainy seasons. The consequences could be severe. Where breeding is restricted to less than 50% of the overall scheme area during a typical dry season, the availability of water resources from the Bwanje dam increases the temporal breeding landscape, changing not only the distribution of breeding but potential seasonal variation in malaria transmission.

3.4 Discussion and Conclusions

The potential spatio-temporal distribution of breeding sites at BVIS is a product of myriad factors. In estimating their probable locations, our models have significant limitations in defining relative breeding potential. First, there are no existing measurements for water volume at BVIS; either diverted from Namikokwe, passing through branching or tertiary canals, or ultimately that passes into farmers' fields. Precise measurements on the total amount of water being applied to each field, in combination with information on irrigation scheduling and crop types would assist in developing a dynamic series of models that estimate breeding potential as a function of total water volume and estimated root water uptake. These data could be coupled with local weather information to further refine models for estimations of water loss through evaporation. A related point is the absence of specific crop variety information at BVIS. This information would assist in better characterizing the scheme in relationship to the growing periods and specific root water uptake characteristics of crop varieties.

An added consideration to both the rainy season and dry season: abundant water resources scenario is the effect of stage of rice growth. Non-consecutive planting times will affect the spatio-temporal distribution of larva species. *An. arabiensis* preferentially breed in open, sun lit pools (Sinka et al., 2010), characteristic of plots in preparation for, or just after transplanting. As rice plants begin to grow and water surfaces are shaded by vegetation, abundance of *An. arabiensis* declines (Sinka et al., 2010). *An. funestus s.s.*, however prefers breeding in areas with emergent vegetation and large, permanent or semi-permanent fresh water bodies (Sinka et al., 2010). Marrama et al (1995) showed that later, grain head formation and maturation stages of rice growth are associated with *An. funestus* breeding. Diuk-Wasser et al (2007) demonstrated a significant relationship between land use, including stages of rice, and abundance of *An. gambiae*. Vectorial capacities of mosquito species are not uniform. Because vector abundance is a critical factor to malaria transmission, cultivation practices will influence the disease ecology of the local area.

The noted association between irrigated agriculture and proliferation of mosquitoes is not novel. Yet, treating irrigated areas as homogenous spatial units leads to inaccurate conclusions on breeding pool formation, persistence, and concomitant exposure risk. It is one thing to assert that irrigation encourages mosquito production, it is quite another to answer where to expect breeding to occur. Particularly for irrigated areas that practice seasonal crop rotation, mixed cropping, or intercropping, the spatio-temporal distribution of crop cover can have profound impacts on the distribution of water resources across irrigated areas and thereby, breeding potential.

The analysis at BVIS showed that the risk potential for mosquito breeding is seasonally asymmetrical across the scheme owing to environmental and anthropogenic factors. The three scenarios presented illustrate how perturbations to the irrigated system in the form of water availability, water management, and crop cover can influence the distribution of aggregated water bodies. It is prudent to consider that female *Anopheles* mosquitoes are most likely to take their bloodmeal's from people living in closest proximity to breeding sites. Thus, changes to the geography of breeding potential across irrigated spaces can have profound implications for the distribution of malaria risk for those living in close proximity to irrigated agriculture. Given the importance of irrigation to resolving food insecurity, it is necessary to continue considering how to provide crops with the water resources necessary for adequate production without exacerbating malaria risk.

CHAPTER 4

4.1 Introduction

There is a strong association between Land Use and Land Cover (LULC) and malaria transmission (Lindblade, Walker, Onapa, Katungu, & Wilson, 2000; Olson, Gangnon, Silveira, & Patz, 2010; Patz & Olson, 2006; Vittor et al., 2009), including Land Use and Land Cover Change (LULCC) for irrigated agriculture (see: Afrane et al., 2004; Ijumba, Mosha, & Lindsay, 2002; Keiser et al., 2005) This chapter considers the association between LULC and *Anopheles* mosquito breeding potential within the Bwanje Valley Irrigation Scheme (BVIS), and the 8km area surrounding the scheme during Malawi's dry season. Eight kilometers was selected to give consideration to the average flight distance of *Anopheles* mosquitoes. The flight range of *Anopheles gambiae s.s.* is uncertain: Costantini et al. (1996) reports less than 1.0km, while Thomas, Cross, & Bøgh (2013) estimated a maximum distance of 1.7km. An 8km distance provides ample consideration to all distances a female mosquito reared at BVIS, and their immediate progeny, would fly in search of a blood meal. Further, this distance provides an adequate estimation of land use and land cover attributable to BVIS and the Bwanje Valley that may promote mosquito development within the area.

4.2 Bwanje Valley and the Bwanje Valley Irrigation Scheme

For the purposes of this study, the phrase 'Bwanje Valley' is used to describe the 8km area surrounding BVIS (Figure 4.1). The Bwanje Valley is characterized by an escarpment to the west dominated by the Dedza-Salima Forest Reserve. To the east, the landscape steadily descends into Lake Malawi. Etched across the valley are the Namikokwe, Nadzipokwe, Livulezi, Chikonbe, and Nadzipulu Rivers. The Namikokwe River, the source of BVIS' irrigation waters, has undergone substantial change to its course since 2002 (JICA, 2005) creating a braided stream network of interweaving channels moving eastward toward the Livulezi River. Twenty-seven villages are located within the Bwanje Valley, each with villagers who participate in BVIS (M. Mafosha, personal communication, August 19, 2016). The primary ethnic group of the area are the Chewa, descendants of the Maravi who migrated to Malawi in the 13th century (DeCapua, 2009). The Chewa are a matrilineal, bantu-speaking people. The Chewa language, Chichewa, is spoken by more than 15 million (Boucher, 2012). A significant cultural institution for the Chewa people is the *Gule wamkulu*, or the 'Great Dance' as a medium for ancestors to communicate with the people (Boucher, 2012). The dance fuses history, religion, and culture and is performed by masked *Nyau* dancers for significant events and rituals. For a review of the Chewa people, the *Gule wamkulu*, and a description of G*ule wamkulu* characters see Boucher (2012).

Prior to the construction of BVIS, the Bwanje Valley was considered 'one of the most economically depressed areas in Malawi' (JICA 1994, pg 2). Farmers practiced traditional wetland (dambo) agriculture at the site of the BVIS (Johnstone, 2011; Veldwisch et al., 2009) and widespread, rain fed agriculture in the surrounding area (JICA 1994). The term 'dambo' is of Bantu origin and refers to seasonally waterlogged areas within floodplains, or along streams (Turner, 1986). The dambo areas at BVIS were traditionally used for rice and sugar cane (Johnstone, 2011), though the prevailing crop in the area was, and continues to be, maize (JICA 1994). As part of the BVIS's construction, an existing 130ha irrigation scheme, the Mtandamula Irrigation Scheme, was absorbed by BVIS; farmers at Mtandamula predominately grew rice (M. Mafosha, personal communication, March 27, 2019). Other crops produced within the Bwanje Valley were groundnuts, pigeon peas, beans, soya beans, pulses, and cotton (JICA 1994).

A brief discussion of BVIS is presented in Chapter 1, Section 1.2.2. For a complete discussion of the scheme's history, irrigation structure and engineering, management, and spatio-temporal distribution of LULC see Chapter 3.

Figure 4.1: The Bwanje Valley and Bwanje Valley Irrigation Scheme (BVIS) located in Dedza district, central Malawi. The Bwanje Valley is defined as the 8km area surrounding BVIS.

4.3 Methods

Dry season variations in LULC for BVIS and the Bwanje Valley and their impact on the distribution of *Anopheles* breeding potential were determined from: (1) SPOT-6 satellite imagery from December 2013; (2) field surveys of LULC at BVIS and the Bwanje Valley during August 2016; (3) soils data from JICA (1994); and (4) onsite interviews with BVIS personnel in 2016, 2017, and 2019. The purpose of sampling only during the dry season was to assess the availability of surface water for mosquito breeding as a function of irrigation in contrast with the surrounding landscape during a time period when water resources are limited. The conceptual framework for this study is presented in Figure 4.2.

The conceptual model for this research consists of three primary components: LULC was determined through field sampling of the Bwanje Valley and BVIS, soils data were assessed for ponding potential, and a suitability model for mosquito breeding pool formation and persistence is constructed that considers LULC, soil ponding characteristics, and the presence of irrigation.

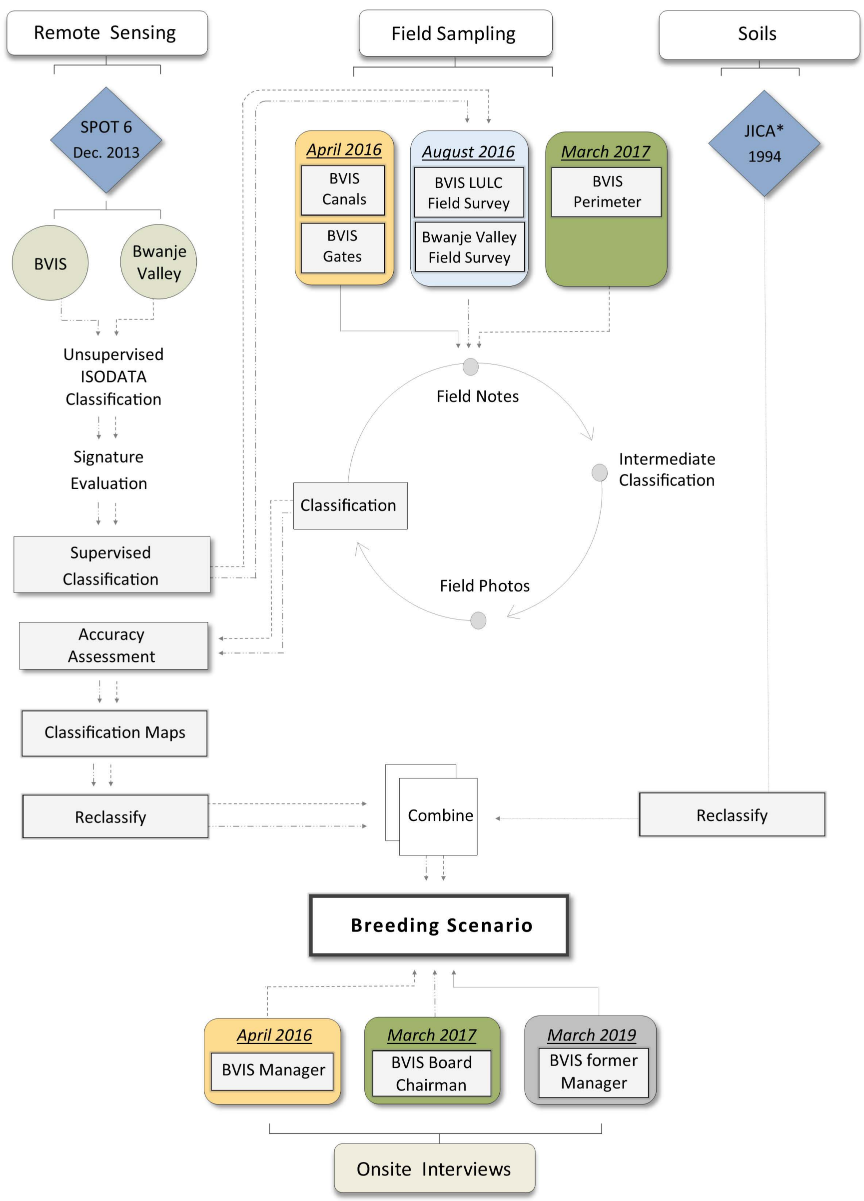


Figure 4.2: Conceptual Framework

4.4 Land Use and Land Cover

4.4.1 Data Preparation

A multispectral SPOT-6 image of the study area was acquired on December 4, 2013 at a spatial resolution of 6.0m for four spectral bands: Blue (0.455 μm — 0.525 μm), Green (0.530 μm — 0.590 μm), Red (0.625 μm — 0.695 μm), and Near-Infrared (0.760 μm — 0.890 μm). Geometric correction to ensure positional accuracy of the imagery was performed using ground control points prior to analysis and a 30m DEM from the Shuttle Radar Topography Mission (SRTM). Sensor calibration and conversion of digital numbers (DNs) to radiance was performed following a solar correction to top of atmosphere (TOA) reflectance using ERDAS IMAGINE™ 2014.

Classification was performed on two separate images generated from the corrected December 2013 scene: BVIS and the Bwanje Valley. The BVIS image included only those pixels located within the scheme. For the Bwanje Valley image, the BVIS boundary was used to omit pixels from the scene so that image statistics and classification for the Bwanje Valley were not skewed by the presence of pixel values attributable to the irrigated landscape. For both images, an unsupervised ISODATA classification was performed where 255 classes were selected with a .98 convergence threshold (see e.g., Messina et al. 1998). Signature evaluation of the ISODATA classification was conducted using the Transformed Divergence measure where separability markers of >1975 were acceptable. Using the edited signature set, a Maximum Likelihood supervised classification was performed. The BVIS image had eleven significant classes of land cover while the Bwanje Valley image had 15. Data preparation and image classifications were processed in ERDAS IMAGINE™ 2014. Field sample sites were selected by stratified random sampling of land cover classes from supervised classifications for each image. At BVIS, 242 sample points were selected; 183 sample points were chosen within the Bwanje Valley.

4.4.2 Land Cover Data Collection

Field based surveys of LULC were carried out in August 2016. A total of 235 sites at BVIS were surveyed over an eight-day period by a field team of three researchers. These samples included 185 of the sites selected from the random stratified sample, and 50 additional 'accuracy assessment' points collected to assist with classification. Most often the selection of accuracy assessment points was made when land cover differed considerably from the surrounding area. Following the BVIS survey, the Bwanje Valley was surveyed over a 6-day period by a field team of two researchers. A total of 51 sites were sampled within the Bwanje Valley from the stratified sample and 53 additional accuracy assessment sites.

For both surveys, at each site, the location and elevation, along with geotagged photographs were captured using a handheld Garmin™ Monterra GPS unit. Field notes describing the LULC at each sample site along with descriptions of LULC in all directions were recorded. Where land cover of surrounding areas differed from that recorded at the sample site, the direction of these areas along with approximate distances were included within field notes. Field note transcriptions and associated GPS data collected at each sample site were combined for LULC map development.

4.4.3 Land Cover Classification

Classification of LULC followed a two-step process: (1) sites were categorized by land use, land cover type, and feature (e.g. maize, rice, bare earth); (2) field notes were used to include information on stage of agricultural growth, appearance of soils, density of plantings, and locations of trees relative to agricultural growth for each feature identified in step 1. Point files of all sample sites and their respective LULC descriptions were generated in ArcMap™ 10.5.1, then overlain with supervised classification imagery. Descriptions of LULC including the number of samples within each class for the Bwanje Valley are presented in Table 4.1. See Chapter 3, Table 3.2 for dry season LULC descriptions for BVIS. Information on engineered structures at BVIS including main, tertiary, and branching canals assisted in differentiating between vegetated and non-vegetated areas.

4.4.3.1 Bwanje Valley Irrigation Scheme

See Chapter 3, section 4.2.3.2.3.2 for presentation of LULC findings at BVIS.

4.4.3.2 Bwanje Valley

The maximum likelihood classification analysis showed fifteen significant classes of land cover for the Bwanje Valley of which, 6 were classified as 'Fallow Agriculture', 4 as 'Mixed Foliage', 2 as 'Mixed Forest', and 3 as 'Bare Earth' (Figure 4.3). Dry season land use for the Bwanje Valley is categorized as 'Agricultural' and 'Non-Agricultural' land. Agricultural land included 'Active' and 'Fallow' vegetation. The dominant land cover type was Fallow Agriculture, including sites categorized as charred ground, dried fields, and shrubbery. The Mixed Foliage classification is characterized by shrubs, grasses, and scattered trees. Mixed Forest areas were predominately made up of trees and located in the western portion of the Bwanje Valley along the escarpment. Bare Earth areas are devoid of vegetation. Sample field photographs for each class as presented in Figure 4.4.

Table 4.1: Land cover classifications for the Bwanje Valley

	Study Area		TOTAL
Class Descriptions	***Sample***	***AA***	
I. AGRICULTURAL LAND			
II. ACTIVE			
Maize			
Young	1	0	**1**
Cowpea			
Cowpea & Shrubbery	2	0	**2**
Cotton			
Cotton	0	1	**1**
II. FALLOW			
Bare Earth			
Dark Soil	2	0	**2**
Dark Soil w/ Straw	0	1	**1**
Dark Soil w/ Straw & Ridging	0	1	**1**
Light Soil	1	0	**1**
Light Soil w/ Straw	1	1	**2**
Light Soil w/ Straw & Ridging	8	4	**12**
Light Soil w/ Ridging	2	5	**7**
Medium Soil w/ Ridging & Emergent Weeds	3	0	**3**
Charred Ground			
Charred Ground on Bare Earth	1	1	**2**
Dried Fields			
Vertical Rice Straw w/ Emergent Weeds	1	4	**5**
Horizontal Rice Straw w/ Emergent Weeds	0	1	**1**
Dried Grass	1	0	**1**
Long Term Fallow			
Medium Soil w/ Ridging & Dried Vegetation	1	1	**2**
Shrubbery			
Dense	2	3	**5**
IV. TREES			
Green Foliage on Bare Soil	1	0	**1**
Green Foliage on Dry Harvested Agricultural Land w Ridging	3	2	**5**
II. NON-AGRICULTURAL LAND			
Bare Earth			
Dark Soil w/ Straw	2	1	**3**
Light Soil	5	1	**6**
Light Soil w/ Green Vegetation	3	4	**7**
Charred Ground			
Charred Ground w/ Dry Vegetation	3	1	**4**
Dried Grass			
Dried Grass	0	5	**5**
Trees			
Green Foliage & Dry Undergrowth	2	1	**3**
Green Foliage on Bare Soil	3	1	**4**
Little Green Foliage w/ Dry Undergrowth	4	7	**11**
Mostly Dried Leaves	0	3	**3**
Dried Trees on Bare Rock	1	0	**1**
Human Influence			
Road	1	0	**1**
Human Dwellings	1	1	**2**
Riverbed			
Riverbed	0	3	**3**

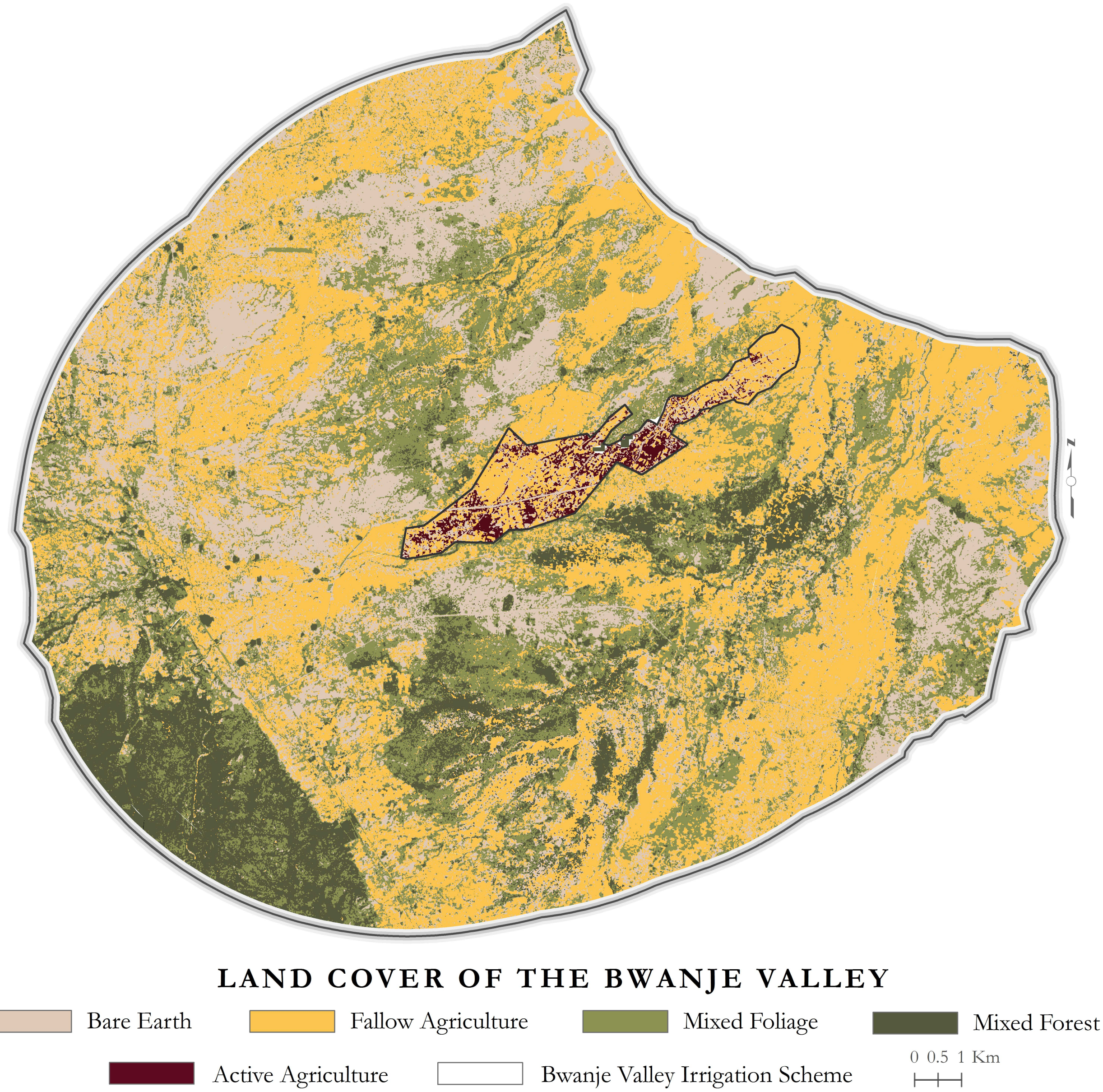


Figure 4.3: Combined LULC Dry Season classification produced for the Bwanje Valley and BVIS.

Fallow Agriculture

Mixed Foliage

Bare Earth

Mixed Forest

Active Agriculture

Figure 4.4: Sample photographs depicting classified dry season land cover types of the Bwanje Valley.

Developing a classification for the Bwanje Valley presented a number of challenges. Differentiating between agricultural and non-agricultural land was often difficult. In some areas, land had been left fallow for extended periods, losing features characteristic of agricultural landscapes including distinct crop rows. When available, local villagers assisted with providing information of land uses for areas of uncertainty. In addition, some non-agricultural lands including dried riverbeds were temporally converted to agricultural land to take advantage of residual moisture during the dry season. One example is east of the BVIS headworks along the Namikokwe River. During the dry season, available water resources past the headworks are severely limited. The characteristic slowing or stagnating of water in the river channels has historically resulted in land transformation of the riverbed to dimba gardens for cultivation of tomatoes, pigeon pea, maize, and rice (Figure 4.5). Our classification includes only one instance of sampled human dwellings. In many cases construction materials for home in the Bwanje Valley include sun baked bricks made from local soils and dried grasses for roofing materials. The materials used for construction of homes across the area make differentiating between homes and naturally occurring environmental features challenging. While some homes have corrugated metal roofs, the small size of many homes often precluded them from being registered as spectrally different than the surrounding landscape. Visual inspection of classification maps and Google Earth Pro 7.3.2.5776 showed that homes were predominately located in areas classified as Bare Earth. Finally, active agriculture in the Bwanje Valley during dry season field surveys was rarely found or sampled outside of BVIS. Only four instances were sampled: (1) Maize, (2) Cowpea and Shrubbery, and (1) Cotton. Cotton is an industrial export crop, often grown by smallholders and the most commonly grown cash crop along escarpments in Malawi (GoM, 2015b). The area of cotton sampled for this study was ~30X30m and was a cash crop grown adjacent to the farmer's home.

Figure 4.5: The Namikokwe River basin east of the BVIS headworks during the dry season. Limited water resources lead to the stagnation of water often resulting in conversion of the area to dimba gardens along the channel.

4.4.4 Validation of Classification Results

Classification accuracies for both maps were assessed using confusion matrices generated in ArcMap™ 10.5.1. The numbers of test pixels for each class were selected to ensure that at least 10-times the number of test pixels were selected per class, as there were classes (see Jensen, 2005). Test pixels were distributed across all classes. Four accuracy tests were applied for each classification: (1) producer's accuracy; (2) user's accuracy; (3) kappa (ϰ) coefficient; and (4) overall accuracy (Tables 4.2 & 4.3). The ϰ coefficient value for the Bwanje Valley classification is .93; overall accuracy is 95%. The ϰ coefficient value for BVIS is .88; overall accuracy is 93%. These values show strong agreement between the classified, thematic map and reference data for both classifications according to the Landis and Koch (1977) >.80 criteria.

Table 4.2: Bwanje Valley classification accuracy assessment. P.ac, producer's accuracy; U.ac, user accuracy; E.O., omission errors; C.O., commission errors

	Fallow	Mixed Forest	Mixed Foliage	Bare Earth	Total	P.ac (%)	O.E. (%)
Fallow	37	0	3	0	40	92.5	7.5
Mixed Forest	0	40	1	0	41	100	0
Mixed Foliage	1	0	35	0	36	87.5	12.5
Bare Earth	2	0	1	40	43	100	0
Total	40	40	40	40	160		
U.ac (%)	92.5	97.5	97.2	93			
C.O. (%)	7.5	2.4	2.7	6.9			
Overall Accuracy	95%						
Kappa	.93						

Table 4.3: Bwanje Valley Irrigation Scheme classification accuracy assessment. P.ac, producer's accuracy; U.ac, user accuracy; E.O., omission errors; C.O., commission errors

	Fallow	Vegetated	Non-Vegetated	Total	P.ac (%)	O.E. (%)
Fallow	38	0	4	42	95	5
Vegetated	0	37	0	37	92.5	7.5
Bare Earth	2	3	36	41	90	10
Total	40	40	40	120		
U.ac (%)	90.5	100	87.8			
C.O. (%)	9.5	0	12.2			
Overall Accuracy	93%					
Kappa	.88					

4.5 Soils

Soils data for the Bwanje Valley were digitized from soils maps produced by JICA as a part of the 1994 "Feasibility Study on Bwanje Valley Smallholder Irrigation Development Project" (JICA, 1994). To assess soil types, JICA representatives verified existing soils data by field surveying the area. Thirty soil sample's physical and chemical properties were verified through laboratory testing including assessment of pH, texture, organic matter content, total P, total C, and total N (JICA, 1994). Included with these data are composition and characteristics of each soil type (landform, altitude, drainage, flooding, ponding, erosion, soil depth, top soil, subsoil, pH, CE, CEC, NPK, surface rockiness, land use and vegetation).

4.5.1 BVIS

See Chapter 3, 3.2.3.1 for description of soil types and their associated properties at BVIS.

4.5.2 Bwanje Valley

The Bwanje Valley is made up of thirty-nine soil unit areas comprising seventeen primary soil types. Greater than 40% of unit areas contain two or more soil types. Parent materials for twelve of the soil types found within the Bwanje Valley are fluvial, colluvial and/or lacustrine sediments; the remaining five are felsic and intermediate igneous and metamorphic rocks (JICA, 1994). Top soil types (0-30cm) include clay, loamy sand, sandy loam, and sandy clay loam. One soil type's (A1f2) top soil is classified as 'variable.' Potential ponding across the area ranges from none to severe (Figure 4.6). Soils along the escarpment are typified by little to no ponding. The expectation for ponding increases moving eastward toward Lake Malawi as a result of poorer drainage (Figure 4.7) (JICA, 1994).

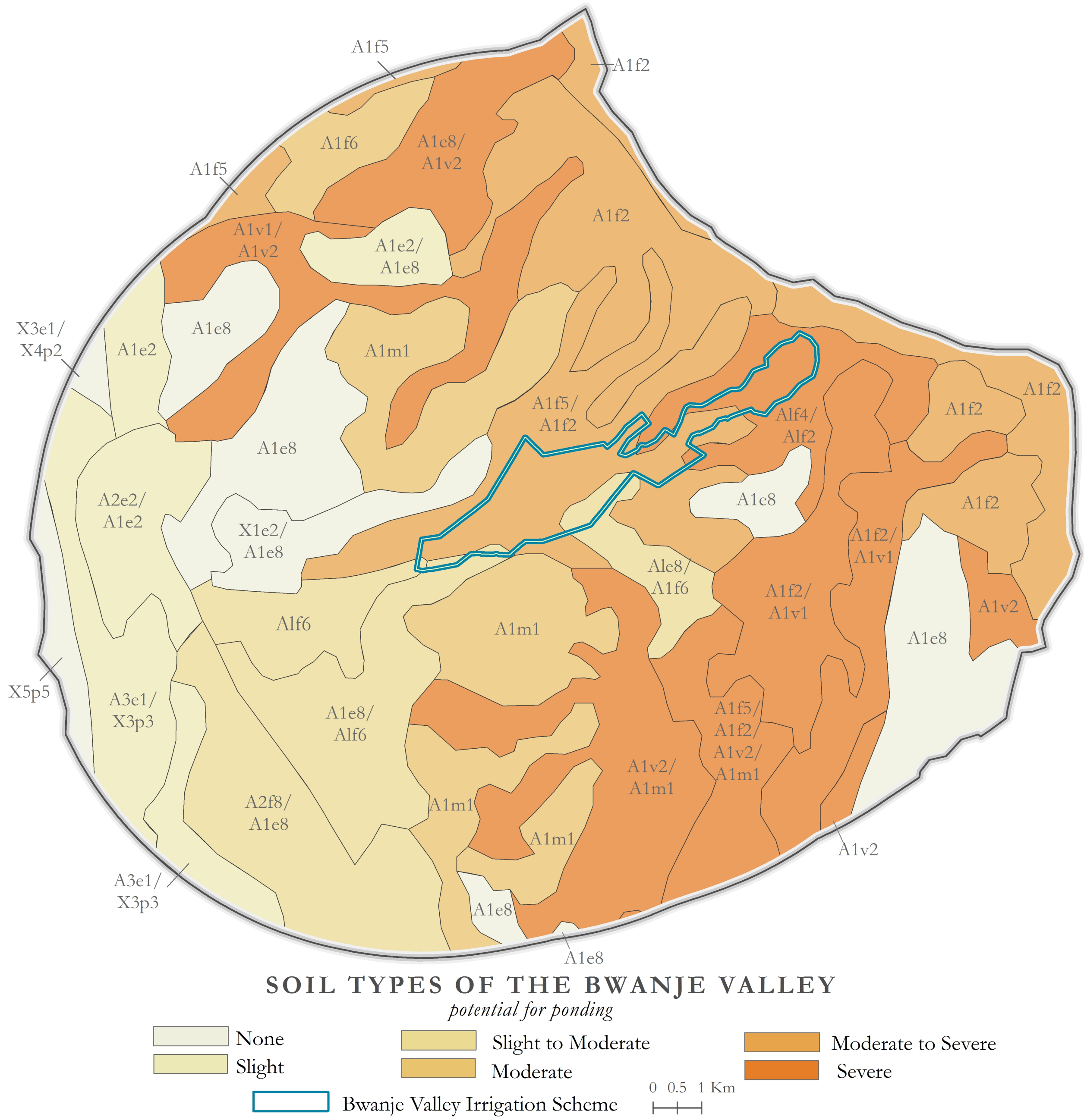


Figure 4.6: Soil types of the Bwanje Valley and their potential for ponding

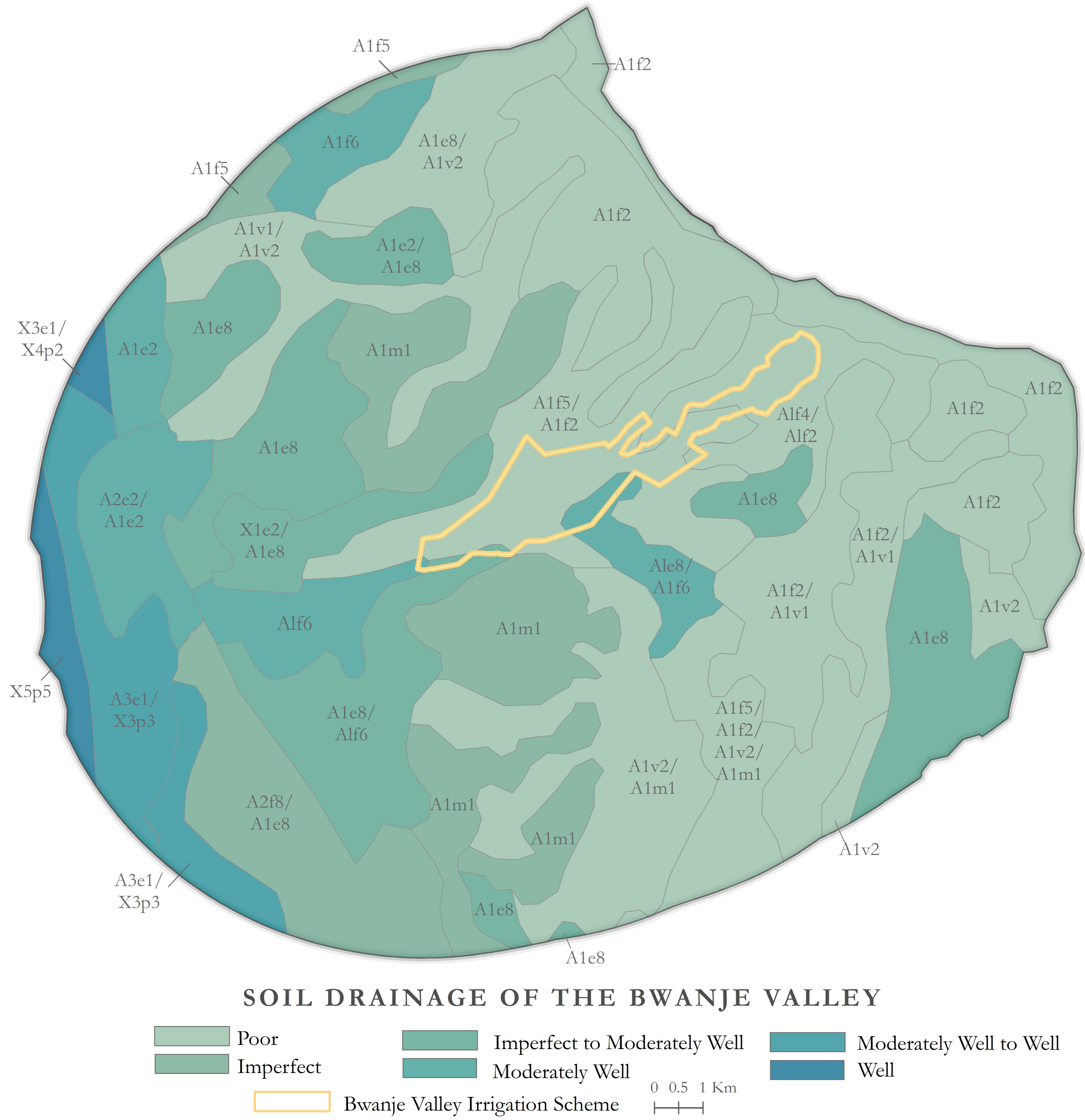


Figure 4.7: Soil drainage of the Bwanje Valley

4.6 Modeling Breeding Pool Suitability

The distribution of surface water available for mosquito breeding is a function of precipitation, soil drainage, LULC, and anthropogenic influence on the landscape. To estimate the spatial distribution of breeding potential during the dry season, a breeding pool suitability model was created for the Bwanje Valley, including BVIS. Soil features, land cover types, and irrigated areas data were used for model construction. Soil features were assigned values of relative likelihood for ponding from one to six; one represented areas of no ponding and six represented areas of severe ponding potential. These polygon features were rasterized at a 6m resolution to match LULC classification data.

Land cover types are Active Agriculture, Mixed Foliage, Mixed Forest, Fallow Agriculture, and Bare Earth; assigned values of 1 (most likely to support breeding) – 5 (least likely), respectively. Ranking of land cover types was determined using two criteria, *Anopheles* breeding site preference and the likelihood of persistent water bodies. *Anopheles* breeding preference was determined through a review of the literature for *An. funestus*, *An. gambiae*, and *An. arabiensis* mosquitoes, the primary mosquito vectors of malaria in Malawi (WHO, 2016). Preferred larval habitats for *An. funestus* include areas of emergent vegetation, along with permanent water bodies in savanna environments (Sinka et al., 2010). Likewise, *An. arabiensis* show preference for dried savanna landscapes along with sparse woodlands. *An. gambiae* larval habitats contain little to no vegetation (Sinka et al., 2010). To that end, Mixed Foliage areas were considered more suitable than forested areas given the preferences of these mosquitoes for sparsely vegetated landscapes for oviposition sites. Bare Earth and Fallow Agriculture land cover types will support the aggregation of water bodies in small depressions, but the loss of water from either infiltration or evaporation renders these areas as unsuitable for mosquito development. Fallow Agriculture was considered more suitable than Bare Earth given the presence of micro depressions within fields as a result of cropping, human and animal footprints. In addition, areas classified as Bare Earth do not possess sugar sources necessary for mosquito survival. Active Agricultural areas are the most suitable areas for breeding given both the persistence of water for oviposition and their demonstrated association with vector breeding (Sinka et al., 2010).

Irrigated areas for this study are known areas where water is supplied regularly through surface irrigation during the dry season. Areas of localized irrigation (bringing water directly to a plant from a water source, i.e. watering can) were not considered, nor were irrigation schemes only operational during the rainy season. To the author's knowledge, the Bwanje Valley contains only two irrigation schemes: BVIS and the Nambuona Irrigation Scheme. Only BVIS met the stated criteria for inclusion, however dry season cultivation at BVIS is limited to ~300ha due to insufficient water resources during the dry season (M. Tarsizio, personal communication, March 17, 2016). This ~300ha area and the remainder of the Bwanje Valley were digitized, reclassified to a binary system (irrigated or non-irrigated), and rasterized to 6m to match the other model inputs. Input grids were combined in ArcMap 10.5.1 to reveal all possible combinations of breeding suitability, then categorically ranked according to presence of irrigation, land cover type, followed by likelihood of ponding.

4.7 Results

4.7.1 BVIS Breeding Suitability

Presentation of findings specific to dry season BVIS breeding suitability, including discussion of anthropogenic influence through water management during the dry season can be found in Chapter 3, section 3.3.1.2.

4.7.2 Bwanje Valley Suitability

Areas of suitable breeding for *Anopheles* mosquitoes throughout the Bwanje Valley have a distinct spatial structure. Ranking of all possible combinations of suitability and the percent of land area for each category is presented in Figure 4.8. Categorization of suitability combinations is based on presence of irrigation and land cover characteristics. Supraoptimal breeding area is most prominent within the irrigated portion of BVIS. The 'supraoptimal' classifier is a function of consistent water availability via irrigation, where surface water persists despite the absence of consistent rainfall during the dry season. Irrigated area occupies 1.78% of the Bwanje Valley. While previous literature has demonstrated an association between irrigated agriculture and the proliferation of adult stage vectors, irrigated landscapes are treated as homogeneous spatial units. Yet, even within BVIS, the map reveals that the southern portion of BVIS's irrigated space possesses a greater percentage of maximally suitable area than other parts of the scheme. These are areas of active agriculture whose situation is a direct result of water management: a greater proportion of water is directed to and subsequently confined within this area as a result of improper drainage. Non-irrigated, active agricultural areas occupy 1.1% of the Bwanje Valley. In the absence of irrigation, these would be considered the most favorable lands for dry-season mosquito breeding. Results show that roughly 25% of the Bwanje Valley is satisfactorily suitable for *Anopheles* breeding concentrated in the central portion of the area. Nearly thirty-six percent of the area is suboptimal; the highest proportion of any classified area. Twenty-five percent is unsuitable and primarily concentrated north of BVIS. For both the suboptimal and unsuitable classifications rapid loss of soil moisture due to evaporation restricts breeding potential.

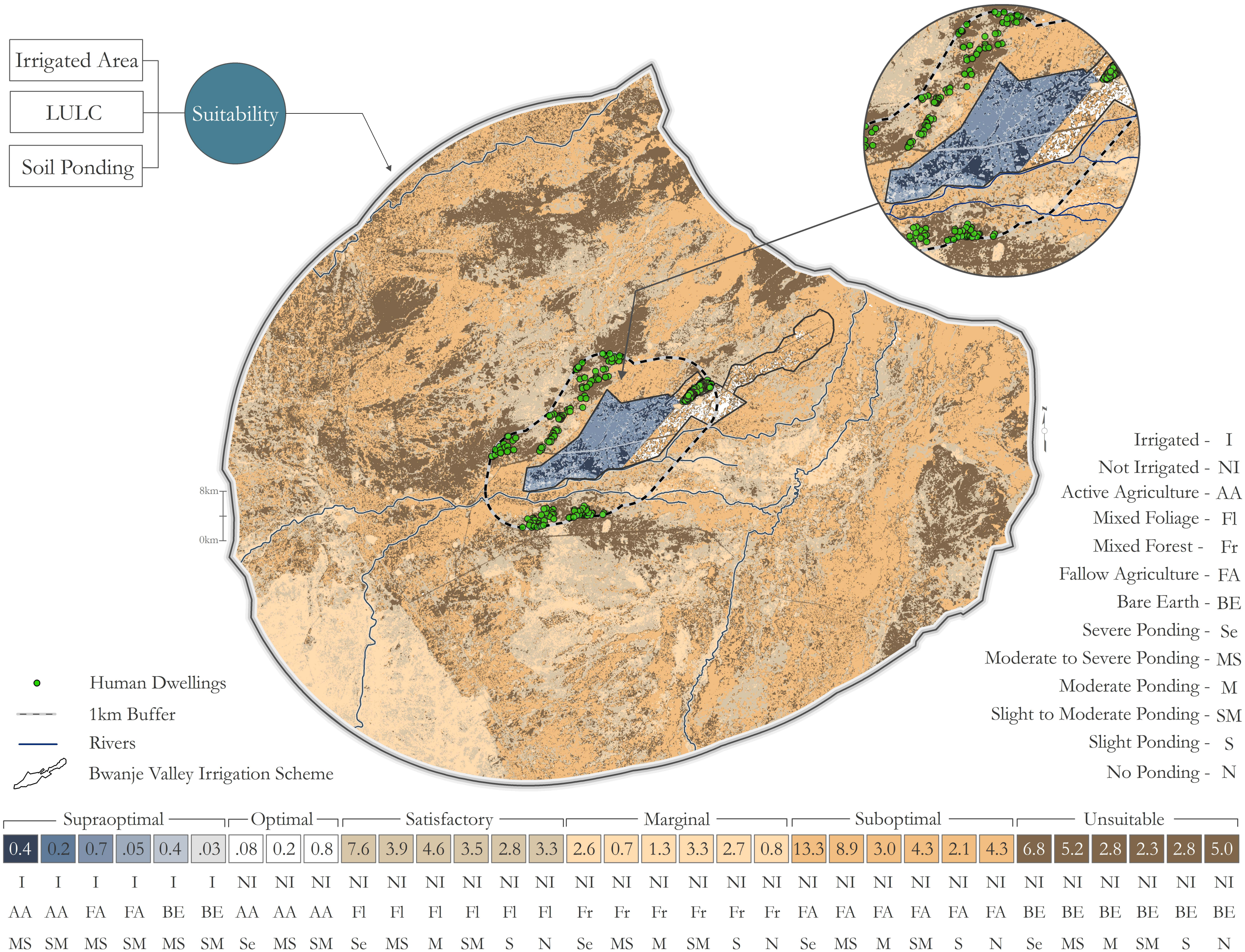


Figure 4.8: Dry season breeding scenario for the Bwanje Valley

4.8 Discussion and Conclusions

Irrigation plays a pivotal role in the distribution of suitable breeding sites for *Anopheles* mosquitoes. While environmental suitability models illustrate the extent of landscape conducive to breeding pool formation and persistence, mosquito presence and their overall fitness are also associated with the availability of plant sugar and, for females, vertebrate blood. Host specificity and preference vary widely among species of mosquitoes and may include such invertebrates as mammals, amphibians, and birds (Foster & Walker, 2009). Malaria transmission and intensity present a complex interplay of biotic and abiotic factors. As surface water availability increases across the landscape for irrigated agriculture, so too does the opportunity for female mosquitoes to lay their eggs and larvae to survive through to adult stage. For humans living in close (<1km) proximity to irrigated schemes, the density of adult *Anopheles* mosquitoes in houses will increase as females seek out human dwellings for blood feeding and resting sites. This relationship will decline with increasing distance from irrigated areas. In irrigated agricultural areas, the consistent availability of surface water for breeding during the dry season changes temporal malaria disease dynamics. For those living in close proximity to irrigated schemes, risk of malaria transmission is higher than those living further away. It is important to note that increases in mosquito populations do not necessarily increase malaria risk. There are myriad factors that affect malaria transmission including the stability of malaria transmission in areas where irrigation is introduced (Ijumba & Lindsay, 2001), housing quality, availability of anti-malarial drugs (N. J. White, 2008), economic status (Collins & Paskewitz, 1995), and the use of insecticide-treated bed nets (Mutuku et al., 2011).

In the Bwanje Valley, supraoptimal conditions for breeding during the dry season are concentrated within BVIS. Human dwellings within 1-km of BVIS were identified using Google Earth Pro 7.3.2.5776. Constantini et al. (1996) demonstrated that maximum flight distance for *Anopheles gambiae s.s.* was <1.0-km while Thomas et al. (2013) reported 1.7km. A total of 320 human dwellings are located within the area. It is expected that temporal disease dynamics for malaria will differ for those living <1km of area classified as 'supraoptimal' in comparison with population at greater distances from the scheme. For anthropophilic mosquitoes, including members of the *Anopheles gambiae* complex (Sinka et al., 2010), mosquito dispersal is short in areas of high human population densities (Carter, Mendis, & Roberts, 2000); mosquitoes will fly no further than necessary for a blood meal.

In rainfed agricultural systems, seasonal peaks in malaria transmission most often occur during the late rainy season or immediately after its conclusion. Dry season malaria transmission is limited by the reduction of inundation, or likely to become inundated areas. Malaria transmission for those 320 households within 1-km of BVIS will not experience the same level of decline in transmission as those beyond 1-km from the scheme. During the dry season, optimal breeding conditions are expected in active agricultural areas given the presence of either formal or informal irrigation measures. A notable limitation of this study is the absence of active agricultural areas located outside of BVIS. Further research on dry season modeling of breeding distribution should prioritize identifying active agricultural areas through remotely sensed or other field-based data.

Irrigated agriculture's impact on spatio-temporal malaria disease dynamics is considerable, particularly as it expands across sub-Saharan Africa to mitigate food insecurity. Agricultural growth through irrigation is often cited as a critical means for the reduction of rural poverty in Africa (You et al., 2010). As such, many African governments including Malawi have adopted policies that specifically target increasing irrigation measures (see: GoM, 2016). As intensification of irrigation continues, research is necessary to fully estimate the impact of scaling irrigated agriculture on malaria risk, particularly during dry seasons. Further, predictive modeling for mosquito suitability should not rely on assumptions that agricultural areas during the dry season are predominately fallow, thus inhibiting mosquito breeding pool formation. The addition of spatially defined irrigated spaces to predictive mosquito models for sub-Saharan Africa is imperative in light of widespread LULCC for irrigation. This is challenging in the absence of up-to-date, spatio-temporal data on irrigated lands at scale. (Thenkabail et al., 2009; FAO, 2016). The findings of this research demonstrate the asymmetrical breeding potential for *Anopheles* mosquitoes as a result of irrigated agriculture during Malawi's dry season. The introduction of irrigation to landscapes not only changes the geography of mosquito breeding, but malaria risk potential for those living in close proximity to irrigated schemes.

CHAPTER 5

5.1 Introduction

The expansion of irrigated agriculture is essential for mitigating food insecurity through increased crop production (Sajidu, Monjerezi, Ngongoro, & Namangale, 2013). While scaling irrigated agriculture has demonstrated significant boosts to crop productivity (ADB, 2013; Melaine & Nonvide, 2017) agrarian transformation of the landscape for irrigated agriculture is associated with encouraging the production of adult malaria mosquito vectors. Water is a requisite for mosquito development. As such, land use and land cover changes (LULCC) that alter the distribution and flow of water across the landscape can have profound impacts on the epidemiology of malaria. Keiser et al. (2005) highlight that as much as 90% of the global malaria problem can be attributed to environmental factors including the establishment of irrigated schemes. Irrigation for crop production encourages the development of significant populations of malaria disease vectors (Sissoko et al., 2004) and pathogen transmission through a number of pathways. First, through the development of vector habitat and the production of adult stage mosquitoes (Van Der Hoek 2004; Mutero et al. 2004). Further, intensification of agriculture involves a significant change to the natural landscape occurring across areas, altering vegetation and extending the spatial distribution of surface water across the landscape. Likewise, irrigation can promote vector longevity by significantly increasing relative humidity over large areas (Secretariat & WHO, 1996). Collectively, landscape modifications for irrigated agriculture have the potential to both promote diversity of breeding sites and reduce predation of vectors (Sutherst, 2004). Further, environmental and ecological changes for irrigated agriculture can increase the frequency of human-vector contact thereby encouraging transmission (Secretariat & WHO, 1996).

Studies on relationship between irrigated agriculture and malaria are well documented in the literature and show divergent conclusions. In some studies, malaria incidence has increased (Afrane et al., 2004; Ghebreyesus et al., 1999; Guthmann, Llanos-Cuentas, Palacios, & Hall, 2002; Jaleta et al., 2013; Keiser, Caldas, et al., 2005; Kibret et al., 2010; Kobayashi et al., 2000; Urama, 2005). Contrastingly, other studies have shown a decrease or no change of infection (Assi et al., 2013; Diakité et al., 2015; Faye et al., 1995; Ijumba, Mosha, & Lindsay, 2002; Klinkenberg, Van Der Hoek, & Amerasinghe, 2004; Mutero et al., 2004). The contradictory nature of such studies suggests the necessity for further investigation on the impact of irrigated agriculture on malaria transmission particularly in light of continued emphasis on expansion throughout malaria endemic areas to meet crop production demands. In this chapter, probable changes to the spatial epidemiology of malaria in Malawi are described through analysis of habitat suitability for *Anopheles gambiae s.s.* mosquitoes, the extent of malaria prevalence, and proposed spatial expansion of irrigated sites through Malawi's Green Belt Initiative.

5.2 Methods

The impact of scaling irrigated agriculture on the spatial distribution of malaria risk potential was determined from: (1) Historical examination of irrigation development, irrigation's current (2015) spatial extent, and intended extent of irrigated sites in Malawi; (2) Habitat suitability for *Anopheles gambiae s.s.* mosquitoes assessed through creation of a Habitat Suitability Model (HSM) in Google Earth Engine (GEE); and (3) Malaria prevalence data from the Demographic and Health Surveys (DHS) Malaria Indicator Survey (MIS) at the cluster level for 2012, 2014, and 2017. The conceptual framework for this study is presented in Figure 5.1.

5.2.1 Irrigated Agriculture in Malawi

5.2.1.1 Irrigation Development and National Policy Frameworks

Expansion of irrigated agriculture in Malawi has occurred against the backdrop of national policy frameworks often tied to strategies to increase agricultural productivity as a means of poverty reduction and economic growth. Historically, Malawi has experienced considerable oscillations in economic growth due in part to external shocks and policy implementation (IMF, 2017). A strongly agrarian society, agriculture is fundamental to economic performance and contributes nearly 30% of annual GDP (Giertz, Caballero, Dileva, Galperin, & Background, 2015). In addition, nearly 80% of the total workforce is employed by the agricultural sector (GoM, 2010). It is unsurprising then that historical development strategies to improve the socio-economic status of the country have emphasized increasing agricultural productivity including through scaling irrigation measures.

Shortly after independence in 1964, the Government of Malawi (GoM) began setting out sectoral strategies and objectives for economic growth through 10-year 'Statement of Development Policies' (DEVPOL and DEVPOL II) (IMF, 2017; Record, 2007). Together, the DEVPOLS aimed at achieving an 8% annual economic growth rate through increasing agricultural productivity, shifting economic activity to the central region, increasing local participation in the economy, and eliminating foreign aid dependence (Record, 2007). Economic growth eventually faltered in the early 1980s after a series of external shocks (National Economic Council, 2000). As a counter measure, Malawi entered into structural adjustment loan negotiations with the IMF and World Bank (IMF, 2017) ultimately implementing structural adjustment programs wherein the Policy Framework Paper (PFP) was designed for executing medium-term economic policies (National Economic Council, 2000).

By January 1996, the GoM began developing Vision 2020 in response mounting concerns over a need for long-term strategy for development management (National Economic Council, 2000). Vision 2020 serves as the overarching framework for formulation, implementation, and evaluation of short and medium-term plans to achieve Malawians long-term Vision for the country. That is, "*By the year 2020*, *Malawi, as a God-fearing nation, will be secure, democratically mature, environmentally sustainable, self-reliant with equal opportunities for and active participation by all, having social services, vibrant cultural and religious values and a technologically driven middle-income economy*" (National Economic Council, 2000, pg 27). The Vision 2020 was launched in 2000. Four medium-term national development strategies were formulated to attain the Vision 2020: the Malawi Poverty Reduction Strategy Paper (MPRSP) and the Malawi Growth and Development Strategies (MGDS I; MGDS II; MGDS III) (GoM, 2017).

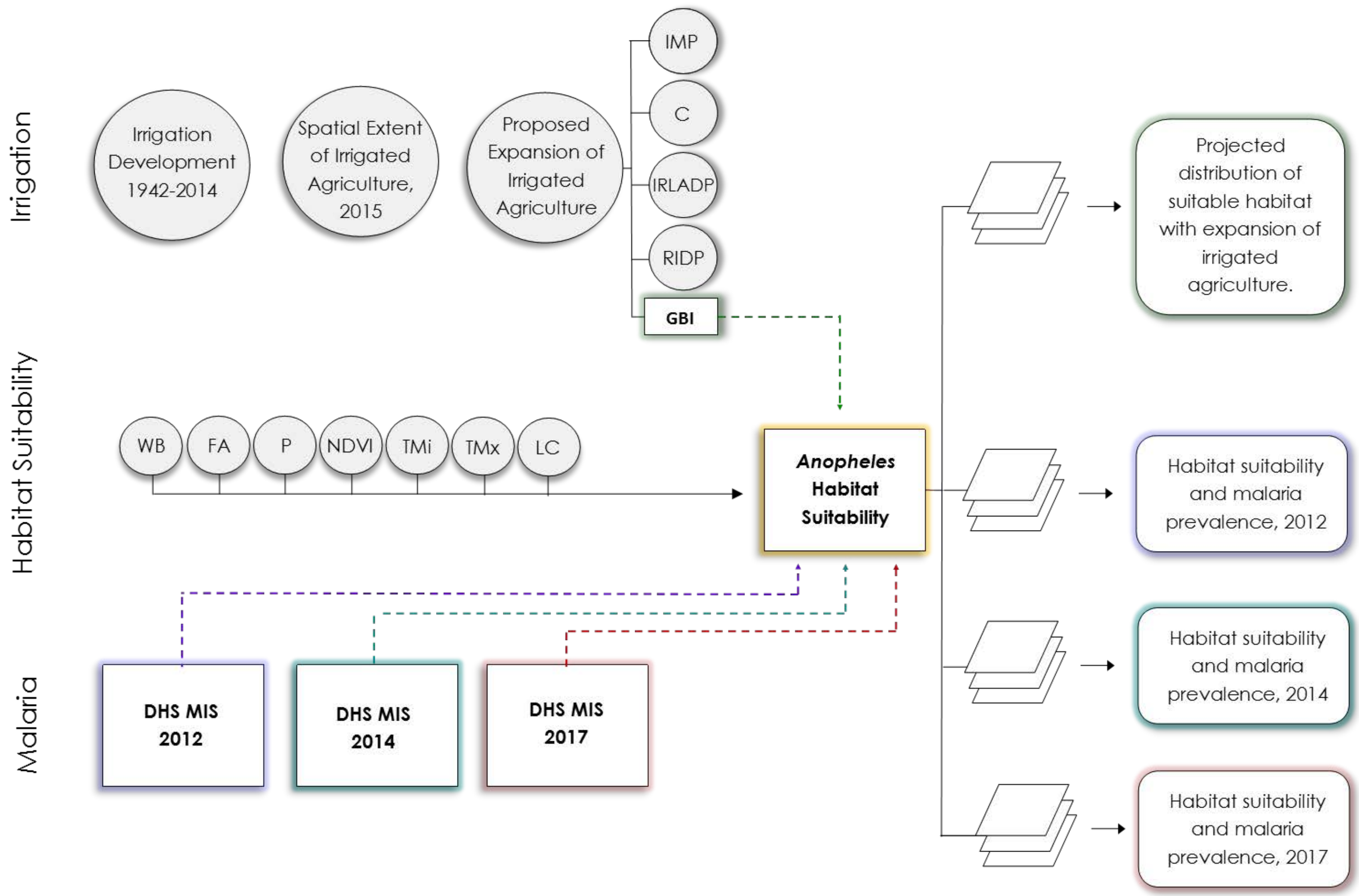


Figure 5.1: Conceptual framework

Strategies to increase agricultural productivity through promotion of irrigated agriculture are outlined in each including, drainage of marshlands for irrigation, construction of small- medium- and large-scale irrigation schemes, construction of multi-purpose dams, rehabilitation of existing irrigation schemes and dams, establishing piped water systems, and developing areas with irrigation potential (GoM, 2002; 2006; 2011; 2017).

Aligned with Vision 2020, the GoM produced the National Irrigation Policy and Development Strategy (NIPDS) in June 2000 as a comprehensive policy to guide irrigation development (GoM, 2000a). The document outlined both policy and development objectives for the irrigation sector. Policy objectives emphasized poverty alleviation, increasing and enhancing food security, creating enabling environments for irrigated agriculture through private sector investment, optimizing government investment in irrigated agriculture, facilitating effective research in irrigation technology, and a focus on competitive financing for irrigation projects along with improvement of marketing systems. To meet these policies, eight development strategies were outlined, notably increasing land area under irrigation so that up to 15% of irrigable land was being effectively utilized. Further, under the NIPDS, government support of the existing sixteen government-run smallholder irrigation schemes was meant to be transferred to farmer's organizations (Ferguson & Mulwafu, 2005). Overall, the goal for irrigation development was to increase incomes and commercialization of the irrigation sector (NIPDS, 2000). By 2016 irrigation potential in Malawi remained largely unexploited (NIP 2016; GoM 2015). In response, the GoM revised the NIPDS. The National Irrigation Policy (NIP) 2016 was formulated as an extension of the NIPDS that includes policies, plans, and monitoring and evaluation systems to ensure sustainable economic growth based on potential for the irrigation sector (NIP, 2016). Objectives are aligned with the MGDS II, Comprehensive African Agriculture Development Program (CAADP), and Sustainable Development Goals (NIP, 2016).

An additional policy effort to meet agricultural growth and poverty reduction goals under the MGDS II is the Agricultural Sector Wide Approach (ASWAp). The ASWAp was developed in 2010 as a priority investment program intended to support activities in the agricultural sector from 2011-2015 (GoM, 2010). Strategies for increasing agricultural productivity are grouped by focus area and include, 'Food Security', 'Commercial agriculture, agro-processing and market development', and 'Sustainable Management of Natural Resources' (GoM, 2010). The 'Sustainable Management of Natural Resources' strategy focuses on sustainable land and water utilization through better water use efficiency and expanding irrigated agriculture through the Green Belt Initiative (GoM, 2010). Figure 5.2 illustrates Malawi's national frameworks associated with irrigation expansion within the Agriculture, Economic, and Irrigation sectors. Together these frameworks work to achieve Malawi's Vision 2020.

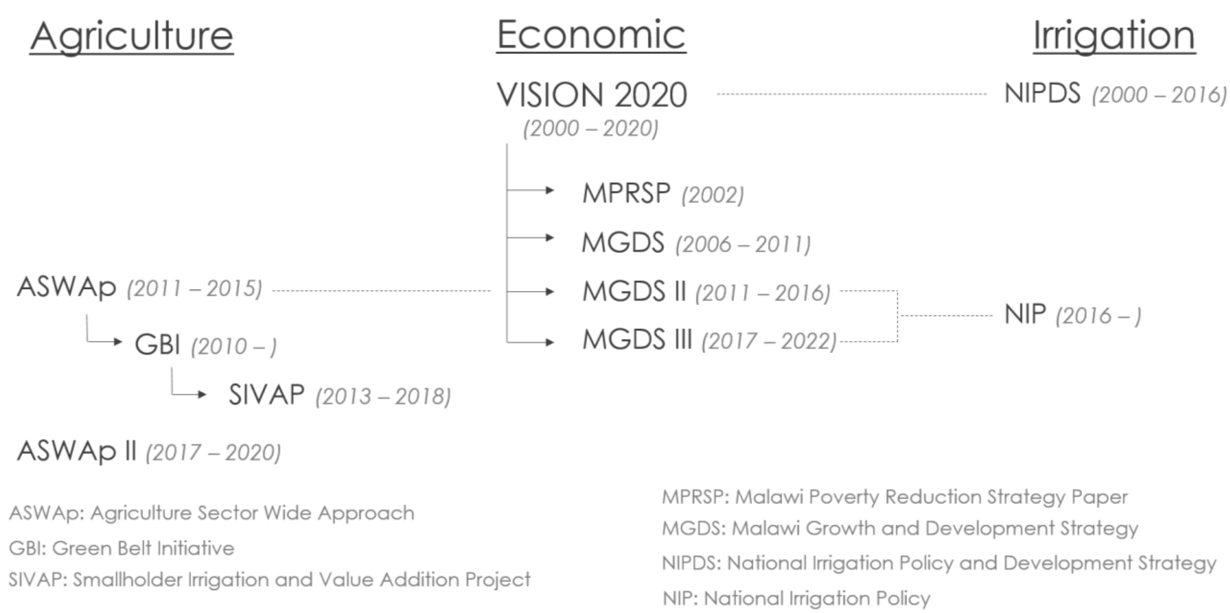


Figure 5.2: Malawi's national frameworks associated with irrigation expansion within the Agriculture, Economic, and Irrigation sectors.

5.2.1.2 Irrigation Development in Malawi

Irrigation development in Malawi is conducted by the public and private sectors, though historically has been predominately spearheaded by the ministry of Agriculture, Irrigation, and Water Development (GoM, 2012b). Public irrigation development generally targets smallholder farmers and focuses on irrigating food security crops, namely rice (World Bank, 2011). Private sector schemes operate at larger scales producing cash crops for the export market (FAO, 2005). Donor financing for irrigation has been provided through a variety of investors including the World Bank, the African Development Bank, the Japanese International Cooperation Agency (JICA), the United States Agency for International Development (USAID), the Arab Bank for Economic Development, and the Government of India (GoM, 2012b).

The systematic development of irrigation schemes in Malawi began in the 1940's under colonial rule as a means of promoting irrigation farming and modernizing peasant agriculture (Gwiyani-Nkhoma, 2005). Prior to this period irrigation farming was limited. Peasant farmers practiced flood cropping and dimba irrigation for vegetables, maize, and rice (Gwiyani-Nkhoma, 2005). Dimba gardens are small plots bordering rivers that are cultivated using residual moisture. White settlers practiced irrigation for the production of tobacco (Gwiyani-Nkhoma, 2005). The colonial government's promotion of small-holder irrigation schemes was the result of several factors including the 1948/9 drought and famine. Irrigated agriculture practices were viewed as adaptive strategies for mitigating such disasters. In addition there was an increasing desire to promote rice production (Gwiyani-Nkhoma, 2005).

Established in 1949, the Limphasa Rice Irrigation Scheme was the earliest colonial irrigated scheme in Malawi (FAO, 2005; Gwiyani-Nkhoma, 2005). Limphasa spanned 700 acres and was located in the Limphasa Dambo within the Nkahata Bay District (Nkahoma, 2005). Additional irrigation projects undertaken during the colonial period were the Shire Valley Project (1952-1979), Phalombe-Chilwa Development Project (1952), and the Njala Rice Scheme (1957) (Gwiyani-Nkhoma, 2005). During the post-colonial period of 1967 and 1982, 16 schemes were constructed (Chirwa, 2002; Gwiyani-Nkhoma, 2011) with a total irrigable land area of 3600ha (FAO, 2005) (Figure 5.3). Designed to increase rice production and train farmers in irrigation farming, the schemes are located along the shores of Lake Malawi, (Karonga, Nkhata Bay, Nkhota Kota) the Lake Chilwa Basin, and the Lower Shire (FAO, 2005; Gwiyani-Nkhoma, 2011).

The 1970's and 1980's were a period of disappointing performance for irrigation in sub-Saharan Africa (Woodhouse et al., 2017). Gwiyani-Nkhoma (2011) reports the failure irrigation farming during this time period stemmed from overdependence on donor funding, lack of local ownership of resources and land alienation, community displacement, failure of the government to consider local context and circumstance during development, and the adoption of structural adjustment policies. It wasn't until the late 2000s that bilateral and other international funders began reinvesting in irrigation and water management (Woodhouse et al., 2017). Expansion of irrigation for Malawi's smallholders during the same period was limited, from 3473ha in 1982 (Gwiyani-Nkhoma, 2005) to 8,255ha in 2002 (Nyondo, 2016). By 2005, irrigated area for smallholder agriculture nearly doubled to 15,988ha (GoM, 2012a). Contrastingly, expansion of irrigation for estate schemes faltered, only increasingly by 225ha during the same period to a total of 48,360ha in 2005 (GoM, 2012a; Nyondo, 2016). Since 2005, irrigation development has been steadily increasing annually for smallholders to 47,611 ha reported in 2015 (GoM, 2015b). The statistics for area under irrigation for estate schemes show only a slight increase from 48,360 ha in 2005 to 52,498 ha (GoM, 2015b).

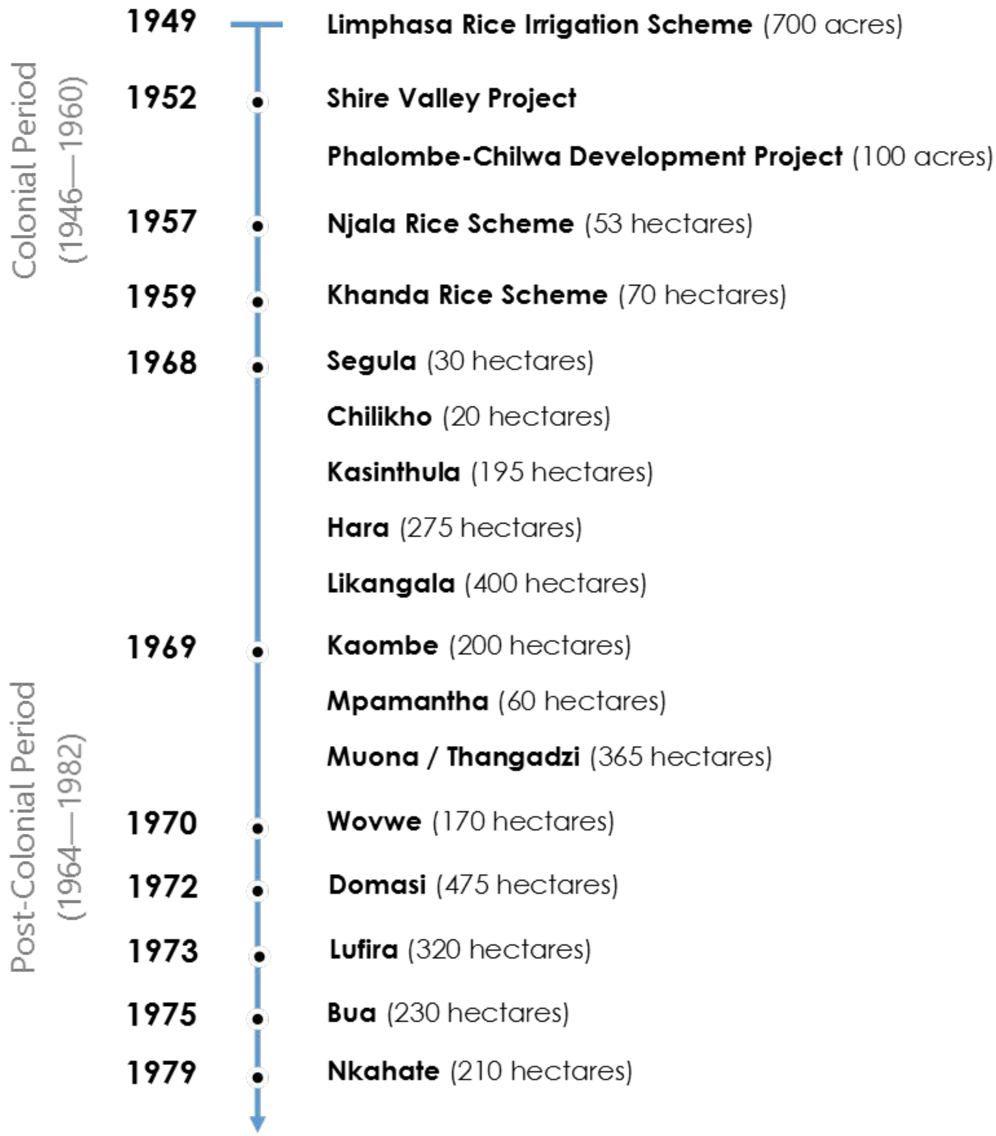


Figure 5.3: Timeline of expansion of irrigated agriculture in Malawi (1949-1979)

5.2.1.3 Spatial Extent of Irrigated Agriculture in Malawi (2015)

The GoM released the Irrigation Master Plan and Investment Framework (IMP) as a comprehensive framework to assist stakeholders in sustainable development and expansion of irrigation in 2015 (2015-2035). Funded by the World Bank, the IMP was developed for the Department of Irrigation as a part of the Irrigation, Rural Livelihoods and Agricultural Development Project (2005-2015) (IEG, 2015). Preparation of the IMP was conducted from November 2013-December 2104 (IMP, 2015). The IMP represents a significant milestone for the Department of Irrigation. It is the nation's first irrigation master plan including a comprehensive inventory of irrigation schemes (IEG, 2015). Previously, discrepancies in reporting of total land area under irrigation have been reported (World Bank, 2010). The IMP is Malawi's first repository of spatially referenced information for irrigated schemes.

Production of the IMP's scheme repository followed a multi-step process owing to previous data inconsistencies (GoM, 2015b). Scheme locations from the 'Small Scale Irrigation Development Study' were uploaded and verified through visual analysis with satellite imagery. To mitigate inconsistencies in location and scheme size, each district supplied one representative to work alongside a GIS specialist to verify location and size of schemes using Google Earth (GoM, 2015b).

The IMP reported land area for irrigation totaled 104,298 ha; 47,611 ha private estate and 56,687 for smallholders by the end of 2014. Appendix 5 of the IMP provides an inventory of existing schemes allocated by type, formal or informal. Formal schemes include estate schemes and those whose development involved some form of engineering design and construction and in some cases schemes that evolved though farmer-constructed diversion structures (GoM, 2015b). Formal schemes are further divided by size (mini, small, medium, and large) and operation (farmer organization or private). Table 5.1 presents a summary of existing schemes.

The agricultural sector in Malawi consists of two primary sub-sectors, estate and smallholder, which contribute 30 and 70 percent respectively to national AgGDP (GoM 2016). Estate schemes are large-scale farming operations whose products are produced almost exclusively for the export market (FAO, 2005). The primary estate-grown crops are sugar, tea, coffee, and tobacco (GoM, 2015c). Fifty-seven estate schemes are located within thirteen districts in Malawi. The largest proportion of total schemes cultivate tea (37%), but 77% of estate scheme's total land area is dedicated to sugar (43,414 ha). Roughly 75% of estate schemes utilize sprinkler irrigation. Other technologies include pumping (8%), central pivot (7%), dams (3%), or drip irrigation (1%) alone or in combination.

Between 2006 and 2014, irrigated land for smallholder farming increased by almost 300% across Malawi (GoM, 2015c). Over 96% irrigated schemes are categorized as 'smallholder' operating predominately by gravity-fed (56%) or treadle pump (29%) irrigation. Other technologies include watering cans (7%) and motorized pumping systems (8%) (GoM, 2015b). Small-scale irrigation schemes predominately cultivate green maize, rice, and an assortment of horticultural crops including sweet potato, leafy vegetables, tomato, and onion (GoM, 2015c). Cropping patterns vary by farmer and include intercropping, mono-cropping, and raised beds.

Data for formal and informal schemes were reviewed for duplicate entries and accurate spatial reference information. One hundred-six duplicate entries were removed from the dataset, predominately within the Mzimba district. Data tabulation yielded 1596 irrigation scheme records; 1370 informal schemes and 226 formal schemes. Spatial reference information was missing for 324 schemes including the entire Nkhotakota district. To account for these schemes locations, the IMPs district maps were georeferenced. All georeferencing and visualization was conducted in ArcMap 10.5.1™. Malawi's existing irrigation schemes by Irrigation Service District (ISD) are presented in Figure 5.4.

Table 5.1: Summary of existing schemes by typology and hectarage

Irrigation Service District	District	Informal schemes	Formal schemes	Informal schemes (ha)	Formal schemes (ha)	Total scheme (ha)
Chikwawa	Chikwawa	74	3	4103	26451	30554
	Nsanje	14	3	542	1100	1642
Blantyre	Blantyre	19	0	259	0	259
	Chiradzulu	3	0	26	0	26
	Mulanje	37	13	318	1032	1350
	Mwanza	15	0	145	0	145
	Neno	5	1	27	150	177
	Phalombe	19	1	461	20	481
	Thyolo	36	9	680	1223	1903
	Balaka	52	4	409	2283	2692
Machinga	Machinga	56	7	2086	867	2953
	Mangochi	62	6	3436	713	4149
	Zomba	67	6	3189	2086	5275
Lilongwe	Lilongwe	190	76	1905	9568	11473
	Ntcheu	33	12	2851	994	3845
	Dedza	93	48	1384	1285	2669
Kasungu	Kasungu	25	0	177	0	177
	Dowa	89	2	3488	165	3653
	Ntchisi	27	1	670	60	730
	Mchinji	19	5	108	26	134
Salima	Salima	5	2	59	112	171
	Nkhotakota	24	15	397	17127	17524
Mzimba	Mzimba	196	0	6223	0	6223
	Nkhata Bay	43	2	598	535	1133
	Rumphi	88	6	1330	439	1769
Karonga	Karonga	26	4	927	989	1916
	Chitipa	53	0	1276	0	1276
		1370	**226**	**37074**	**67225**	**104299**

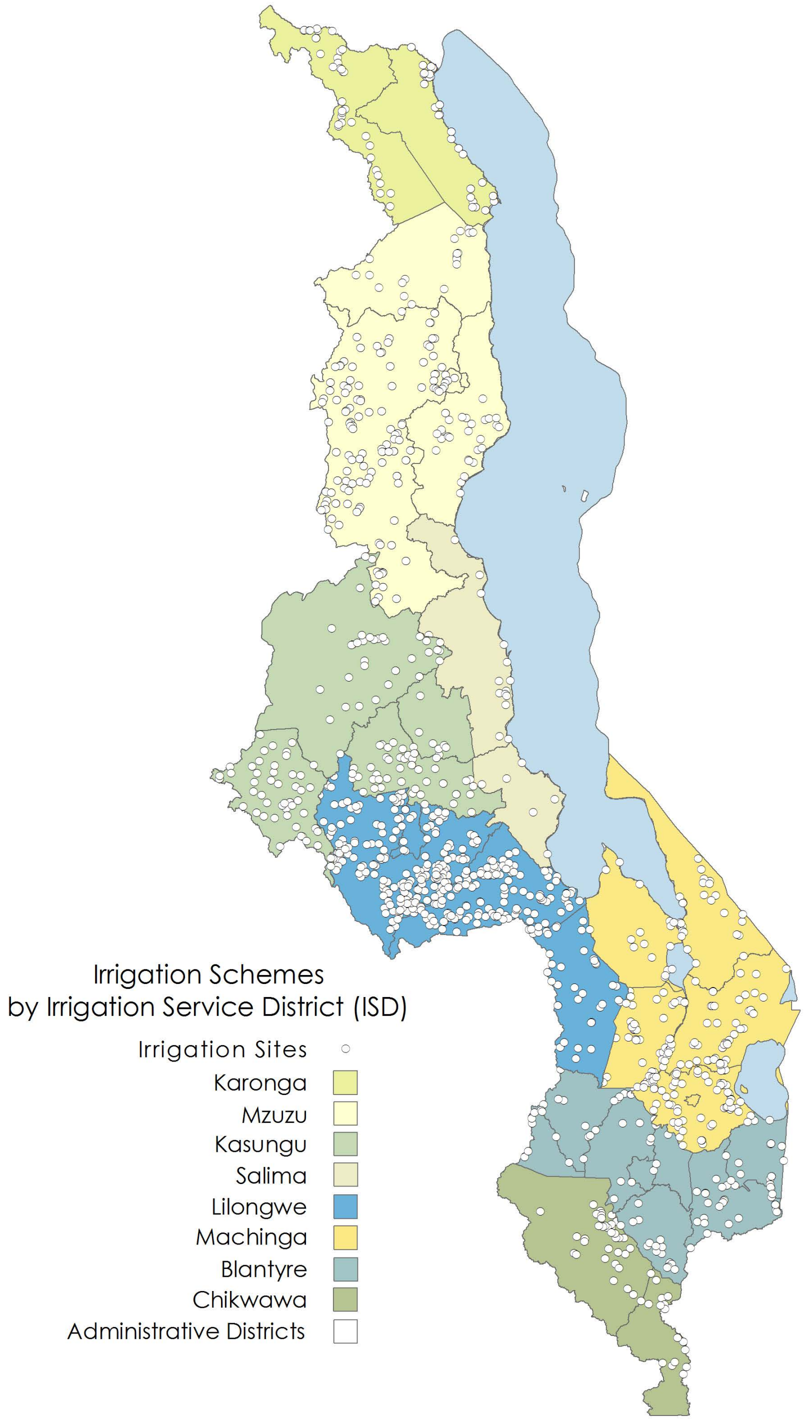


Figure 5.4: Spatial Extent of Irrigated Agriculture in Malawi (2015)

5.2.1.4 Expansion of Irrigated Agriculture

The possibilities for irrigation development in Malawi are considerable: potential irrigable land is roughly 400,000 hectares of which only 104,298ha have been developed (GoM, 2015b, 2015a). The

IMP aims to increase irrigable area to 220,000 hectares by 2035 through a combination of expanding existing schemes, working to develop schemes previously identified and at various stages of feasibility, and identification of additional schemes (GoM, 2015b). Statistics for existing, considered, and potential irrigation schemes are presented Table 5.2. These gains will be in initiated in three phases: (1) 20,000 hectares; (2) 28,500 hectares; and (3) 67,500 hectares. The total cost of the IMP is projected to be roughly $2.0 billion USD over 20 years. Given the financial challenge this presents to the GoM, financing options include: (1) the GoM development budget; (2) development partners; (3) international investment banks and equity funds; (4) private agribusiness companies; and (5) individual farmers.

Table 5.2: Existing, considered, and new irrigation schemes under the IMP (Data Source: Irrigation Master Plan and Investment Framework, 2015)

Scheme Type	**Area (ha)**	**Potential Increase (ha)**	**Future Increase (ha)**
Existing Schemes			
Estate	47,5000	22,500	70,000
Smallholder	56,500	23,500	80,000
Sub-Total	**104,000**	**46,000**	**150,000**
Considered Schemes			
Shire Valley	22,000	0	22,000
Commercial estates	8,500	200	8,700
Chikwawa (GBI)	6,300	0	6,300
On-going DOI Schemes	6,000	0	6,000
PRIDE Schemes	4,000	0	4,000
Songwe River	3,000	0	3,000
Sub-Total	**49,800**	**200**	**50,000**
New Potential Schemes			
Dambo	41,700	20,3000	62,000
Other new schemes	24,500	0	61,000
Future Lake Pumping	0	62,000	62,000
Sub-Total	**66,200**	**118,800**	**185,000**
Total	**220,000**	**165,000**	**385,000**

Potential irrigation schemes are divided into five types: Irrigation Master Plan Potential Irrigation Schemes (IMPPIS), Considered Schemes, Rural Infrastructure Development Program (RIDP) II, or Irrigation, Rural Livelihoods and Agricultural Development Project (IRLADP), and Green Belt Initiative (GBI) Schemes (Figure 5.5). The IMPPIS were selected using Multi-Criteria Decision Analysis (MCDA) assessed at the Water Resource Area (WRA) level. Ranking parameters for the MCDA included geophysical suitability, market orientation and linkages, economic viability, environmental acceptability, stakeholder support, and land tenure systems. There are 85 IMPPIS and four Considered Schemes. Considered Schemes were previously selected by the Department of Irrigation prior to the IMP. There are 10 RIDP II schemes previously identified under the RIDP Project. The RIDP Project aims to reduce dependency on rain fed agriculture, diversify cropping, mitigate vulnerability to drought, and enhance rural income and food security. The IRLADP schemes include 12 schemes previously identified by the Irrigation Rehabilitation and Development and Catchment Conservation (GoM, 2015b).

The GBI was introduced in 2010 in direct response to criticisms of the Farm Input Subsidy Program (FISP) (Chinsinga, 2017). While FISP has been described as, "one of the most ambitious and successful assaults on hunger in the history of the African continent" (Denning et al., 2009) many international donors were skeptical that FISPs achievements were largely circumstantial given favorable climatic patterns (Chinsinga, 2017; Chinsinga & Chasukwa, 2012). Further, questions arose on efficiency and effectiveness of inputs along with long-term affordability (Chinsinga & Chasukwa, 2012). In response, the GoM implemented the GBI with the objective of, "us[ing] available water resources to increase agricultural production, productivity, incomes and food security at both household and national levels, and to spur economic growth and development through development of small and large scale irrigation and maximization of rain-fed agricultural practice" (Chinsinga & Chasukwa, 2012). The seven major components of the GBI are: (1) Crops, Livestock, and Fisheries

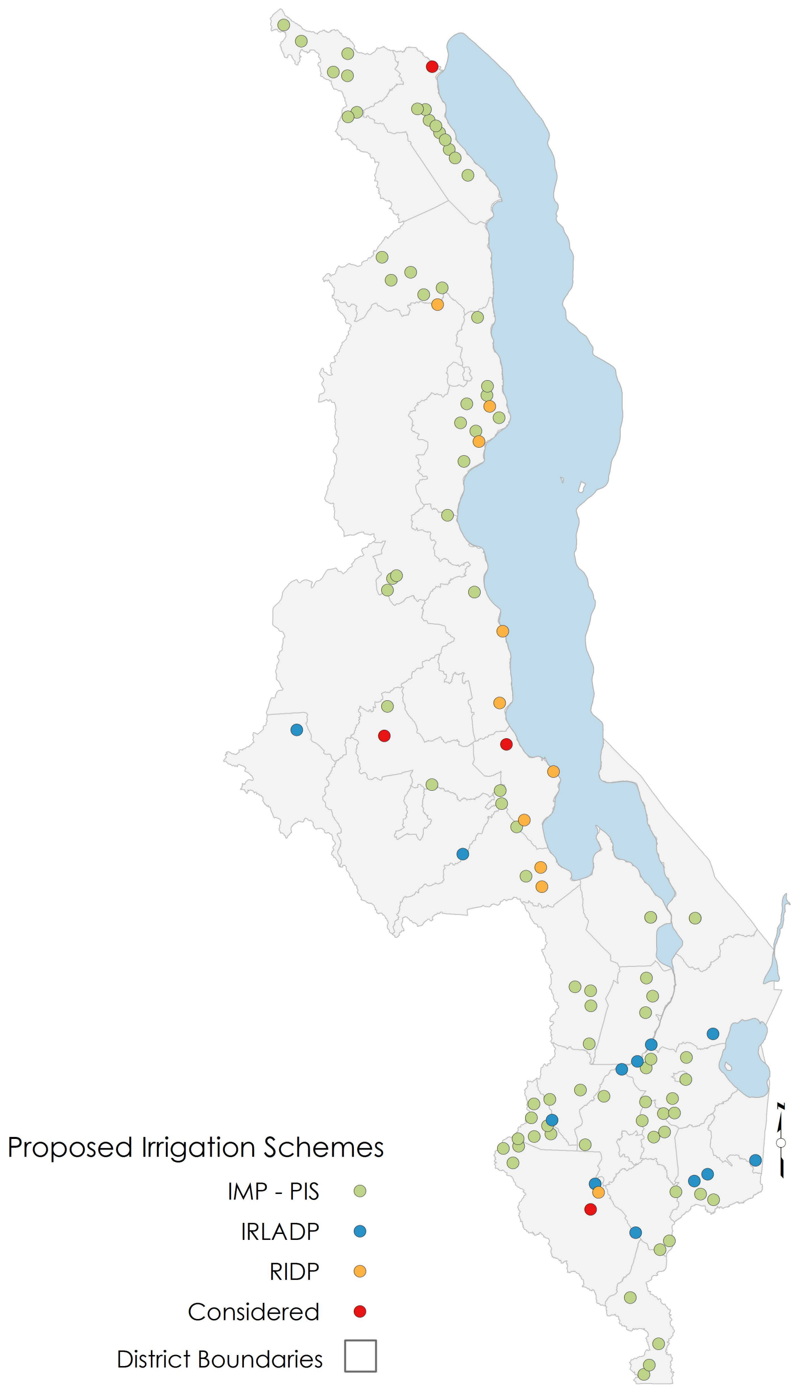


Figure 5.5: Malawi's proposed irrigation schemes, by type.

Development; (2) Infrastructure Development and Rehabilitation; (3) Land Administration; (4) Environmental Management; (5) Technology Development and Dissemination; (6) Institutional

Development and Capacity Building; and (7) Agro-processing and Market Development (GoM, 2015b).

Under the GBI, large tracts of land all within 20km of Malawi's three lakes and thirteen perennial rivers have been offered to local and foreign investors in an effort to increase irrigable area to 1 million hectares (Chinsinga & Chasukwa, 2012; GoM, 2015b). The 25 conceptual GBI site locations are presented in Figure 5.6; many of whose area overlaps with those proposed sites presented in the IMP. Since the GBI's inception, progress has been slow owing to financial constraints, lack of political will, and land acquisition issues (Mkwanda, 2017). By 2015, only four potential scheme locations had been thoroughly assessed owing to financial restrictions. One in Chikwawa, Salima, Mangochi, and Karonga (GoM, 2015b).

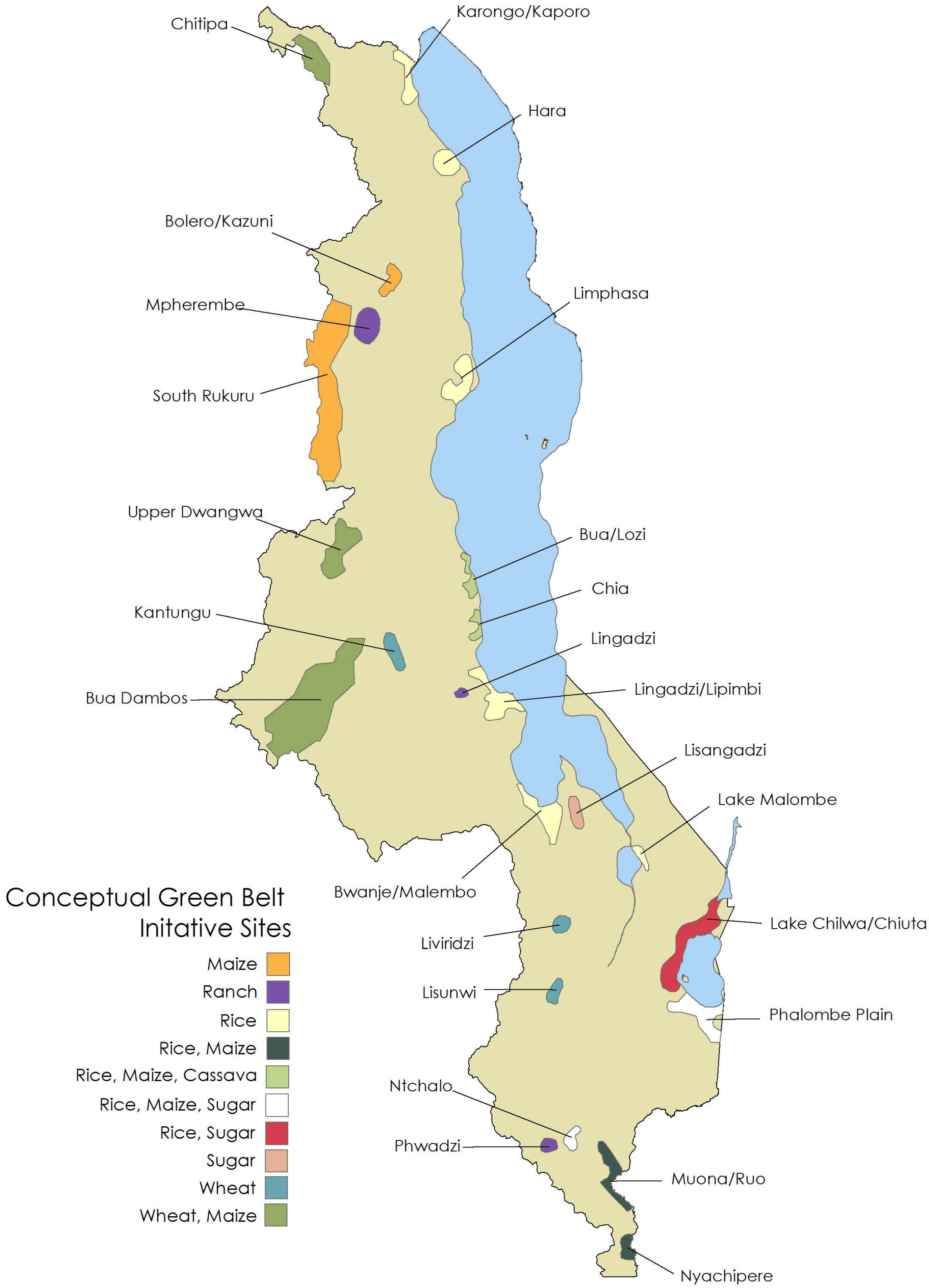


Figure 5.6: Proposed Green Belt Initiative Sites including intended crop types. Total area for proposed irrigation across GBI sites is nearly 1,000,000ha.

5.2.2 Modeling Habitat Suitability for Mosquitoes

Ecological Niche Theory (Grinnell 1917) contends that species' fitness is directly linked to environmental conditions. As such, Habitat Suitability Models (HSMs) are 'operational applications of ecological niche' (Hirzel & Le Lay, 2008) where predictions of a target species likelihood of spatio-temporal occurrence are determined based on environmental characteristics (Hirzel & Le Lay, 2008). Predictive models of species distribution provide valuable, cost effective information to end users for myriad applications including environmental management, risk awareness, and conservation. Likewise, for testing the effect of climate change on species distributions (Dueri, Bopp, & Maury, 2014). Predictions of human risk exposure to infectious disease vectors using HSMs have been performed for several vector species including ticks (Johnson et al., 2016), triatomines (Sarkar et al., 2010), and mosquitoes (Ayala et al., 2009).

In an era of big data, the availability of satellite-derive global climate, terrain, and land cover datasets presents an opportunity for modeling the suitability of malaria disease vectors across geographies and time scales. Leveraging Google Earth Engine, a raster-based dynamic mosquito suitability model was constructed at a 250-m spatial resolution. The model's intended outcomes are 1) assist in identification of predicted locations of mosquito species for spatially targeted control efforts; and 2) produce an open-source, agile model for end users to model distributions of any mosquito species, across any geography, with or without extensive knowledge of working with geospatial datasets. For the purposes of this study, the model is parameterized for the malaria vector, *Anopheles gambiae s.s.* in Malawi for 2012, 2014, and 2017 to coincide with Demographic and Health Surveys (DHS) Malaria Indicator Survey (MIS) years.

Malaria is a considerable public health issue in Malawi (DHS, 2017) and is vectored by three principle mosquito species: *An. gambiae s.s.*, *An. arabiensis* and *An. funestus* (Chavasse, 2002). *An. gambiae s.s.* is the most efficient of the three vectors in transmitting malaria (Coetzee, 2004) and belongs to the *Anopheles gambiae sensu lato (s.l.)* complex. The *An. gambiae s.l.* complex comprises seven morphologically, indistinguishable sibling species: *An. gambiae sensu stricto (s.s.)*, *An arabiensis*, *An. quadriannulatus* species A, *An. quadriannulatus* species B, *An. melas*, *An. merus*, and *An. bwambae* (Bass, Williamson, Wilding, Donnelly, & Field, 2007). The geographical distribution of *An. gambiae s.s.* is widespread across sub-Saharan Africa, though predominately concentrated along 10°N latitude and between 10-20°S latitude in Tanzania, Malawi, Mozambique, and Zambia (Wiebe et al., 2017). Over time, the *An. gambiae s.s.* species diverged into two strains, Mopti (M) and Savannah (S), but is often considered a singular species in the literature (Becker et al., 2003). For this reason, *An. Gambiae s.s.* is modeled as a single species in this study, rather than the specific M and S forms.

5.2.2.1 GEE

Google Earth Engine (GEE) is an open-source, cloud based platform designed for users to access and process their own private data, or data from GEE's multi-petabyte geospatial catalog (Gorelick et al., 2017). Users access GEE through an application programming interface and associated web-based interactive development environment. While traditional methods of data storage and analysis may preclude users from storing, managing, and processing very large geospatial datasets, GEE removes these barriers, allowing users to more readily process data and disseminate their results (Gorelick et al., 2017). For a complete review of the GEE platform, including system architecture and data distribution models see Gorelick et al., (2017). The GEE platform was selected for model construction to ensure that the widest possible audience of end users could access and use the model without limitations related to data storage or computational processing power.

5.2.2.2 Habitat Suitability Modeling Methods

5.2.2.3 Model Construction

To determine the spatio-temporal distribution of *An. gambiae s.s.* mosquitos, a raster-based dynamic species distribution model was constructed in GEE that uses abiotic and biotic variables specific to the species biological requirements (Table 5.3). Suitable areas are defined as those which encourage the creation and persistence of breeding sites for oviposition. Parameter thresholds for each of the input variables were selected on the basis of literature review and are described in the following section. Given the importance of model flexibility for end-users, parameter thresholds are adjustable based on users' unique knowledge of the target species and study area. Customizable variable thresholds are available for start and end year, temperature minimum (Tmin) and maximum (Tmax), NDVI, precipitation percentile, and flow accumulation percentile. Beyond identifying suitable areas, the model provides fine-resolution explicit information on the drivers of suitability. This function allows users to investigate not only the geography of suitable areas, but what variables, or combinations of variables encourage or restrict the likelihood of the species inhabitation across space. To do so, predictor variables are partitioned into three categories: climate, land, and water.

5.2.2.3.1 Predictor Variables

Table 5.3: Predictor variables, data sources, resolutions, and threshold variables for model construction

	Data Sources	Product	Spatial Resolution	Temporal Resolution	Threshold Value
Temperature	NASA MODIS	MOD11A2.006	1-km	8-day	Min: 18°C Max: 32°C
NDVI	NASA MODIS	MOD13Q1.006	250-m	16-day	>=.30
Land Cover	NASA MODIS	MCD12Q1.006 MCD12Q1.051	500-m	Annual	See table 5.3
Precipitation	UCSB Climate Hazards Group	CHIRPS Pentad	~5-km	Pentad	>50% Max: 3200mm
Flow Accumulation	WWF	HydroSHEDS	15 arc seconds	-	>=25%
Water Bodies	JRC	GSW1_0	30m	-	

5.2.2.3.1.1 Climate

Temperature

Temperature is critical to mosquito life-history (Beck-Johnson et al., 2013; Lyons, Coetzee, & Chown, 2013; Shapiro, Whitehead, & Thomas, 2017). During aquatic life stages, higher ambient temperatures encourage faster development, but have also been shown to cause declining larval survivorship. Likewise, rising environmental temperature significantly increases adult mortality (Christiansen-Jucht, et al. 2014). Bayoh & Lindsay (2004) demonstrated that the upper and lower temeprature thresholds for *An. gambaie s.s.* larval development were 18°C and 32°C. At higher (38-40°C) or lower (10-12°C) temperatures, larval survivorship was shortened significantly. Throughout most of sub-Saharan Africa, larvae may regularly experience high temperatures, particularly during dry seasons, though in some cases only for a limited number of hours during the day. To cope, larvae will dive down away from the water surface (Hauf &Burgess, 1956) or move into shaded areas of breeding pools (Foley et al 2002).

Temperature thresholds for TMin and TMax are set to 18°C and 32°C, respectively (Bayoh & Lindsay, 2004). Data were acquired from the Moderate Resolution Imaging Spectroradiometer (MODIS) Terra Land Surface Temperature and Emissivity 8-Day Global dataset (MOD11A2) V006 at a 1-km spatial resolution. These data are a composite of the corresponding daily MODIIAI Land Surface Temperature (LST) (Google, 2018). Data are available from 03-05-2000 through present day (05-2019), providing an extensive, historical dataset for modeling.

5.2.2.3.1.2 Land

Land Use and Land Cover

There is a significant correlation between Land Use and Land Cover (LULC) and distributions of mosquito species (Munga et al., 2009). The geography of vector abundance is a product of numerous factors including the availability and productivity of aquatic habitats, proximity of larval habitats to sugar and blood meal sources, and species-specific site preferences. *An. gambiae s.s.* larval habitats are characterized as open, sunlit pools (Becker et al., 2003) with little to no vegetation (Sinka et al., 2010). Munga et al. (2009) demonstrated that preferred breeding habitats for *An. gambiae* included deforested, cultivated or natural swamps, and cow hoof prints. Further, Sinka et al. (2010) describes *An. gambiae* habitats as those often associated with human activity including rice fields, wheel ruts, or areas of rice cultivation. The environmental niche of the M- and S-forms of *An. gambiae* were assessed by Simard et al. (2009) in Cameroon. Results showed that habitat suitability for S-form mosquitoes included dry savannah, areas of higher evapotranspiration and lower water vapor pressure, and spaces highly degraded by human activity; S-form's avoided evergreen forest, preferring dry savanna and deciduous forest (Simard et al., 2009). M-form mosquitoes preferred areas of with higher frequency of forested area, greater sunlight exposure, higher water vapor pressure, and lower temperatures and evapotranspiration.

Data for LULC are taken from MODIS Land Cover Type Yearly Global (MCD12Q1) V051 and V006 Type 1 product at a 500-m resolution and 1-year cadence. Data availability ranges from Jan 1, 2001 to December 31, 2016 and were reduced to a single LULC layer by calculating mode. To determine whether a class of LULC was suitable, class descriptions from the LULC data product were compared to the aforementioned habitat requirements (Table 5.4).

Table 5.4: MODIS Type 1 LULC classes and their suitability for *An. gambiae s.s.*

Class ID	Class Description	Suitable *An. gambiae s.s.* Land Cover
1	Evergreen Needleleaf Forests: dominated by evergreen conifer trees (canopy >2m). Tree cover >60%.	No
2	Evergreen Broadleaf Forests: dominated by evergreen broadleaf and palmate trees (canopy >2m). Tree cover >60%	No
3	Deciduous Needleleaf Forests: dominated by deciduous needleleaf (larch) trees (canopy >2m). Tree cover >60%.	No
4	Deciduous Broadleaf Forests: dominated by deciduous broadleaf trees (canopy >2m). Tree cover >60%.	No
5	Mixed Forests: dominated by neither deciduous nor evergreen (40-60% of each) tree type (canopy >2m). Tree cover >60%.	No
6	Closed Shrublands: dominated by woody perennials (1-2m height) >60% cover.	No
7	Open Shrublands: dominated by woody perennials (1-2m height) 10-60% cover.	No
8	Woody Savannas: tree cover 30-60% (canopy >2m).	Yes
9	Savannas: tree cover 10-30% (canopy >2m).	Yes
10	Grasslands: dominated by herbaceous annuals (<2m).	Yes
11	Permanent Wetlands: permanently inundated lands with 30-60% water cover and >10% vegetated cover.	Yes
12	Croplands: at least 60% of area is cultivated cropland.	Yes
13	Urban and Built-up Lands: at least 30% impervious surface area including building materials, asphalt and vehicles.	Yes
14	Cropland/Natural Vegetation Mosaics: mosaics of small-scale cultivation 40-60% with natural tree, shrub, or herbaceous vegetation.	Yes
15	Permanent Snow and Ice: at least 60% of area is covered by snow and ice for at least 10 months of the year.	No
16	Barren: at least 60% of area is non-vegetated barren (sand, rock, soil) areas with less than 10% vegetation.	No
17	Water Bodies: at least 60% of area is covered by permanent water bodies.	Yes

NDVI

The Normalized Difference Vegetation Index (NDVI) is a measure of vegetation presence and health (Jensen, 2005) and is calculated as a ratio of the Red and Near-infrared (NIR) spectral bands:

$$\frac{NIR - Red}{NIR + Red} \tag{3}$$

Higher values of NDVI are associated with healthier vegetation whereas lower values typically signal poor vegetative health, or little to no vegetation present. The NDVI measure is used here as an identifier for suitable land areas for larval breeding sites and mosquito development. Vegetation has several functions during mosquito's life history including providing necessary plant sugars for energy and nutrition (Foster & Walker, 2009). Vegetated areas also provide natural resting sites, particularly for exophagic mosquito species. During resting-periods, shade provided by vegetated cover may inhibit excess water loss, reducing mosquito's risk of dehydration and desiccation (Debebe, Hill, Tekie, Ignell, & Hopkins, 2018). Vegetative cover is an important factor in the distribution of larval habitats. For example, in contrast to *An. gambiae's s.s.* preference for sunlit pools, *An. flavirostris* is characterized as 'shade-loving' for its propensity for breeding in pools that are partially shaded (Foley, Torres, & Mueller, 2002). Further, shade from overhanging plants may reduce the risk of predation on mosquito larvae and provides protecting from surface disturbance (Metzger, 2004). Studies on the relationship between mosquito species and NDVI are not novel (e.x., Dambach et al., 2012; Juri et al., 2014; Lourenço et al., 2011). Notably, Kelly-Hope, Hemingway, & McKenzie (2009) described the relationship between *An. gambiae s.s., An. arabiensis,* and *An. funestus* and NDVI along with other environmental factors in Kenya. Findings showed mean NDVI was significantly correlated with each of the three species; *An. funestus* was positively correlated with NDVI while *An. gambiae s.s., An. arabiensis* were negatively correlated with NDVI. Mean NDVI values measured between the three species ranged from .46 — .52.

Beyond an association with mosquito distributions, there is a well-established relationship between NDVI and malaria (e.g., Haque et al., 2010; Hay, S.I., Snow, R.W., Rogers, 1998; Sewe, Ahlm, & Rocklöv, 2016). Hay, Snow, & Rogers (1998) demonstrated that malaria infection was associated with a minimum NDVI threshold of .30 — .40 at three sites in Kenya. These findings were corroborated by the work of Sewe, Ahlm, & Rocklöv (2016) who showed that values >0.40 were negatively associated with mortality. A conservative >=.30 value is adopted herein to define suitable areas. NDVI data were acquired from the 19-year MODIS Terra Vegetation Indices 16-day Global archive (MOD13Q1) at a resolution of 250-m.

5.2.2.3.1.3 Water

Precipitation

Water is necessary for mosquito development and survival. To estimate inundated, or likely to become inundated areas that would support breeding, annual mean precipitation was calculated from the Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS), version 2.0 product at a resolution of 0.05 arc degrees (~5km). Data are available from Jan 1, 1981 – April 26, 2019. Estimating an accurate precipitation range that provides adequate water resources for breeding pool formation to support larval development is challenging. Mosquito eggs are laid either on or in water, or in areas likely to pool; only a film of water is necessary to support mosquito development through the larval and pupal periods (Foster & Walker, 2009). Lindsay et al. (1998) examined the relationship between climate variables (including precipitation) and the geographic ranges of *An. gambiae s.s.* and *An. arabiensis* throughout Africa. Results showed that total annual precipitation necessary for *An. gambiae s.s.* was 330-3224mm.

Analysis showed that precipitation values render all of Malawi suitable for *An. Gambiae* habitat at a =>300mm threshold. Everywhere is suitable at a sub-optimal level. In order to locate the most suitable areas, an annual precipitation amount threshold of >50% (relative to Malawi) was adopted, while still abiding by the annual maximum threshold described by Lindsay et al. (1998) (3200mm).

The production of larval habitats should expand and proliferate during periods of seasonal rainfall and accumulated precipitation.

Flow Accumulation

Flow accumulation (FA) assists in identifying areas prone to ponding based on drainage characteristics of the landscape. These data assist in identifying streams, water channels, and dambo areas, and are necessary for calculating other hydrologic indices used in previous mosquito distribution models (e.g., Topographic Wetness Index (TWI)) (e.g. Alimi et al., 2015; Mccann et al., 2014). In Kenya, McCann et al. (2014) showed that TWI along with distance to nearest stream were the two most important environmental variables for predicting larval habitats for *An. gambiae s.l.*. FA and TWI differ only slightly; TWI is calculated as a function of FA and slope of a landscape. FA was used here to maximize potential suitability around flow accumulation areas so that gently sloping areas would not be excluded.

To delineate probable breeding habitat as a function of FA, the World Wildlife Fund (WWF) HydroSHEDS Flow Accumulation mapping product was used at a spatial resolution of 15 arc-seconds (~500m). The product is based on elevation data obtained by NASA's Shuttle Radar Topography Mission (SRTM) from Feb 11, 2000 — Feb 22, 2000 (Lehner, Verdin, & Jarvis, 2008). To calculate FA, Digital Elevation Models (DEMs) are used to determine the natural drainage from a given pixel to adjacent, downslope pixels. Based on flow direction, the accumulated flow to each pixel is calculated and returned. (ESRI, 2018). This model assumes that pixels with a greater number of cells flowing into them represent areas of higher likelihood of breeding potential. To that end, suitable areas were determined by setting a threshold of >=25% to identify those pixels of highest FA, which corresponds well with visual interpretations of satellite images in Malawi, then setting these pixels as 'suitable.'

Water Bodies

A water bodies layer was produced to capture areas along permanent water body (e.g., rivers, streams) margins likely to pool and support vector breeding. Water bodies were identified using the JRC Global Surface Water Bodies Mapping Layer, v1.0 data product. These data were acquired from a composite of >3 million Landsat 5/7/ 8 scenes acquired between March 16, 1984 and October 10, 2015 at a spatial resolution of 30-meters (Pekel, Cottam, Gorelick, & Belward, 2016). Water bodies were buffered by 250-m to locate water-rich soils within proximity to permanent water areas. A 250-m buffer was selected in order to be consistent with the spatial resolution of the flow accumulation layer. Water body data were subsequently masked to remove rivers, streams, and lakeshores where larvae habitat is unsupported due to regular disturbance to the water surface via wind and waves.

5.2.2.4 Model Outputs

Variable thresholds are used to create binary, suitable (1) vs unsuitable (0) maps for each predictor during the defined time-period based on the mean. All predictor variable maps are then combined using Boolean logic to produce suitability maps for the target species. Results are displayed in two fashions: suitability ranking (low — high) and combined suitability by type (Climate, Land, Water) to elucidate suitability drivers (Figures 5.7—5.9). The 2012 product shows that approximately 4.45% of Malawi's land areas exhibits suitable water conditions for *Anopheles gambiae s.s.*, approximately 39.79% for water plus another factor, and 6.19% is supraoptimal, meeting suitability thresholds for water presence, terrain characteristics, and climatic conditions. The 2014 product differs only slightly from the 2012 product: approximately 4.89% of land area meets suitable water conditions to support vector breeding, approximately 34.23% is suitable according to water and climate or water and land criteria, and 6.21% is supraoptimal. Of the three models produced, the 2017 product shows the largest percentage of Malawi's total land area as supraoptimal (6.86%). Approximately 5% of Malawi exhibits suitable water conditions, and roughly 35.46% are suitable for water and another factor. In all models, areas that exhibit suitable conditions for land cover characteristics alone are most common: 44.50% (2012), 51.47% (2014), and 46.70% (2017).

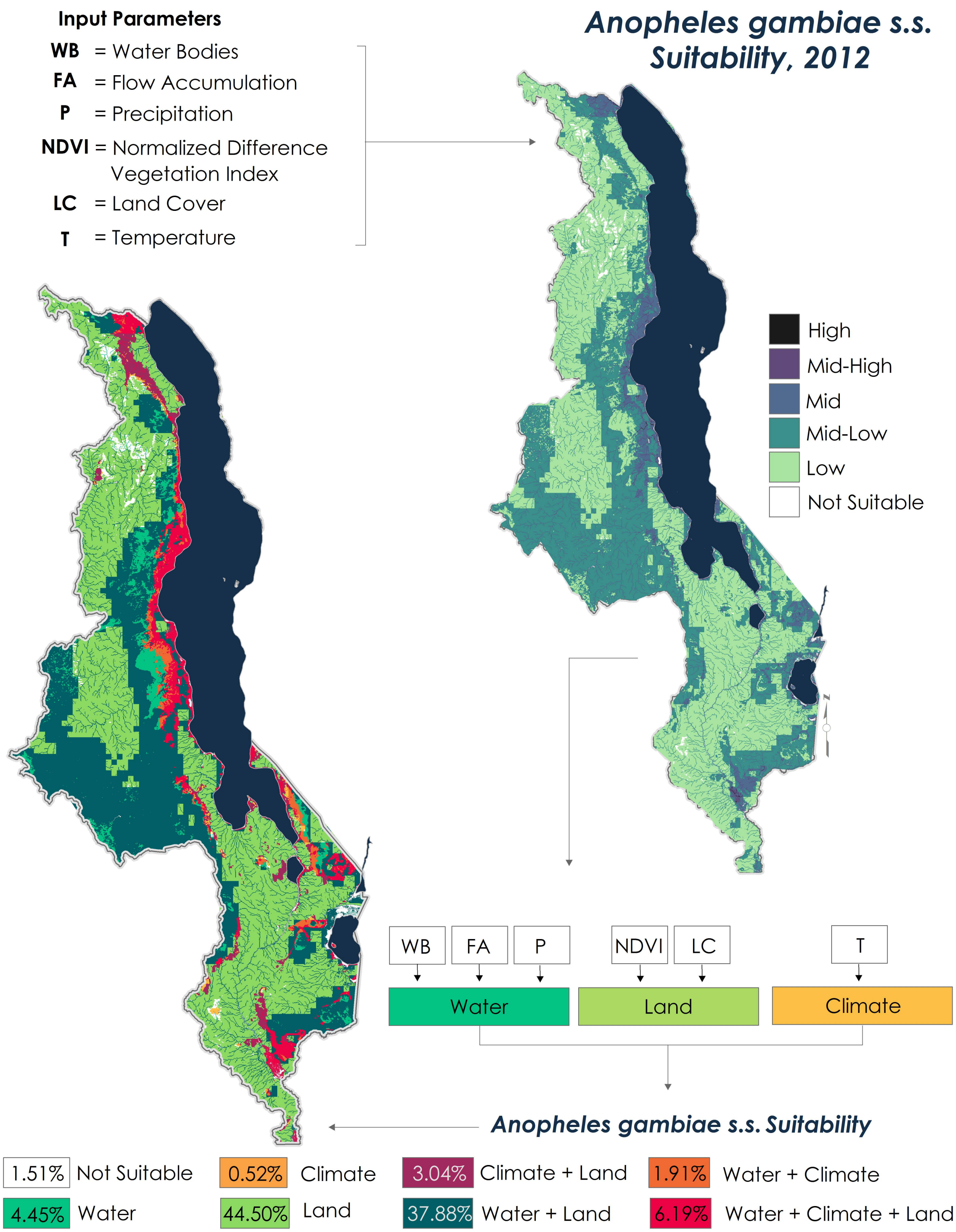


Figure 5.7: *Anopheles gambiae s.s.* habitat suitability in Malawi, 2012

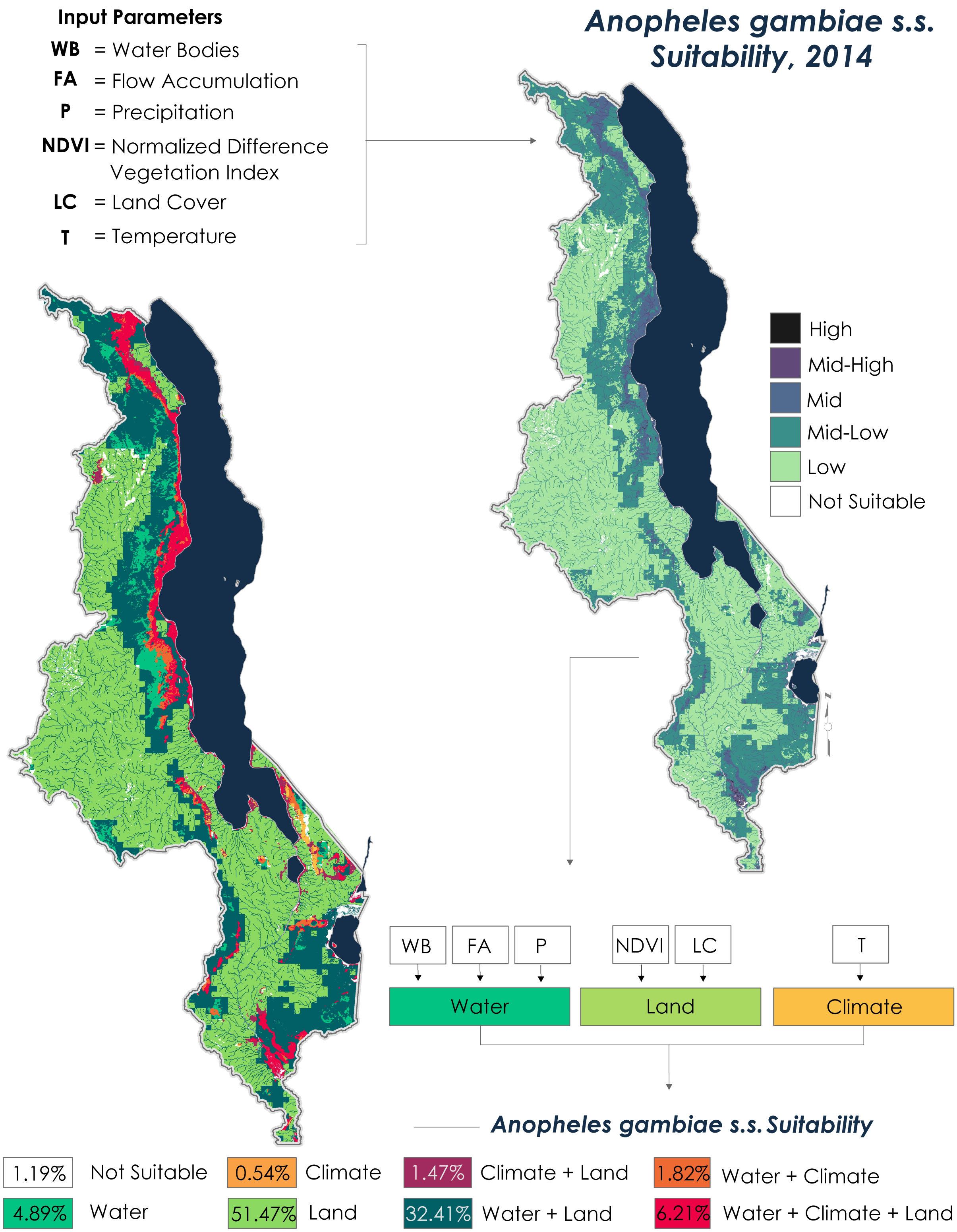


Figure 5.8: *Anopheles gambiae s.s.* habitat suitability in Malawi, 2014

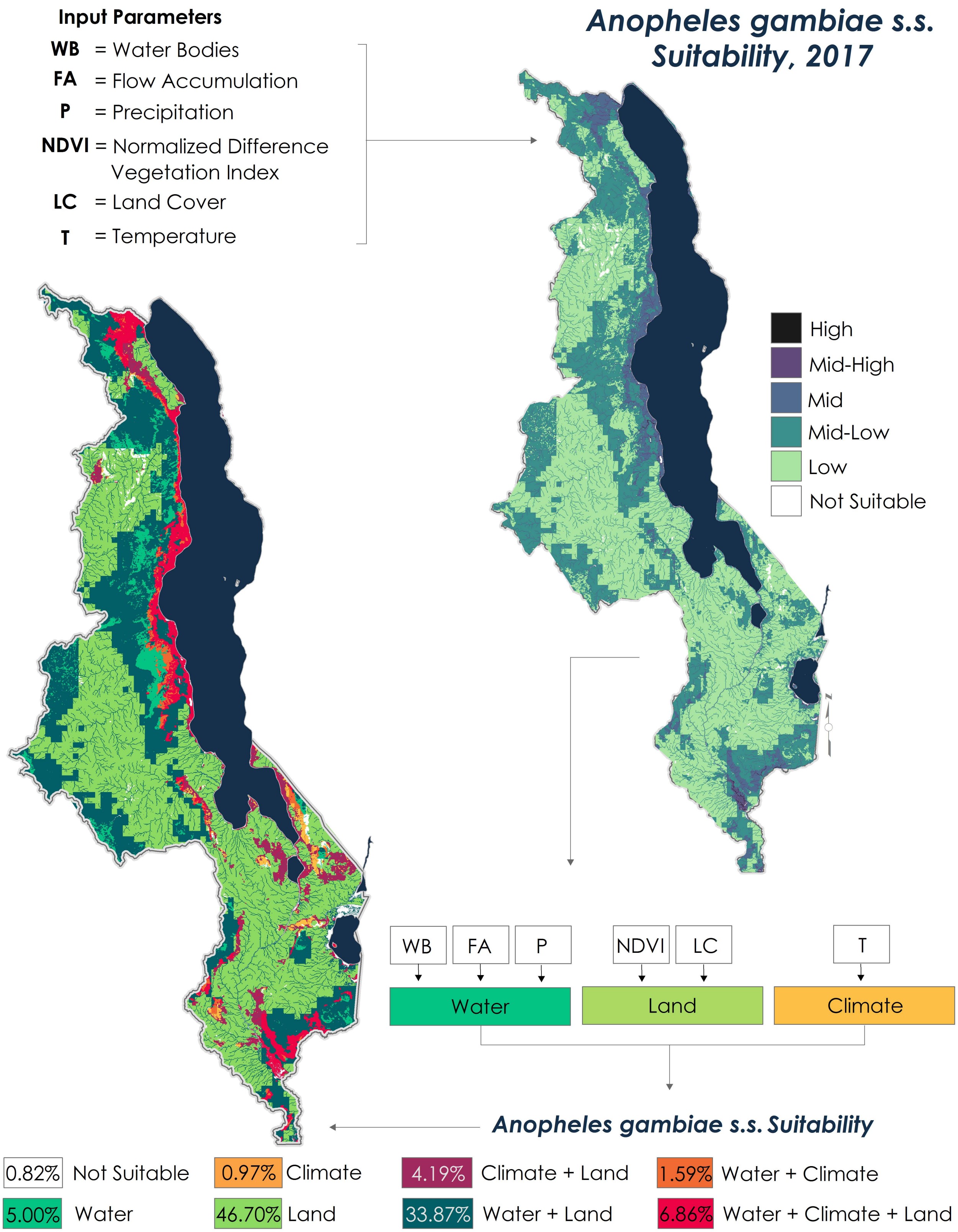


Figure 5.9: *Anopheles gambiae s.s.* habitat suitability in Malawi, 2017

5.2.3 Malaria in Malawi

5.2.3.1 DHS MIS

Reliable estimations of historical spatio-temporal distribution of malaria prevalence in Malawi is challenging in the absence of long-standing standardized measures of the burden of disease (Mathanga et al., 2012). Malaria prevalence data for this study was taken from the Demographic and Health Surveys (DHS) Malaria Indicator Surveys (MIS) in Malawi. The DHS Program is the largest sample survey program in history (Zuehlke, 2009) with a mission to provide accurate, nationally representative data on population, health, and nutrition (USAID, 2019b). Since its inception in 1984, the DHS program has taken part in more than 400 surveys in 90 countries (USAID, 2019b). Funding for the DHS Program is provided by USAID and is implemented by ICF (formerly, Inner City Fund) (USAID, 2019a). Since 2000, the standard DHS survey has included a malaria-related questions including ownership and use of bed nets, prevalence of fever in children, and intermittent preventative treatment of pregnant women (DHS, 2019a).

The MIS is a standalone survey specific to assessing core malaria indicators at the national, regional, and provincial levels. MIS surveys were developed by the Monitoring and Evaluation Working Group (MERG) of Roll Back Malaria and were first conducted in 2011 (DHS, 2018). Data are collected on household ownership and use of Insecticide-Treated Nets (ITNs), diagnostic blood testing via Rapid Diagnostic Testing (RDT) and Microscopy for children under five, indoor residual spraying, treatment of fever in children under five, and intermittent preventative treatment for pregnant women (DHS, 2019b). Three MIS surveys have been conducted in Malawi: MIS 2012, MIS 2014, and MIS 2017.

5.2.3.2 DHS MIS Data and Processing

The DHS MIS data (https://www.dhsprogram.com/data/available-datasets.cfm) and associated GPS data were used to analyze the distribution of malaria prevalence in Malawi for years 2012, 2014, and 2017. Data for each MIS survey year was requested and approved using the registration process (http://dhsprogram.com/data/new-user-registration.cfm). Malaria prevalence for all MIS surveys is observed through microscopic detection of malaria parasites (microscopy) and SD BIOLINE Malaria Ag. P.f/Pan (HRP-II)™ rapid diagnostic test (RDT). An RDT detects the presence of the *P.falciparum*-specific, histidine-rich protein-2 (HRP-2), not the malaria parasite (DHS, 2017). Moody (2002) showed that HRP-2 remains in the blood for up to a month despite adherence to an antimalarial regimen. In areas that experience high rates of *P. falciparum,* this can lead to inflated prevalence rates via RDT detection (DHS, 2017). For this reason, this analysis defines prevalence as parasitemia (via microscopy) in children ages 6-59 months given the holoendemic nature malaria in Malawi. Data are analyzed at the regional and cluster level. Malawi contains three DHS regions: northern, central, and southern. The DHS clusters are geo-referenced groupings of households that participated in each survey. To protect confidentiality of survey participants, clusters are displaced (Burgert, Colston, Roy, & Zachary, 2013) according to their classification, rural or urban (Perez-Heydrich & Emch, 2013). Rural locations are displaced 0—5km (with 1%, or every 100th point displaced 0—10km) and urban locations are displaced 0—2km. Displacement is random in both direction and distance (Perez-Heydrich & Emch, 2013). Analysis at the cluster level provides the finest resolution data available for survey years. The location of each cluster varies by survey. Malawi contained 140 clusters (96 Rural, 44 Urban) in 2012, 140 (90 Rural, 50 Urban) in 2014, and 150 (90 Rural and 60 urban) in 2017. Prevalence rates for each survey cluster were calculated by using the weighted sum of children ages 6-59 months who tested positive for parasitemia via microscopy divided by the total number of children tested. All statistical data processing was conducted in STATA /IC 15.1 then exported to ArcMap 10.5.1™.

5.2.3.3 Malaria Prevalence in Malawi

Since the DHS MIS Survey in 2012, Malawi has made progress in controlling Malaria according to MIS reports. Overall prevalence in 2017 was 24.3%, down from 27.7% in 2012. Malaria prevalence data for Malawi DHS MIS Surveys 2012, 2014, and 2017 are provided in Table 5.5. Subsequent sections discuss statistics for each survey year in greater detail.

Table 5.5: Percentage of children ages 6-59 months according to microscopy for Malawi DHS MIS Surveys 2012, 2014, and 2017

	Malaria Prevalence according to microscopy (2012)		**Malaria Prevalence according to microscopy (2014)**		**Malaria Prevalence according to microscopy (2017)**	
Background Characteristics	Microscopy positive	Number of Children	Microscopy positive	Number of Children	Microscopy positive	Number of Children
Overall Prevalence	27.7	2167	33.2	2023	24.3	2485
Region						
Northern	19.8	306	28.5	387	11.2	268
Central	34.4	916	36.1	774	26.0	1065
Southern	23.9	944	32.6	861	25.7	1152
Age (in months)						
6-8	21.1	105	20.6	112	7.6	141
9-11	18.4	106	30.4	105	7.3	120
12-17	20.0	266	19.0	237	14.8	278
18-23	22.4	243	28.0	269	26.1	227
24-35	30.9	478	35.5	458	22.5	517
36-47	30.0	488	37.5	401	29.4	528
48-59	32.7	480	41.1	440	31.5	674
Sex						
Female	28.3	1157	31.7	1009	24.3	1238
Male	27.0	1010	34.6	1014	24.3	1246
Residence						
Urban	9.4	280	10.8	275	4.0	339
Rural	30.4	1887	36.7	1748	27.5	2145

2012

The 2012 DHS MIS Survey was conducted from in April and May 2012 and included 3500 households across 140 clusters (DHS, 2015) (Figure 5.10). A total of 2167 children were sampled for malaria infection via blood smear for microscopy identification of malaria parasites. Of these, 1566 (72.3%)

were negative and 601 were positive (27.7%) for infection; overall prevalence was 27.7%. A larger percentage of children in rural areas (30.4%) experienced malaria infection than children residing in urban areas (9.4%). The largest percentage of positive malaria infection recorded, was 81% and located ~30-kilometers southwest of Lilongwe. Of the remaining nearly 18% of clusters with prevalence rates =>50%, all were concentrated in the Southern and Central regions. Regional analysis showed that the Northern region experienced the lowest overall rates at 19.8%. The Southern and Central regions overall prevalence's were 23.9% and 34.4%, respectively.

2014

The DHS MIS survey was conducted from May 2 – June 10, 2014 and included 3500 households (DHS, 2015) (Figure 5.11). Overall malaria prevalence in children ages 6—59 months declined by 10% from the 2010 recorded statistics (43%) (DHS, 2015). There were 2023 children that participated in the 2014 Malawi DHS MIS. Of these, 1352 (67%) were negative and 671 were positive (33%) for infection. The number of children positive for malaria infection was higher in rural areas (37%) than urban (11%). Prevalence rates ranged from 0 to 100% among the 140 clusters sampled. Overall prevalence for 2014 was 33.2%. Regional analysis shows that the Central region had the highest infection rate (36.1%), followed by the Southern (32.6%), and Northern (28.5%) regions. Roughly 15% of survey clusters had prevalence rates >=50%. Five clusters had prevalence rates >80%; two were located along Lake Malombe in the Southern region, 1 near Nkhotakota on the Lake Malawi Lakeshore, and the remaining two west of Mzimba along the Zambian border.

2017

Data collection for the 2017 DHS MIS Survey was conducted from April 15 – June 16, 2017 among 3750 households (DHS, 2017) (Figure 5.12). The total number of children that participated in this analysis was 2485. Microscopy results showed that 1592 children were negative (64%) and 892 (36%) were positive for malaria infection; *P. falciparum* accounted for 95.3% of infection. Consistent with previous surveys, a larger percentage of children were positive for malaria in rural as opposed to urban areas. There were 150 clusters analyzed with a minimum prevalence of 0 and maximum of 83.3%. Overall prevalence was 24.3%, a considerable decrease from 43% in 2010 (DHS, 2017). Clusters number 3 and 135 were missing geographic information and were subsequently were removed from the dataset prior to export to ArcMap 10.5.1™ for visualization. Regional analysis showed that the Southern and Central regions had nearly identical malaria prevalence rates, 25.7% and 26%, respectively. The percentage of children who tested positive in the Northern region was 11.2%, a decline of more than 17% from the previous 2014 MIS survey. Roughly 7% of survey clusters had prevalence rates >=50%; more than a 50% decline from 2014 (16%). Of these, half are located along the Lake Malawi lakeshore, with one of the remaining clusters near Mt. Mulanje in the southern region, and three within 40km Malawi's capital, Lilongwe. There were 34% of clusters where malaria prevalence was 0. Nineteen of these clusters were located in Malawi's two largest cities, Lilongwe in Blantyre.

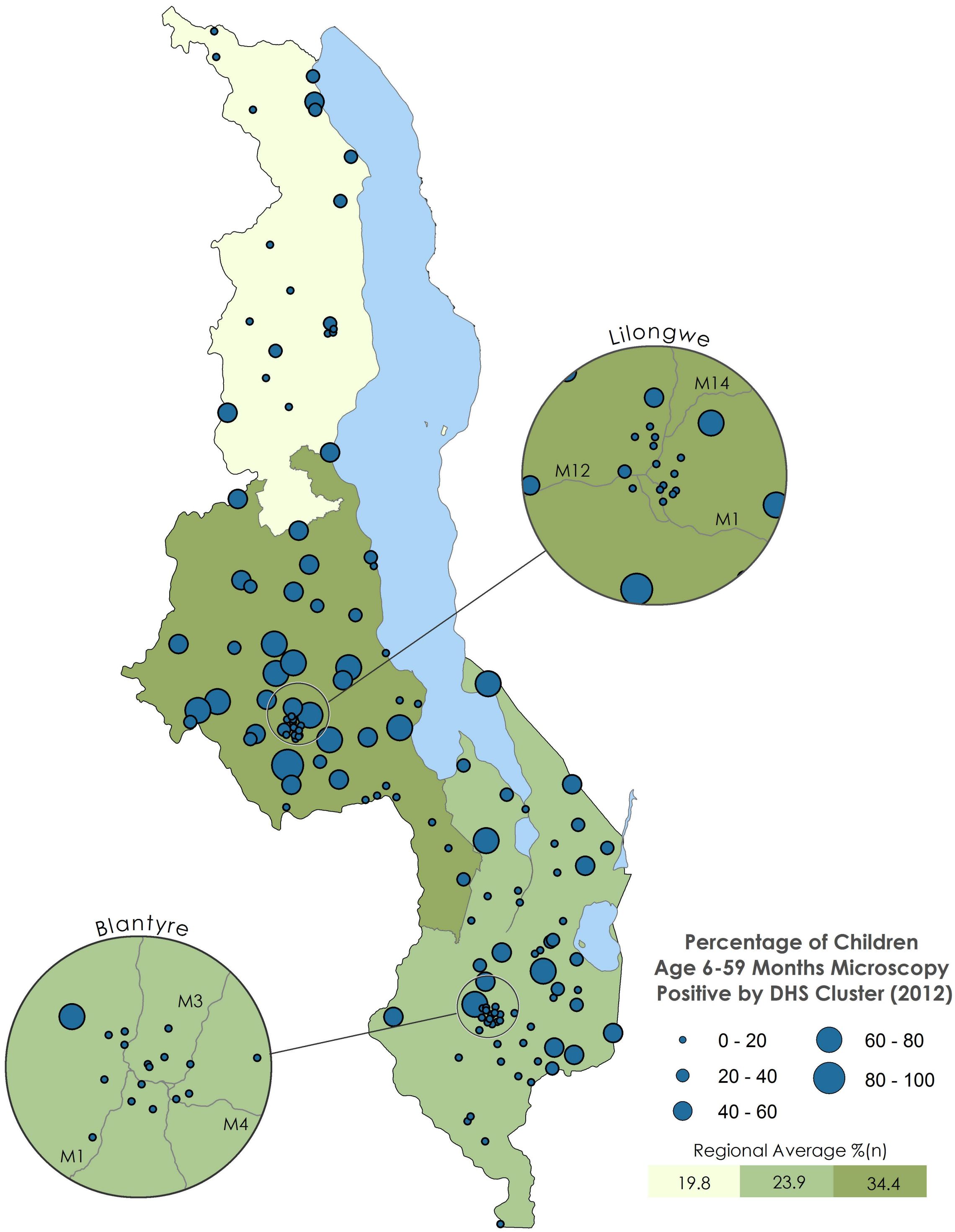


Figure 5.10: Percentage of Children Age 5-59 Months Microscopy Positive for Malaria Infection by DHS Cluster (2012).

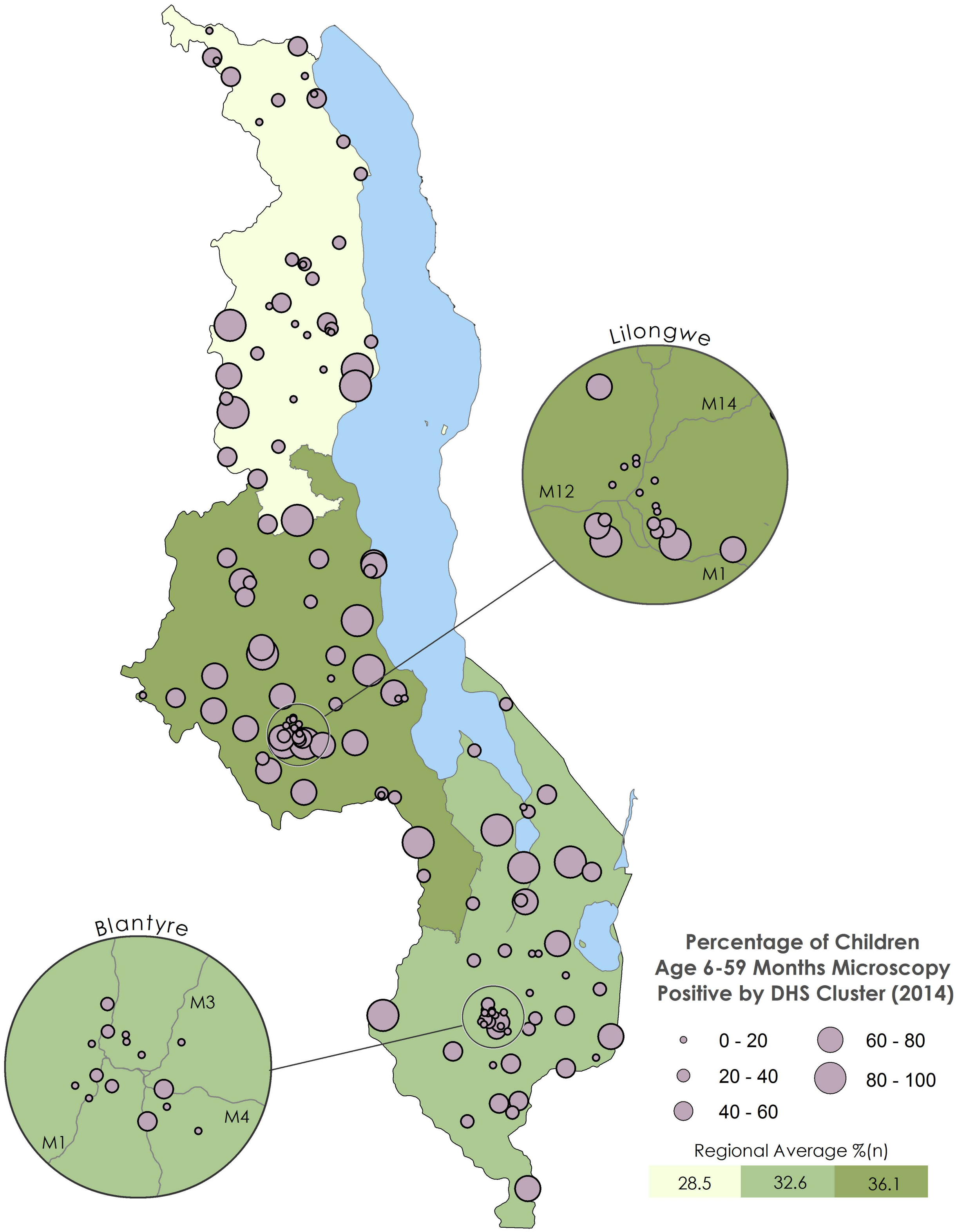


Figure 5.11: Percentage of Children Age 5-59 Months Microscopy Positive for Malaria Infection by DHS Cluster (2014).

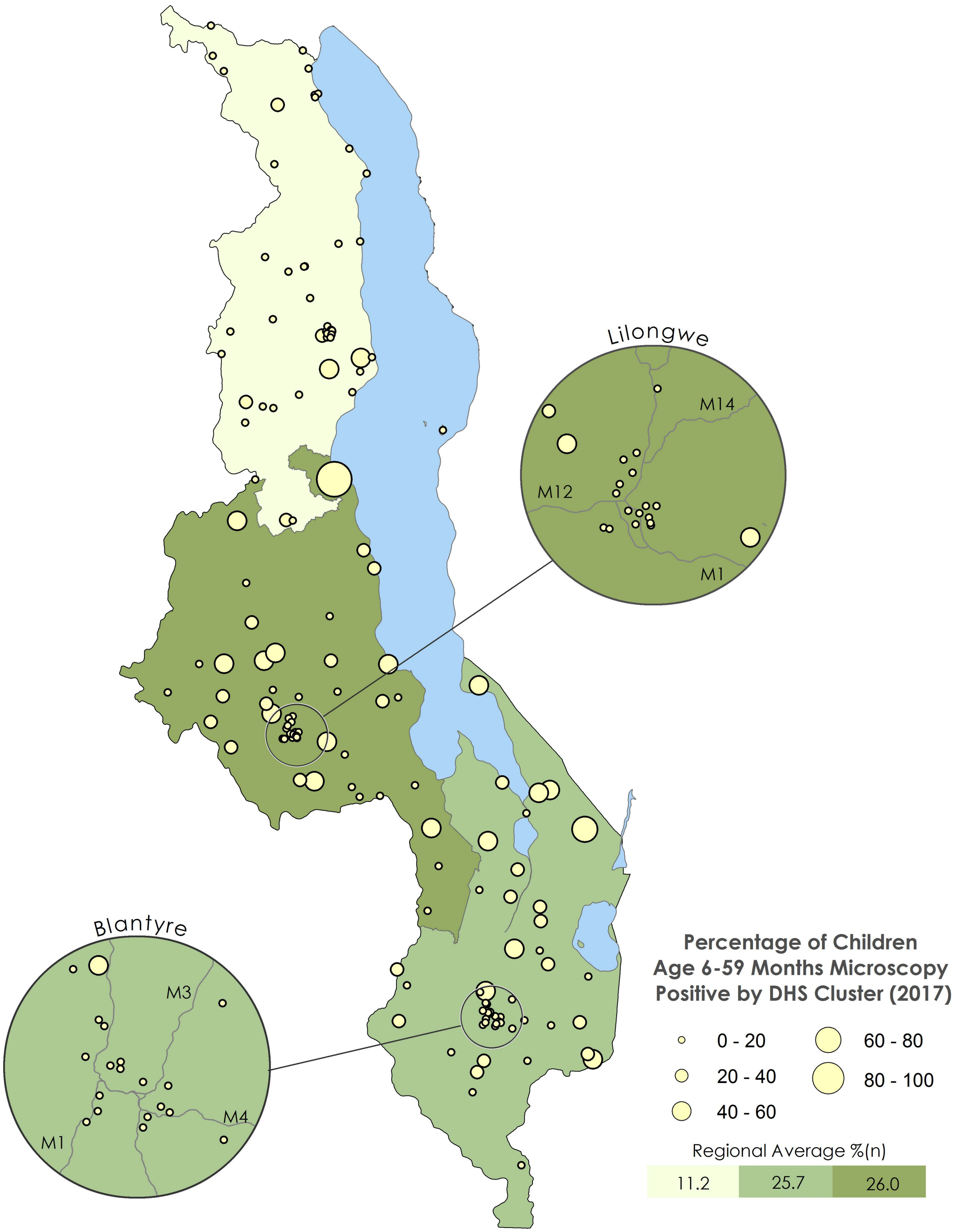


Figure 5.12: Percentage of Children Age 5-59 Months Microscopy Positive for Malaria Infection by DHS Cluster (2017).

5.3 Results

5.3.1 Habitat Suitability and Malaria Prevalence

Malaria prevalence in Malawi has a distinctly spatial character, in part a result of environmental characteristics that define suitable ecological zones for malaria mosquitoes. To examine these relationships, malaria prevalence data were overlaid for each DHS MIS year with the associated years produced HSM. Suitability drivers associated with each DHS cluster were assessed by buffering clusters to 5-km for consistency of results per the recommendations of Perez-Heydrich & Emch (2013).

The 2012 product shows that among DHS clusters, habitat suitability is most often defined as land areas exhibiting suitable land characteristics (44.28% Rural; 55.89% Urban), followed by areas suitable for land and water characteristics (42.05% Rural; 30.90% Urban) (Figure 5.13). Among clusters surveyed for the 2012 year, areas exhibiting habitat suitability based on climate alone were least likely (0.22% Rural; 0.40% Urban). This is unsurprising given the overall percentage of land area suitable based only on climate is low (.52%). Supraoptimal (Land, Climate and Water) areas represented 7.14% of land area within rural clusters and 5.39% of land area with urban clusters respectively.

Habitat suitability drivers among 2014 DHS clusters show similar findings to the 2012 results (Figure 5.14). Suitable land areas as defined by land characteristics cover the largest areas: 52.14% in rural areas and 68.54% in urban. Suitable areas based on land and water characteristics alone represent 33.40% of rural areas and 21.02% of urban. Clusters that include supraoptimal areas are nearly four times greater in rural areas (8.80%) as opposed to urban (3.69%).

The 2017 product shows supraoptimal areas for rural and urban areas as 7.90% and 6.28%, respectively (Figure 5.15). Consistent with previous years analysis suitable land areas according to land characteristics are greatest for both rural and urban areas (53.18% rural; 68.93% urban), followed by suitable areas defined by land and water characteristics (31.85% rural and 18.08% urban).

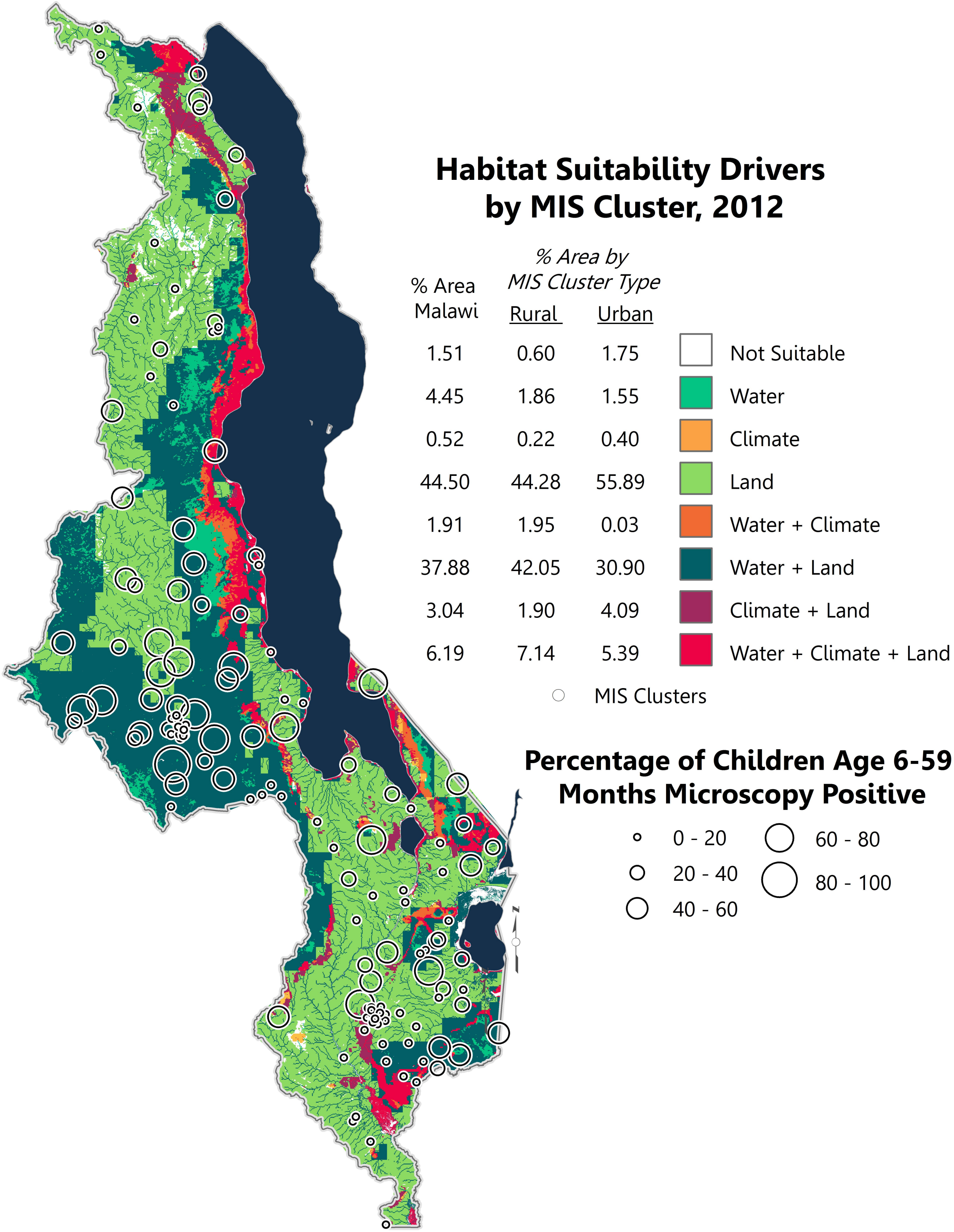


Figure 5.13: Habitat suitability drivers by MIS cluster, 2012

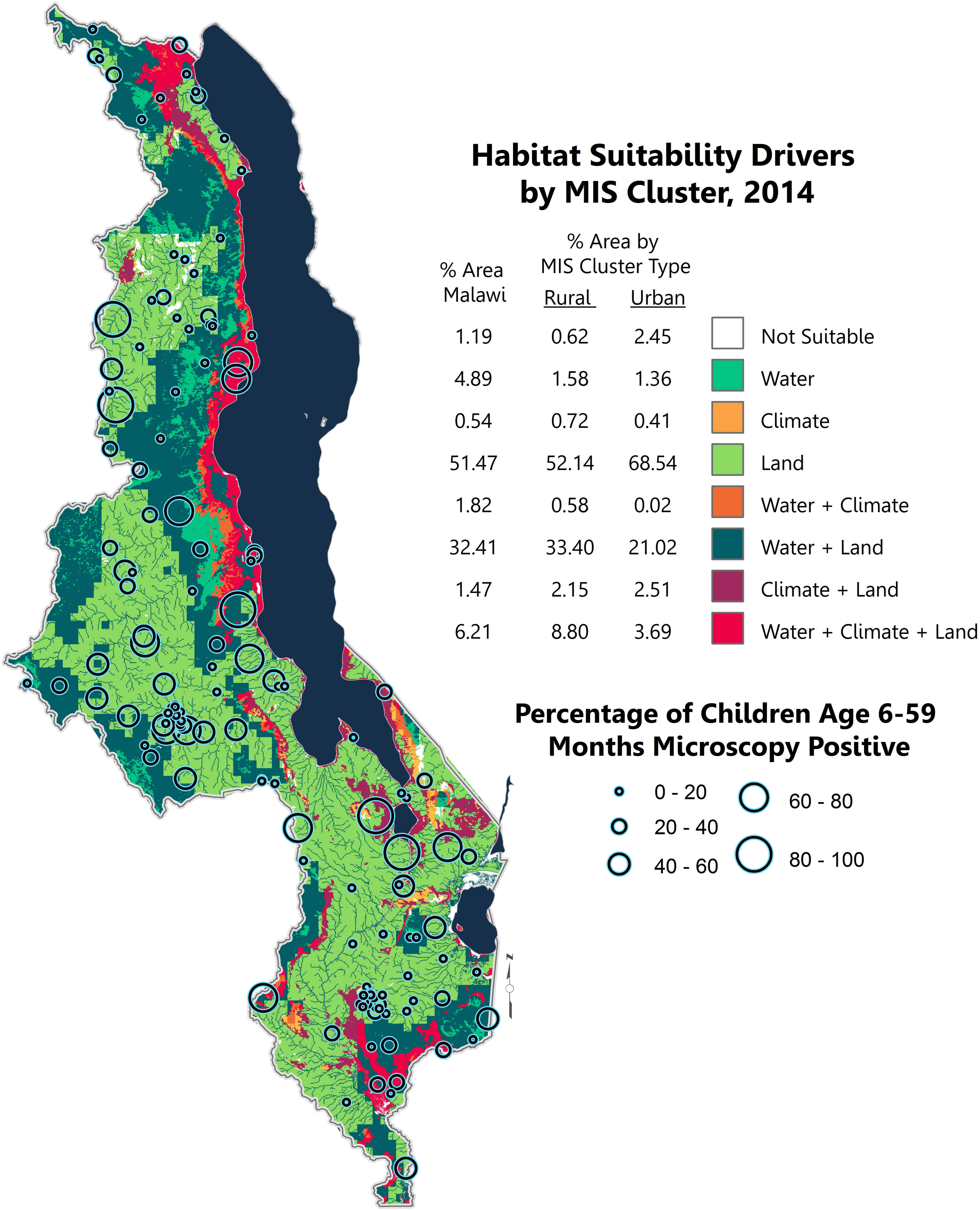


Figure 5.14: Habitat suitability drivers by MIS cluster, 2014

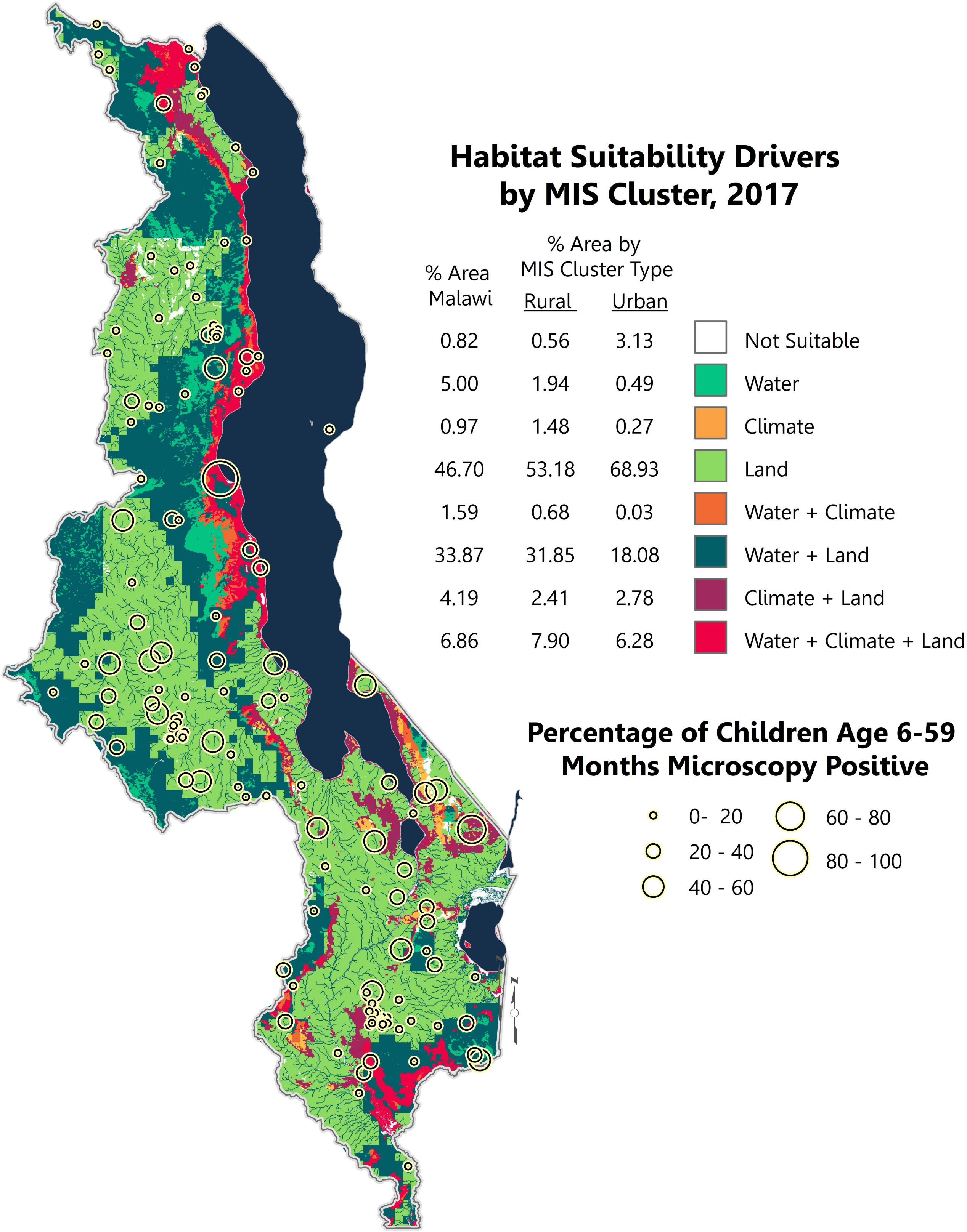


Figure 5.15: Habitat suitability drivers by MIS cluster, 2017

5.3.2 Scaling Irrigation and Malaria Risk in Malawi

To examine the expansion of *Anopheles gambiae s.s.* niche as a result of LULCC for irrigated agriculture, an estimation of maximum extent of habitat suitability was produced using the results of the 2017 habitat suitability model and potential GBI area data (Figure 5.16). The GBI area's pixels were re-classified to represent where suitable land and water characteristics for breeding would occur upon LULCC for irrigated agriculture. At the national scale, results show that while the 2017 product demonstrated that approximately 6.86% (~6.7 million km²) of Malawi was supraoptimal for breeding, this increases to 7.06% (~6.9 million km²) under the GBI scenario. Notable changes also involve areas suitable for land and water characteristics. In 2017, 24.90% of Malawi's was suitable based on land and water characteristics. This number increases to 40.66% with the expansion of GBI sites.

Under the GBI scenario, the percent area for habitat suitability and total maximally suitable area in square kilometers was assessed for each of the 25 GBI proposed sites (Table 5.6). Results show that the Limphasa site will possess the largest percentage of total area maximally suitable according to water, climate, and land characteristics for *An. gambiae s.s.* breeding (78%) with a maximally suitable area of 359 km². Other notable sites according to total maximally suitable land area are Karonga (43.7%; 123.94 km²) and Bua/Lozi (55.5%; 104.29 km²). Eight sites demonstrate no maximally suitable area: Chitipa, Mpherembe, Upper Dwangwa, Kantungu, Bua Dambos, Lisunwi, Phwadzi, and Lingadzi.

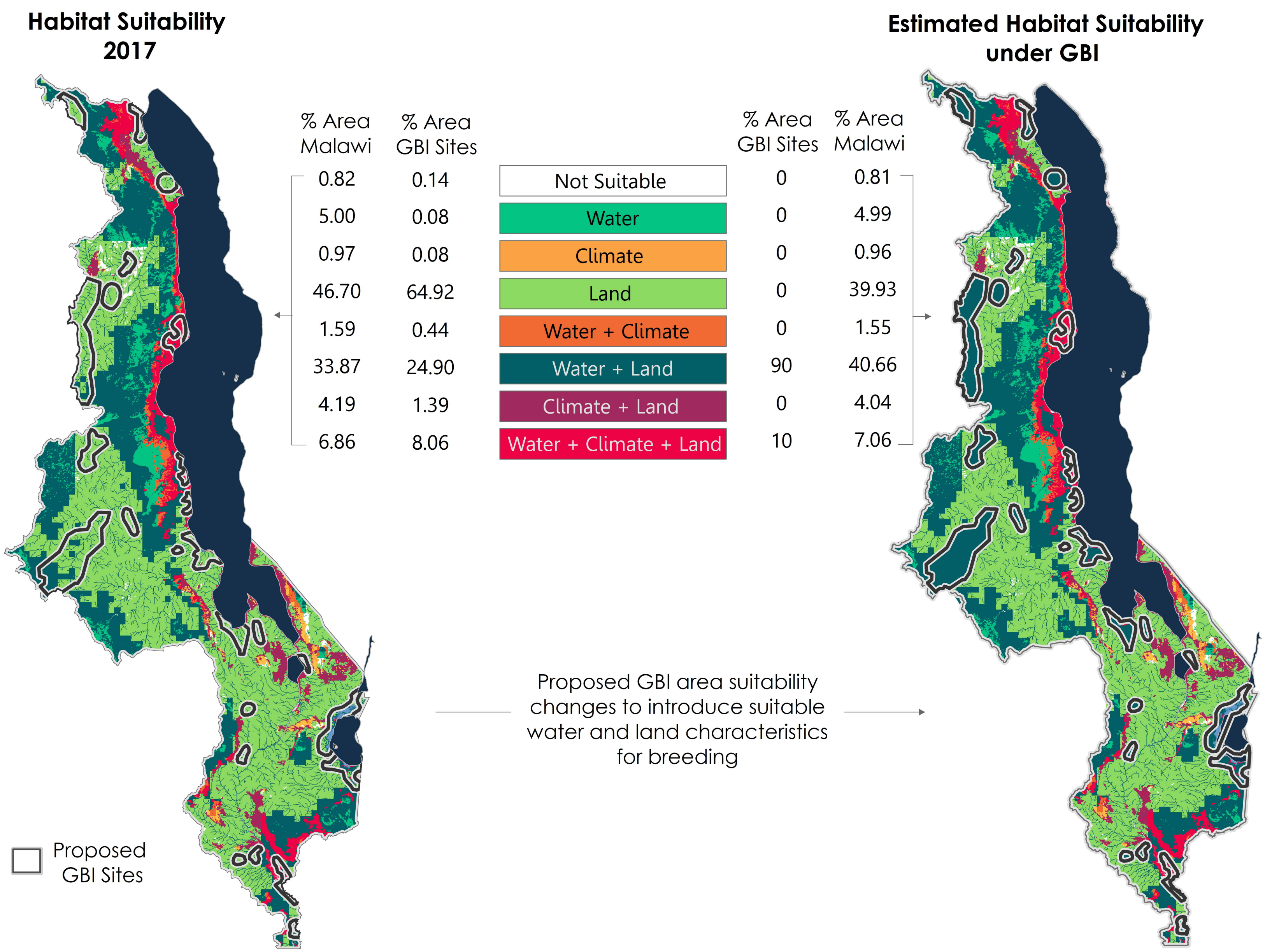


Figure 5.16: Change in distribution of habitat suitability for *An. gambiae s.s.* after LULCC for GBI sites under a maximum estimation

5.4 Discussion and Conclusions

As has been highlighted in this chapter, estimated habitat suitability under the GBI shows an increase of nearly 200,000 sq km in supraoptimal breeding area for *An. gambiae s.s.* mosquitoes across Malawi. Analysis of GBI sites showed that while eight sites would not possess any supraoptimal land area, the remainder of sites would possess 0.01—359 km² of supaoptimal land area for breeding. In light of the findings of Chapter 3, a notable consideration is that irrigated spaces are not homogenous; risk of breeding will be asymmetrical based on site characteristics including timing and intensity of irrigation, soil properties, management, and crop type. Likewise, it would an oversimplification to conclude that simply an increase in the likelihood of aggregated surface water for breeding would increase malaria transmission in the local area without site specific information including distance of the irrigated scheme to human habitation and the stability of malaria transmission in the local area.

Using data from this study on GBI sites including proposed crop types, habitat suitability under and estimated GBI scenario, and malaria prevalence data for 2017 where clusters were <5km from proposed schemes, a ranked categorization of GBI sites based on their likelihood to increase malaria risk through production of larval habitat is presented (Table 5.7). Recommendations were determined through a three-step process. First, by considering total supraoptimal land area for each site, followed by assessment of proposed crop type. Proposed crop types include cereal grains (wheat, maize), rice, sugar, and cassava. Other GBI sites are intended for ranching, rather than cultivation. Crop types were ranked according to their water needs and traditional methods of irrigation (1—5, rice, sugar cane, maize, wheat, cassava; most likely to encourage vector breeding to least likely). Ranching operations were ranked least likely to encourage vector breeding due in part to limited aggregated water bodies on site but also the breeding preferences of *An. gambaiae s.s.* mosquitoes for open, sun lit pools generally free of organic matter; these conditions are likely not readily met on ranching operations. It is assumed that areas with crop types such as rice that are irrigated through consistent flood irrigation would encourage greater vector production than crop types sensitive to water logging. Where more than one crop type was listed per site, the crop type with the greatest water needs was considered in the absence of data for percent area or seasonality of cultivation for each crop. The final consideration in ranking recommended sites to develop was the prevalence of malaria within 5-km of the proposed site. Sites with no MIS clusters that meet the <5km criteria are listed separately. An alternative method for gathering data on malaria prevalence for these areas would use Malawi's Health Management Information System (HMIS).

The GBI site whose LULCC for irrigated agriculture is least likely to substantially impact malaria transmission is Chitipa. Chitipa possess no maximally suitable area for breeding and the area is intended to cultivate wheat. In contrast to a crop such as rice where flood irrigation is often practiced, wheat is sensitive to waterlogging (Herzog, Striker, Colmer, & Pedersen, 2016). It is expected that aggregated pools of water suitable for breeding would not exist long enough for mosquitoes to develop from aquatic to adult stages under these conditions. Further, two 2017 MIS clusters were located <5km of the Chitipa site with no detectable malaria parasitemia via microscopy. Other sites that demonstrate very little or no maximally suitable land area for breeding are Mpherembe, Upper Dwangwa, Kantungu, Linggadzi, Bua Dambos, Lisunwi, Phwadzi, and South Rukuru. Each of these sites proposed crop types are cereal grains (maize or wheat), or are intended as ranching operations limiting the availability of consistent surface water available for breeding. The number of MIS clusters <5km from each of these sites ranges from 0—6; mean percentage of malaria prevalence among these clusters ranges from 0—41.2%. Five sites had no MIS clusters <5km: Phwadzi, Lingadzi, Lisangadzi, Lisunwi, Kantungu, and Liviridzi.

The GBI site most likely to increase malaria risk for those residing in closest proximity to the scheme is Limphasa. Total maximally suitable area for *An. gambiae s.s.* is approximately triple that of remaining sites (359 km^2) and land area is intended for rice cultivation. According to 2017 MIS surveys, mean malaria prevalence is 22.4% for the four clusters within 5-km of the scheme. These data indicate that malaria mosquitoes are clearly present within the area. It is expected that the increase in surface water availability from Limphasa would encourage the proliferation of mosquitoes and in turn change the epidemiology of malaria for the local area. Other GBI sites where greater consideration should be given to development in light of their impact on malaria risk are Karonga/Kaporo, Bua/Luzi, Muona/Ruo, Phalombe Plain, Lake Malombe, Lingadzi/Lipimbi, Hara, and Ntchalo. Beyond the amount of land area maximally suitable for breeding potential, each of these sites are intended for rice to some measure. Further information on the percentage of land area within each site intended for rice cultivation and the seasonality of planting would assist in further defining risk potential for the area. The number of MIS clusters for these sites is 0—5; prevalence rates range from 0—27.2%. Two sites require further investigation on malaria disease dynamics for the local area in the absence of MIS data: Chia and Nyachipere.

Table 5.6: Percent area of habitat suitability for proposed GBI sites under a maximum estimation

GBI Site	Proposed Crop Type	Proposed Area (km²)	% Area Habitat Suitability: No Data	Unsuitable	Water	Climate	Land	Water +Climate	Water + Land	Climate + Land	Water + Climate + Land	Total Supraoptimal Area (km²)
Chitipa	Wheat, Maize	412.282	10.9	-	-	-	0.007	-	89.12	-	-	**0**
Karonga/Kaporo	Rice	283.617	6.0	0.03	-	-	-	-	50.2	-	43.7	**123.94**
Hara	Rice	275.268	6.7	-	-	0.01	0.1	-	80.4	0.02	12.8	**35.23**
Bolero/Kazuni	Maize	178.943	0.002	0.002	-	-	0.1	-	98.6	-	1.3	**2.33**
Mpherembe	Ranch	331.593	0.005	0.005	-	-	0.1	-	99.9	-	-	**0**
Limphasa	Rice	460.258	13.5	-	-	-	-	0.002	8.56	-	78.0	**359.00**
South Rukuru	Maize	2028.11	4.8	-	-	-	0.03	-	95.13	-	0.0005	**0.01**
Upper Dwangwa	Wheat, Maize	526.367	0.02	-	-	-	0.1	-	99.9	-	-	**0**
Bua/Lozi	Rice, Maize, Cassava	187.912	27.5	-	-	-	-	-	17.0	-	55.5	**104.29**
Chia	Rice, Maize, Cassava	129.32	32.0	-	-	-	0.03	-	20.43	0.01	47.5	**61.43**
Kantungu	Wheat	206.575	-	-	-	-	0.1	-	99.9	-	-	**0**
Lingadzi/Lipimbi	Rice	525.127	18.32	-	-	-	.03	-	75.94	.0007	5.71	**29.98**
Bua Dambos	Wheat, Maize	2353.69	0.42	-	-	-	0.02	-	99.6	-	-	**0**
Bwanje/Malembo	Rice	471.85	14.22	-	-	0.0004	0.06	-	82.6	.001	3.13	**14.77**
Lisangadzi	Sugar	153.641	-	-	-	-	0.07	-	86.6	0.02	13.27	**20.39**
Liviridzi	Wheat	109.909	-	-	-	-	0.11	-	96.1	0.02	3.81	**4.19**
Lake Malombe	Rice	88.4879	10.52	-	-	0.01	0.06	-	31.5	0.03	57.9	**51.23**
Lisunwi	Wheat	117.766	0.22	-	-	-	0.11	-	99.7	-	-	**0**
Lake Chilwa/Chiuta	Rice, Sugar	884.768	50.2	-	-	-	0.02	-	48.3	0.002	1.48	**13.09**
Phalombe Plain	Rice, Maize, Sugar	679.408	33.5	-	0.001	-	0.03	-	58.63	0.0006	7.81	**53.06**
Phwadzi	Ranch	87.463	0.02	-	-	-	0.10	-	99.9	-	-	**0**
Ntchalo	Rice, Maize, Sugar	108.087	2.92	-	-	-	0.12	-	88.93	0.01	8.02	**8.67**
Muona/Ruo	Rice, Maize	307.162	16.63	-	-	-	0.03	-	54.3	-	29.10	**89.38**
Nyachipere	Rice, Maize	127.416	11.45	-	.0007	-	0.04	0.006	80.65	-	7.90	**10.07**
Lingadzi	Ranch	45.7031	-	-	-	-	0.17	-	99.83	-	-	**0**

Table 5.7: Ranked categorization of GBI sites based on their likelihood to increase malaria risk through production of larval habitat

		Habitat Suitability			Malaria		Crop Type
Rank	**GBI Site**	**Proposed Area (km²)**	**% Max Suitable Area**	**Total Max Suitable Area (km²)**	**Number of MIS Clusters <5km**	**Mean % MIS Cluster Prevalence <5km**	**Proposed Crop Type**
Sites to Develop: Least likely to increase malaria risk							
1	Chitipa	412.28	0	0	2	0	Wheat
2	Mpherembe	331.59	0	0	1	5.3	Ranch
3	South Rukuru	2028.11	0.0005	0.01	4	18.0	Maize
4	Bua Dambos	2353.69	0	0	6	19.4	Wheat, Maize
5	Bolero/Kazuni	178.94	1.3	2.33	3	9.1	Maize
6	Upper Dwangwa	526.37	0	0	1	41.2	Wheat, Maize
Malaria prevalence information needed							
-	Phwadzi	87.46	0	0	0	n/a	Ranch
-	Lingadzi	45.703	0	0	0	n/a	Ranch
-	Lisangadzi	153.64	13.27	20.39	0	n/a	Sugar
-	Lisunwi	117.766	0	0	0	n/a	Wheat
-	Kantungu	206.58	0	0	0	n/a	Wheat
-	Liviridzi	109.91	3.81	4.19	0	n/a	Wheat
More consideration need: Most likely to increase malaria risk							
1	Limphasa	460.26	78.0	359.00	4	22.4	Rice
2	Karonga/Kaporo	283.62	43.7	123.94	5	13.3	Rice
3	Bua/Lozi	187.91	55.5	104.29	2	27.2	Rice, Maize, Cassava
4	Muona/Ruo	307.16	29.10	89.38	1	0	Rice, Maize
5	Phalombe Plain	679.41	7.81	53.06	1	14.3	Rice, Maize, Sugar
6	Lake Malombe	88.488	57.9	51.23	1	0	Rice
7	Lingadzi/Lipimbi	525.13	5.71	29.98	3	25.3	Rice
8	Hara	275.27	12.8	35.23	1	5.0	Rice
9	Ntchalo	108.09	8.02	8.67	1	10	Rice, Maize, Sugar
Malaria prevalence information needed							
-	Chia	129.32	47.5	61.43	0	n/a	Rice, Maize, Cassava
-	Nyachipere	127.42	7.90	10.07	0	n/a	Rice, Maize
Special Consideration							
-	Bwanje/Malembo	471.85	3.13	14.77	0	n/a	Rice
-	Lake Chilwa/Chiuta	884.77	1.48	13.09	0	n/a	Rice, Sugar

There are two sites in need of special consideration. The Bwanje/Malembo site involves a planned extension of the Bwanje Valley Irrigation Scheme (BVIS) that is currently undergoing significant changes to its agroecology. In late 2018 construction of the Bwanje Dam was completed (Warm Heart News, 2018) with the intention of supplying sufficient water resources to 600-ha of the 800-ha scheme throughout the dry season (M. Mafosha, personal communication, March 27, 2019). Traditionally farmers at BVIS have grown rice during the rainy season and maize, cowpea, and beans over only 300-ha during the dry season due to limited water resources. It is anticipated that during the 2019 dry season that 600-ha of the scheme will be cultivated with rice, while the remaining 200-ha will include conventional dry season crops (M. Mafosha, personal communication, March 27, 2019). These changes will impact malaria disease dynamics of the area. Further, while no MIS clusters were located within 5-km during the 2017 surveys, cross-sectional malariometric surveys of fourteen villages within 6-km of BVIS were conducted in April 2016 and 2017 by Mangani et. al (unpublished data). Results show that household distance to BVIS is a significant predictor of malaria risk. Prevalence of infection across participants (N =5489) within 3-km of the scheme in 2016 was 33.3%; households 3—6kms was 25.9%. The intended changes to cropping practice at BVIS afforded by the Bwanje Dam present an opportunity for investigating the immediate changes to vector breeding and subsequent malaria transmission within the area prior to intended expansion under the GBI.

The other GBI site in need of special consideration prior to development is the Lake Chilwa. During analysis it was noted that many of the site boundaries digitized from the Irrigation Master Plan data either did not line up exactly with the Malawi boundary in GEE or portions of the sites were not included in the GEE analysis due to their being classified as water bodies from the JRC Global Surface Water Bodies data and were subsequently masked out during processing. For this reason, many of the GBI sites include areas of 'No Data' pixels. For the Lake Chilwa site, >50% of total area is classified as 'No Data.' Further analysis should 1) seek to improve the accuracy to of the Lake Chilwa site relative to Lake Chilwa; and 2) examine the JRC water bodies data layer and digitize if necessary a water bodies layer that is a better representation of water body margins.

The Government of Malawi (GoM) has a long-standing history of developing policies and initiatives aimed at increasing irrigation not only to mitigate food insecurity concerns, but improve overall rural livelihoods and boost economic growth (e.g., GoM, 2000b, 2015b, 2016). Through the GBI, Malawi has adopted the most aggressive expansion plan for irrigated agriculture to date; nearly 1 million hectares of land are meant to be converted along Malawi's rivers and lakes. The potential impact of such widespread change is considerable in light of Malawi's continued battle with malaria infection. As irrigation continues to expand across Malawi, geographically informed analysis of GBI sites in relationship to habitat suitability and historical malaria prevalence can assist in estimating to what extent the epidemiology of malaria will change with LULCC for irrigated agriculture. These data can elucidate sites in need of further consideration and provisioning in an effort to improve food security through irrigation without exacerbating malaria risk.

CHAPTER 6

6.1 Introduction

Development of irrigated agriculture will not occur without at least some sort of implicit scaling. Yet, this dissertation has demonstrated that 'scaling up' in research and development and natural resource management literature lacks a common ontology. Working toward irrigated agricultural solutions that mitigate food insecurity while simultaneously inhibiting the production of adult stage mosquito vectors will involve a wide range of actors embedded within myriad social and environmental systems. Uncertainty on what it means to scale up either a product or process for irrigated agriculture should not be a barrier to meeting the critical health and food security needs being addressed through irrigation interventions. In this regard, this dissertation not only provides a conceptual framework for defining scaling up and putting it in to practice for development, but also contributes new knowledge on the impact of scaling irrigated agriculture on spatio-temporal malaria disease dynamics. Primary contributions include: (1) Designed a conceptual framework to aid in precision of terminology for development activities; (2) Demonstrated marked differences in malaria risk for those residing in close proximity to irrigated schemes as a product of the heterogeneity of irrigated spaces; (3) Showed that irrigated agriculture is a driver of spatio-temporal change in the geography of malaria risk that occurs during dry seasons; (4) Demonstrated that irrigated agricultural drivers of LULCC are associated with mosquito production; (5) LULCC for irrigated agriculture will change the geography of suitable *Anopheles gambiae s.s* habitat; (6) Scale matters for malaria risk exposure; (7) Developed an open-source, dynamic habitat suitability model in Google Earth Engine (GEE) for end-users to model habitat suitability for any mosquito species; and (8) Developed a policy protocol to target irrigation implementations while simultaneously mitigating malaria risk.

6.2 Overall Contributions

6.2.1 Toward a Common Ontology of Scaling Up in Development

Chapter 2 explores the lack of ontological agreement for the phrase 'scaling up' in Research and Development (R&D) and Natural Resource Management (NRM) literature. This dissertation is conducted against a backdrop of policies and development initiatives on the part of government and international development partners aimed at scaling irrigated agriculture to mitigate food insecurity and boost economic growth. Ontological ambiguity devalues scaling up by contributing not only to the regularly reported 'success' of programs, but also the failure of these programs to scale as both a product and process. Ultimately, how scaling up is conceptualized impacts how it is operationalized, influences monitoring and evaluation, and affects program success.

To explore the varying definitions of scaling up in development literature, definitions from available Consultative Group on International Agricultural Research (CGIAR) Centers, the United States Agency for International Development (USAID) and the International Fund for Agricultural development (IFAD) were analyzed. Findings suggested that across institutions there was a distinct categorizations of terms used to define 'scaling up' that centered on individual, or combinations of Interventions, Mechanism, or Outcomes. Or, more directly, what is being scaled, how is scaling occurring, and ultimately to what end? Further, it was apparent that 'scale' is applied in two forms: a verb and a noun. The verb form is demonstrated directly in the mechanisms of scaling up. As a noun, to take an innovation to scale implies project success; there is greater emphasis on project outcomes. Rather than call for improved definitions, a conceptual framework was constructed to assist in how to define scaling up through separation of actions related to process (verb) and outcomes (noun). Importantly, the model also emphasizes the necessary role of monitoring and evaluation on both the innovation being brought to scale and scaling up efforts. The implementation of the proposed framework not only works to define a clear pathway for success but allows for critical examination of value judgments regarding development to be examined.

6.2.2 LULCC for Irrigated Agriculture and its Impact on Mosquito Distribution

Aim #1: Address land cover and land use decisions and their impact on the spatio-temporal structure of agricultural growth and mosquito distribution by:

1. Describing the LULC of BVIS and the Bwanje Valley its impact on breeding pool formation through development of a land classifications system for irrigated agriculture in rainy and dry seasons

Aim # 2 Demonstrate the influence of irrigation schemes for agriculture on mosquito breeding pool formation and persistence by:

1. Modeling breeding pool scenarios based on spatio-temporal, environmental, and anthropogenic characteristics at BVIS under three scenarios
2. Describing the association between LULC and breeding potential at BVIS contrasted with the 8-km area surrounding the scheme

Scaling irrigated agriculture to enhance crop productivity is a common tool for ensuring food security. Yet, LULCC for irrigated agriculture impacts biotic interactions within ecosystems that have been shown to encourage vector and pathogen transmission, including malaria (Boelee & Madsen, 2006; Ijumba & Lindsay, 2001; J.M.Hunter, L.Rey, K.Y.Chu, E.O.Adekolu-John, 1993; Patz, Graczyk, Geller, & Vittor, 2000). The association between irrigated schemes and the proliferation of malaria mosquitoes is well documented (see e.g. Ijumba & Lindsay, 2001; Kibret et al., 2010), yet irrigated spaces are treated as homogenous spatial units when in fact important distinctions can be made. Land cover, specifically crop type, engineering, water management, and scheme management play critical roles in defining risk potential for breeding pool formation and persistence within irrigated spaces. The aim of Chapter 3 was two-fold: first, describe the results of a characterization study conducted at the BVIS to explore the influence of the scheme's spatial distribution on breeding pool formations; second, to generate spatio-temporal breeding scenarios at BVIS to illustrate how perturbations to irrigated systems influence the distribution of breeding site potential and overall disease ecology for the local area.

The distribution of aggregated water bodies in an irrigated space is influenced by a number of factors. To that end, BVIS was characterized using multiple sources of information including: (1) satellite imagery from the SPOT-6 sensor at two time periods to assist in LULC classification; (2) spatial structure and land cover information derived through field sampling during Malawi's rainy and dry seasons; (3) Soils data from JICA (1994); and (4) onsite interviews conducted with BVIS personnel at three time periods. Field based surveys of BVIS demonstrated that the spatial distribution of water bodies was influenced by seasonality, soil properties, timing and intensity of irrigation, drainage, land cover, crop water requirements, and management. Projected distributions of breeding were constructed under three scenarios: rainy season, dry season with limited water resources, and dry season with abundant water resources. Importantly, while each model depicts similar areas of maximally suitable area for breeding, the abundance of adult stage vectors produced within these areas is seasonally variable. It is expected that during prototypical dry seasons with limited water resources, the number of vectors produced will be lower than the number produced from the same area during the rainy season and dry season with abundant water resources. This is a direct result of water availability and crop water requirements. The area of highest breeding potential during the dry season is occupied by maize, a crop that unlike rice does not require continuous flooding, limiting breeding potential. Rice is cultivated throughout the same area during the rainy season and is the proposed crop type to be cultivated once water resources from the Bwanje Dam are available during the dry season. Rice dependency on water provides a consistent, favorable environment for mosquito oviposition and subsequent rearing of adult stage vectors (IRRI, 1988). Results elucidate how the heterogeneity of the landscape both in land cover and in land and water management influence the spatio-temporal distribution of risk for mosquito breeding.

Chapter 4 addressed how LULCC for irrigated agriculture changes the distribution of breeding risk for malaria mosquitoes across landscapes and in turn, malaria disease ecology for local areas during the dry season. Irrigated agriculture provides a stable source of surface water availability throughout the dry season; a period when mosquito breeding is often limited. To estimate breeding potential, the study had two primary objectives: (1) Develop a dry season LULC classification system through field-based surveys of the Bwanje Valley; and (2) Construct a breeding pool suitability model to differentiate breeding risk potential between the Bwanje Valley and BVIS. In this study, the 'Bwanje Valley' was defined at the 8km area surrounding BVIS. An 8km distance gave consideration to the maximum recorded flight distance of the *Anopheles gambiae s.s.* mosquito, while also providing adequate estimation of LULC attributable to BVIS and the Bwanje Valley that may promote mosquito development. Findings demonstrated that suitable breeding areas throughout the Bwanje Valley had a distinct spatial structure. Categorization of suitability showed supraoptimal areas for mosquito breeding were concentrated within BVIS. In comparison, the surrounding Bwanje Valley ranged from merely satisfactory to unsuitable. Models demonstrated the asymmetrical breeding potential for *Anopheles* mosquitoes as a result of irrigated agriculture. In turn, not only does irrigation change the geography of mosquito breeding, but seasonal malaria disease dynamics through lengthening of transmission windows and risk potential for those residing in close proximity to irrigated spaces.

6.2.3 Malaria Vulnerability and Dynamic Changes to Irrigated Agriculture

Aim #3: Assess the impact of dynamic changes in irrigated agriculture on malaria vulnerability in Malawi by:

1. Examining the spatio-temporal change in irrigated agriculture at the national scale
2. Describing habitat suitability for *Anopheles gambiae s.s.* mosquitoes in Malawi through construction of a habitat suitability model in Google Earth Engine

3. Addressing the historical and plausible future impact on malaria vulnerability driven by scaling irrigated agriculture

Irrigation development in Malawi dates back to the 1940's spurred by national policy frameworks often tied to efforts to increase economic growth. Outlined in the Government of Malawi's (GoM) Irrigation Master Plan, irrigable area is intended to expand to 220,000 hectares (ha) by 2035; 104,299 ha had been developed by 2015 (GoM, 2015b). Further, through the Green Belt Initiative (GBI), the GoM has committed to offering nearly 1 million hectares for irrigation development. Chapters 3 and 4 highlight the impact of irrigated agriculture on mosquito breeding pool formation and persistence. It is expected that the production of adult stage *Anopheles* mosquitoes from irrigated areas will result in greater risk exposure to infectious bites for those living in close proximity to irrigated schemes compared with those living further away. Further, where irrigation is conducted during the dry season, malaria prevalence will be higher for those living nearer to irrigated sites.

The impact of expansion of irrigated agriculture on the spatial distribution of malaria vulnerability in Malawi was examined by: (1) Investigating the historical and current (2015) distribution of irrigated agriculture in Malawi; (2) Developing a habitat suitability model in Google Earth Engine (GEE) for the malaria vector, *Anopheles gambiae s.s.* to determine suitable landscape for the species across Malawi; (3) Assessing malaria prevalence data from the Demographic and Health Surveys (DHS) Malaria Indicator Survey (MIS) at the cluster level; (4) Examining relationships between habitat suitability drivers and malaria prevalence from the 2012, 2014, and 2017 MIS surveys; and (5) Modeling maximum estimations of habitat suitability using the produced habitat suitability model for 2017 and potential GBI area data.

Study findings show habitat suitability drivers among MIS clusters for 2012, 2014, and 2017 are most often associated with suitable land characteristics (NDVI and Land Cover), followed by the combination of suitable land and water (precipitation, water bodies, and flow accumulation) characteristics. Areas described as supraoptimal for breeding occurred most often in rural, as opposed to urban clusters for each survey year. These areas exhibited suitable conditions based on climate, land, and water characteristics. A maximum estimation of habitat suitability using the results of the 2017 habitat suitability model and potential GBI area data elucidated the expansion of *An. gambiae s.s.* niche driven by LULCC for irrigated agriculture. Notable changes included the expansion of supraoptimal area from 6.86% (~6.7 million km^2) in the 2017 product to 7.06% (~6.9 million km^2) under the GBI scenario. Further, the expansion of areas suitable according to land and water characteristics from 24.90% in the 2017 product to 40.66% in the GBI scenario. These data along with information on proposed crop type for each GBI site were used to provide a ranked categorization of GBI sites based on their likelihood to increase malaria risk through the production of suitable breeding sites for malaria mosquitoes. Twelve sites were categorized as least likely to increase malaria risk, eleven as most likely to increase malaria risk, and two where additional consideration is needed. As irrigation expands under the Irrigation Master Plan in Malawi, geographically informed analysis of irrigation sites in relationship to habitat suitability and historical malaria prevalence can assist in estimating to what extent the epidemiology of malaria will change with LULCC for irrigated agriculture. Further, what re-consideration or provisioning may be necessary to mitigate malaria transmission risk through the production of *Anopheles* mosquitoes.

6.2.4 Measuring agreement of predictive mosquito habitat

This work produced models of suitable breeding habitat for malaria mosquitoes at different spatial units and scales. Results of the Malawi habitat suitability model in GEE presented in Chapter 5 are at a 250-m resolution. Habitat suitability models at BVIS (Chapter 3) and the Bwanje Valley (Chapter 4) are at a 6-m resolution. To estimate agreement of model outputs for the GEE and Bwanje Valley (BV) model, the Kappa (κ) coefficient was used after clipping the GEE model to the Bwanje Valley perimeter. Confusion matrices were produced in ArcMap™ 10.5.1. and reference (test pixel) data for each class were selected from the BV map; 60 test pixels were selected per class (see e.g. Jensen, 2005). The κ coefficient value indicates poor agreement between the two models (0.07), this is in part a result of differences in spatial resolutions but also data product inputs for each model. Visual inspection highlights the impact of each model's spatial resolution on modeled outputs at this scale. The GEE model shows four suitability classes: unsuitable, suboptimal, marginal, and satisfactory. The majority (80.1%) is classified as suboptimal for breeding, with 17.7% classified as Marginal. Marginal areas in the GEE model are strongly influenced by the Flow Accumulation variable, following river and ephemeral stream channels in the area. Less than 1% is satisfactory for breeding, located in the far western portion of the Bwanje Valley. A notable difference between the GEE and BV model is the absence of optimal and supraoptimal classified area in the GEE model. This is due to the absence of land use information on irrigated area encoded within the LULC data used to construct the GEE model. It is important to note that while global scale data are useful, they do not provide specific local scale information. Irrigation at BVIS critical to defining suitable breeding habitat in the Bwanje Valley, yet it is not reflected in the GEE model. Contrastingly, the LULC data product used in the construction of the BV model were collected from in-situ field measurements of the Bwanje Valley which provide a more accurate estimation of LULC across the Bwanje Valley, and thereby representation of mosquito breeding opportunity. Finally, there are distinct differences in temporal periods for each model. The GEE habit suitability model is constructed on an annual, not seasonal basis. The BV model is a representation of habitat suitability during the dry season at the Bwanje Valley.

6.3 Future Research

6.3.1 Interpretations of Scaling and Their Influence on Development

How institutions define scaling up influences how scaling is operationalized (i.e., the intervention and/or pathway to scaling), influences monitoring and evaluation, and affects program success. As was discussed in Chapter 2, scaling up lacks ontological commitment across R&D institutions. With this being the case, it would not be unreasonable to assume that how scaling programs are conceptualized by different governments vary too. The research and conceptual model presented in Chapter 2 provides a framework for engendering further consideration on the precision of scaling up terminology. Multiple development partners and foreign governments have partnered with Malawi to scale irrigated agriculture (e.g., USAID, JICA, European Union). Future work could present commonalities and discrepancies in the meaning of scale, not only over time, but among institutions and partners to describe how conceptions of scale have and could continue to influence development interventions.

6.3.2 Heterogeneity in Irrigated Landscapes

This dissertation found that not only do irrigated agricultural spaces create asymmetrical breeding potential for malaria mosquitoes across landscapes, but even within irrigated spaces, the distribution of breeding risk is heterogeneous. The aggregation of water bodies suitable for oviposition in irrigated schemes is the result of a number of factors. As a result, there is no single solution to mitigating and controlling vector populations. Engineering, water management, scheme management, and crop selection and geography individually and collectively influence where and to what extent mosquitoes will reach adult stage. To effectively irrigate for mosquito control, the irrigation system as a whole from movement of water from irrigation source, to field application, timing and intensity of watering coincident with soil properties, ponding potential, and root water uptake of plants must be given adequate consideration.

Mosquito larval surveying was conducted at the Bwanje Valley Irrigation Scheme in May 2017 and March 2019 to coincide with rice growing stages; mature and newly transplanted, respectively. Sampling was designed with specific consideration for irrigation structure at BVIS. Sample transects followed alternating tertiary canals across the scheme (N=41). At each transect, research assistants sampled at 30m intervals to coincide with average plot size. Collection sites were recorded using a handheld Global Positioning System (GPS), then inspected for water status: Present/Absent; Moving/Still, and stage of rice growth within the sample plot: "Transplant", Tillering", "Panicle", "Flowing", and "Mature". Observations of total water within each plot sampled were recorded as, "Completely flooded", "Partially flooded", or "Scattered puddles." Where water was present, larvae were sampled with a standard 350 ml mosquito dipper (Kenea et al., 2011; Kweka et al., 2012) with maximum of ten dips. Larvae were transferred to a container and identified on the basis of larval and pupal characteristics, and counted. While present, Culicines were excluded from analysis. For the survey conducted in March 2019, all sites were sampled 2—3 days after irrigation had been applied to plots. Future work will cross reference the results of these surveys with the modeled predictions of breeding pool risk produced in Chapter 3.

The research in Chapter 3 provides an initial step in estimating the spatial distribution of breeding pools within irrigated agricultural schemes. However, at present these estimates are static and do not reflect the influence of changes in crop phenology, or timing and intensity of irrigation. As is discussed throughout this dissertation, *Anopheles* mosquitoes have characteristic breeding preferences and vary in their efficiency in transmitting malaria. In Chapter 3, the differences related to vegetative growth stage and *An. funestus*, *An. gambiae*, and *An. arabiensis* are described. Developing pixel-level time series of phenology would not only assist in measuring spatio-temporal changes in vegetation dynamics and breeding potential but would be useful in determining the specific mosquito species breeding within the irrigated space as well. Beyond phenology alone, future studies should consider the use of Monte Carlo simulations to model the probability of breeding pool potential based on perturbations to the irrigated system including crop type(s) and their spatial arrangement within the irrigated space, timing and intensity of irrigation, precipitation events, and drainage. This technique could further elucidate the geography of malaria transmission risk through the production of adult stage vectors for those living in close proximity to irrigated schemes.

6.3.3 Spatial Structure of Active Agriculture

Chapter 5 examined the association between breeding pool suitability at BVIS contrasted with the Bwanje Valley. Primary findings showed surpraoptimal breeding was most prominent within the irrigated portion of BVIS demonstrating the impact of LULCC for irrigated agriculture on the Bwanje Valley and its inhabitants. In the absence of irrigation, active agricultural areas would be considered the most favorable areas for dry season mosquito breeding. The suitability model presented does not adequately address the spatial distribution of active agricultural spaces throughout the study area. During field surveying for LULC in the Bwanje Valley, instances were rare resulting in the absence of an active agricultural LULC class beyond BVIS. Future studies should work to specifically identify these areas either through field based observation or remotely sensed methods to more accurately assess risk potential for breeding.

6.3.4 Surface Wetness

Water availability is a requisite for mosquito development. During oviposition, females will lay their eggs either on or in the water, or on solid substrates that are likely to become inundated (Foster & Walker, 2009). As such, malaria transmission is limited to regions that allow for the formation and persistence of water bodies suitable for oviposition. These water bodies are not a linear function of rainfall, but rather are a product of precipitation, antecedent soil moisture, soil type, and rates of evapotranspiration (Shaman & Day, 2005). The relationship between vector populations and water availability make hydrology models and hydrologic monitoring useful as a predictive tool for mosquito abundance. To further estimate the spatial distribution of mosquito breeding pool formation in irrigated agricultural schemes and/or the surrounding landscapes, time series simulations of surface wetness could be produced through combination of Synthetic Aperture Radar (SAR) data and high spatial resolution Digital Elevation Models (DEMs). Comparisons of estimated soil moisture between irrigated and non-irrigated spaces in combination with data on LULC may provide important insights into understanding the distribution of breeding risk.

6.3.5 Spatio-Temporal Expansion of Irrigated Agriculture

Irrigated agriculture in Malawi began in the late 1940s and has since expanded to 104,299 ha as of 2015 (GoM, 2015b). While statistics on the estimates of irrigated area exist in the literature, the geography of irrigated area in Malawi was unrecorded until the completion of the Irrigation Master Plan and Investment Framework in 2015. Were these data available, it would have been enlightening to investigate correlations between the geography of irrigation expansion along with changes to malaria prevalence data according to the MIS surveys. One method to estimate the geographical extent of irrigated agricultural area over time would be through examination of remotely sensed, time-series NDVI and Enhanced Vegetation Index (EVI) data for Malawi during the dry season. NDVI is a measure of both vegetation presence and health (Jensen, 2005); EVI is similar to NDVI but has the added benefit of canopy reflectance properties and soil reflectance correction. There are considerable differences in NDVI for irrigated and non-irrigated crops; irrigated areas demonstrate higher NDVI values than non-irrigated (Krishnankutty Ambika, Wardlow, & Mishra, 2016). These differences in values during the dry season may assist in differentiating between irrigated and non-irrigated areas to create high spatial-resolution irrigated maps for Malawi. This method has successfully been applied to mapping irrigated area in India (Krishnankutty Ambika et al., 2016; Sharma et al., 2018) and Arizona (Zheng, Myint, Thenkabail, & Aggarwal, 2015).

6.3.6 Habitat Suitability and Malaria Prevalence

Malaria is an ongoing, significant public health issue in Malawi (DHS, 2017). While this research demonstrates habitat suitability drivers for MIS clusters, there is a need to explore the relationship between habitat suitability defined by the HSM product produced as a part of this work and malaria prevalence. Distributions of disease vectors are directly related to environmental conditions that support the biological requirements for species survival. Thus, malaria cases are assumed to be positively linked to potential habitat suitability. One method for examining the relationship between habitat suitability variables and malaria prevalence is Geographically Weighted Regression (GWR).

Rather than examining global estimates, GWR allows for local variation and rates of change in model coefficients in order to better understand the spatial structure of observed relationships (Brunsdon, Fotheringham, & Charlton, 1996; O'Sullivan & Unwin, 2014). GWR could be implemented to explore local effects of habitat suitability variables on malaria prevalence data for 2012, 2014, and 2017.

There is significant interest in the relationship between irrigated agriculture and malaria as irrigation is scaled to meet global food demands. By examining LULCC for irrigated agriculture and malaria risk, this dissertation contributes important information on the impact of scaling irrigated agriculture in Malawi on spatio-temporal malaria disease dynamics. LULCC for irrigated agriculture alters landscapes and encourages the production of malaria vectors. The purpose of this body of work is not to undermine irrigation, nor to contend that efforts to increase irrigated agriculture should cease. Rather, in light of continued LULCC for irrigated agriculture across scales, there should be specific consideration given to how human-environment interactions, even those whose intentions are rooted in promoting positive health outcomes, can simultaneously lead to declining outcomes in other health arenas. Scaling irrigated agriculture is an effective, existing intensification strategy for meeting food production demands to ensure global food security. It is necessary then to consider how irrigation can be effectively scaled such that it does not encourage the proliferation of *Anopheles* mosquitoes, particularly in malaria-endemic areas.

APPENDICES

APPENDIX A:

Rainy Season LULC Data: BVIS

Rainy Season BVIS LULC Classification Table

Class Descriptions	BVIS Sample	BVIS AA	TOTAL
I. AGRICULTURAL LAND			
I. ACTIVE			
Rice			
Flooded Field	2	0	**2**
Flooded Field w/ Dried Grasses	2	0	**2**
Early Growth w/ Visible Water & Grasses	2	1	**3**
Early Growth w/ Visible Light Standing Water	1	0	**1**
Early Growth w/ Visible Dark Standing Water	0	2	**2**
Mid-Growth w/ Visible Light Standing Water	1	0	**1**
Mid-Growth w/ Visible Dark Standing Water	0	2	**2**
Panicle	14	8	**22**
Panicle w/ Dried Grasses	3	1	**4**
Panicle & Grasses: Tall	8	1	**9**
Varied Growth Stages	2	1	**3**
Maize			
Mature	7	0	**7**
Past Maturity	5	2	**7**
Sweet Potato			
Mature	1	1	**2**
Young	2	0	**2**
Sweet Potato & Grasses	0	1	**1**
Sweet Potato & Emergent Shrubbery	1	0	**1**
Pumpkin			
Intermediate Growth Stage & Grasses	1	0	**1**
Mixed Cropping			
Sweet Potato: Young & Panicle Rice	1	1	**2**
Sweet Potato: Mature, Maize: Mature, & Rice: Panicle	0	1	**1**
Rice: Panicle & Maize: Mature	3	2	**5**
II. FALLOW			
Grasses			
Tall	3	1	**4**
Tall and Standing Water	1	1	**2**
Human Influence			
Road	1	0	**1**
Straw Structure on Bare Soil	1	1	**2**

Class Descriptions	BVIS Sample	BVIS AA	TOTAL
II. IRRIGATION INFRASTRUCTURE			
Concrete Canal w/ Flowing Water, Bare Earth & Dried Grasses	1	0	**1**
Concrete Canal w/ Flowing Water & Emergent Grasses	2	1	**3**
Concrete Canal w/ Flowing Water, Emergent Grasses & Maize	0	1	**1**
Concrete Canal w/ Flowing Water, Emergent Grasses & Dried Grasses	0	3	**3**
Concrete Bridge Over Dirt Canal w/ Emergent Grasses	0	1	**1**
Dirt Canal w/ Standing Water & Dried Grasses	0	1	**1**
Dirt Canal w/ Standing Water & Panicle Rice	0	1	**1**
III. TREES			
Banana Trees	1	1	**2**
Green foliage on flooded rice plot	1	0	**1**
Trees: Roadway Adjacent	1	0	**1**

Rainy Season BVIS LULC Classification Photos

I. AGRICULTURAL LAND

II. ACTIVE

Rice

Flooded Field

Sample Photos:

LULC_73

LULC_86

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND

II. ACTIVE

Rice

Flooded Field w/ Dried Grass

Sample Photos:

LULC_4

LULC_9

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND

II. ACTIVE

Rice

Early Growth w/ Visible Water & Grasses

Sample Photos:

LULC_11

LULC_17

Accuracy Assessment Photos:

AA_91

I. AGRICULTURAL LAND
II. ACTIVE
Rice
Early Growth w/ Visible Light Standing Water
Sample Photos:  LULC_81
Accuracy Assessment Photos: None

I. AGRICULTURAL LAND	
II. ACTIVE	
Rice	
Early Growth w/ Visible Dark Standing Water	
Sample Photos: None	
Accuracy Assessment Photo:	
 AA_167	 AA_144

I. AGRICULTURAL LAND
II. ACTIVE
Rice
Mid-Growth w/ Visible Light Standing Water
Sample Photos:

LULC_80

Accuracy Assessment Photos:
None

I. AGRICULTURAL LAND
II. ACTIVE
Rice
Mid-Growth w/ Visible Dark Standing Water
Sample Photos: None

Accuracy Assessment Photos:

AA_150

AA_97

I. AGRICULTURAL LAND

II. ACTIVE

Rice

Mature

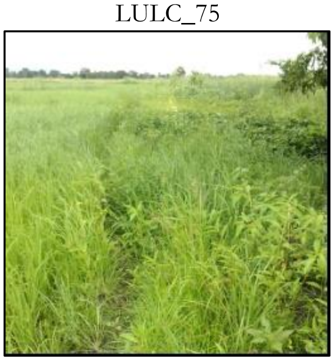
Sample Photos:

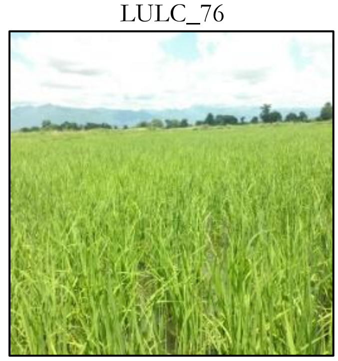

LULC_70

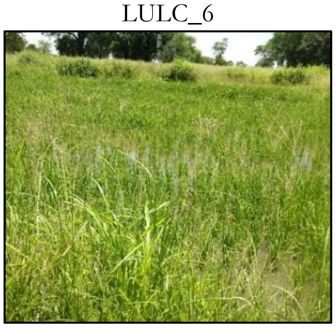

LULC_74


LULC_75


LULC_76


LULC_6


LULC_85


LULC_157


LULC_158


LULC_159


LULC_160


LULC_161


LULC_162

Accuracy Assessment Photos:

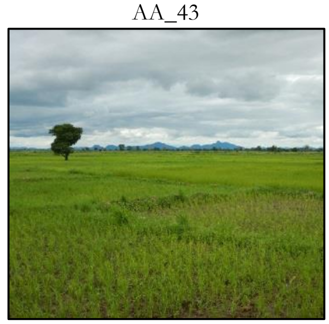

AA_127


AA_154


AA_171


AA_43


AA_59


AA_7

	 AA_75  AA_148

I. AGRICULTURAL LAND	
	II. ACTIVE
	Rice
	Mature w/ Dried Grasses

Sample Photos:

LULC_20

LULC_18

LULC_72

Accuracy Assessment Photos:

AA_62

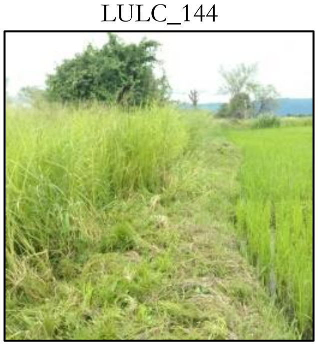
I. AGRICULTURAL LAND	
	II. ACTIVE
	Rice
	Mature & Grasses: Tall
	Sample Photos:

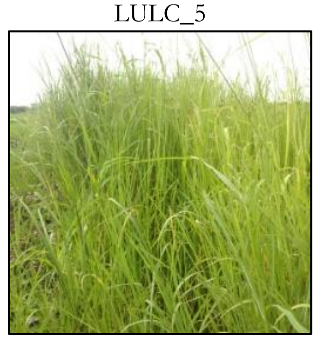

LULC_23

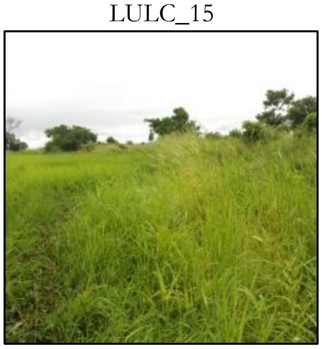

LULC_21

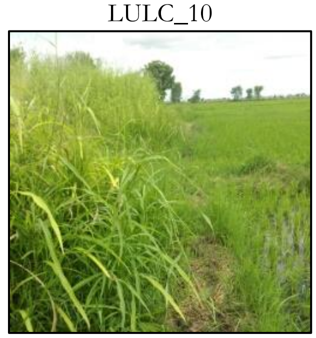

LULC_144


LULC_5


LULC_15


LULC_10


LULC_7


LULC_32

	Accuracy Assessment Photos:  AA_31

I. AGRICULTURAL LAND	
	II. ACTIVE
	Rice
	Varied Growth Stage
	Sample Photos:  LULC_13  LULC_84
	Accuracy Assessment Photos  AA_13

I. AGRICULTURAL LAND

II. ACTIVE

Maize

Mature

Sample Photos:

LULC_91

LULC_28

LULC_50

LULC_58

LULC_94

LULC_97

LULC_83

Accuracy Assessment Photos

I. AGRICULTURAL LAND
II. ACTIVE
Maize
Past Maturity

Sample Photos

LULC_37

LULC_64

LULC_93

LULC_95

LULC_96

Accuracy Assessment Photos:

AA_25

AA_110

I. AGRICULTURAL LAND

II. ACTIVE

Sweet Potato

Mature

Sample Photos:

LULC_69

Accuracy Assessment Photos:

AA_137

I. AGRICULTURAL LAND

I. ACTIVE

Sweet Potato

Young

Sample Photos:

LULC_3

LULC_78

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND

I. ACTIVE

Sweet Potato

Sweet Potato & Grasses

Sample Photos:

None

Accuracy Assessment Photos:

AA_33

I. AGRICULTURAL LAND
I. ACTIVE
Sweet Potato
Sweet Potato & Emergent Shrubbery
Sample Photos:  LULC_68
Accuracy Assessment Photos: None

I. AGRICULTURAL LAND
I. ACTIVE
Pumpkin
Intermediate Growth Stage & Grasses
Sample Photos:  LULC_92
Accuracy Assessment Photos: None

I. AGRICULTURAL LAND
I. ACTIVE
Mixed Cropping
Sweet Potato: Young & Rice: Mature
Sample Photos:

LULC_60

Accuracy Assessment Photos:
None

I. AGRICULTURAL LAND
I. ACTIVE
Mixed Cropping
Sweet Potato: Mature & Rice: Mature
Sample Photos: None
Accuracy Assessment Photos:

AA_142

I. AGRICULTURAL LAND
I. ACTIVE
Mixed Cropping
Sweet Potato: Mature Maize: Mature & Rice: Mature
Sample Photos: None
Accuracy Assessment Photos:  AA_141

I. AGRICULTURAL LAND
I. ACTIVE
Mixed Cropping
Rice: Mature & Maize: Mature

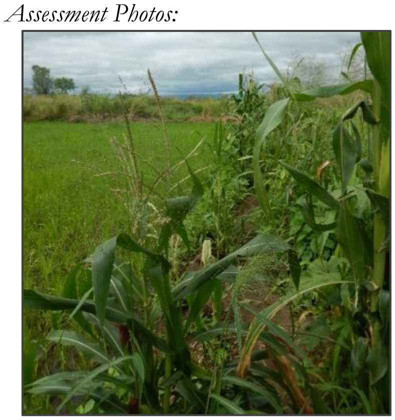
Sample Photos:

LULC_53

LULC_29

LULC_41

Accuracy Assessment Photos:



AA_162

AA_165

I. AGRICULTURAL LAND

II. FALLOW

Grasses

Tall

Sample Photos:


LULC_1


LULC_2


LULC_22

Accuracy Assessment Photos:


AA_29

I. AGRICULTURAL LAND	
II. FALLOW	
Grasses	
Tall & Standing Water	
Sample Photos: None	
Accuracy Assessment Photos:  AA_104	

I. AGRICULTURAL LAND	
II. FALLOW	
Human Influence	
Dried Grass	
Sample Photos:  LULC_67	
Accuracy Assessment Photos: None	

I. AGRICULTURAL LAND

II. FALLOW

Human Influence

Straw Structure on Bare Soil

Sample Photos:

LULC_79

Accuracy Assessment Photos:

AA_70

I. AGRICULTURAL LAND		
	III. IRRIGATION INFRASTRUCTURE	
		Concrete Canal w/ Flowing Water & Bare Earth + Dried Grass
		Sample Photos:  LULC_77
		Accuracy Assessment Photos: None

I. AGRICULTURAL LAND

III. IRRIGATION INFRASTRUCTURE

Concrete Canal w/ Flowing Water & Emergent Grasses

Sample Photos:

LULC_63

LULC_88

Accuracy Assessment Photos:

AA_6

I. AGRICULTURAL LAND

III. IRRIGATION INFRASTRUCTURE

Concrete Canal w/ Flowing Water, Emergent Grasses & Maize

Sample Photos:
None

Accuracy Assessment Photos:

AA_47

I. AGRICULTURAL LAND
III. IRRIGATION INFRASTRUCTURE
Concrete Canal w/ Emergent Grasses & Dried Grasses
Sample Photos: None
Accuracy Assessment Photos:

AA_2

AA_77

AA_19

I. AGRICULTURAL LAND		
	III. IRRIGATION INFRASTRUCTURE	
		Concrete Bridge Over Dirt Canal w/ Emergent Grasses
		Sample Photos: None
		Accuracy Assessment Photos:  AA_46

I. AGRICULTURAL LAND		
	III. IRRIGATION INFRASTRUCTURE	
		Dirt Canal w/ Standing Water & Emergent Grasses
		Sample Photos:  LULC_39
		Accuracy Assessment Photos: None

I. AGRICULTURAL LAND
III. IRRIGATION INFRASTRUCTURE
Dirt Canal w/ Standing Water & Dried Grasses
Sample Photos: None
Accuracy Assessment Photos:

AA_73

I. AGRICULTURAL LAND
III. IRRIGATION INFRASTRUCTURE
Dirt Canal w/ Standing Water & Mature Rice
Sample Photos: None
Accuracy Assessment Photos:

AA_123

I. AGRICULTURAL LAND

IV. TREES

Banana Trees

Sample Photos:

LULC_90

Accuracy Assessment Photos:

AA_26

I. AGRICULTURAL LAND

IV: TREES

Green Foliage on Flooded Rice Plot

Sample Photos:

LULC_65

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND
IV: TREES
Banana Trees & Dense Shrubbery
Sample Photos: None
Accuracy Assessment Photos:  BVIS_AA_159

I. AGRICULTURAL LAND
IV: TREES
Green Foliage on Roadway
Sample Photos:  *LULC_66*
Accuracy Assessment Photos: None

Rainy Season BVIS Data

ID	Name	X	Y	Elev	Pnt_Type	PntAcq	Offset_Dis	Class	SubClass	Land_Cover	Land_Use	Notes
1	LULC_1	34.63208	-14.234	452.6	Sample	On	0	Fallow	Grasses	Grasses: Tall	Agricultural Land	Tall grasses lining tertiary canal
2	LULC_10	34.62554	-14.24431	472.4	Sample	On	0	Active	Rice	Rice: Mature & Grasses: Tall	Agricultural Land	Boundary - tertiary canal ridge. The canal is not functional (tall grass growing)
3	LULC_11	34.62472	-14.24533	471.8	Sample	On	0	Active	Rice	Rice: Early Growth w/ Visible Water & Grasses	Agricultural Land	Boundary - just next (close) to the main drain.
4	LULC_13	34.62251	-14.24478	471.5	Sample	On	0	Active	Rice	Rice: Varied Growth Stages	Agricultural Land	Point within the scheme on the ridge between rice paddy plots ~90m to the boundary on the southern part.
5	LULC_144	34.62185	-14.24439	469.3	Sample	On	0	Active	Rice	Rice: Mature & Grasses: Tall	Agricultural Land	
6	LULC_15	34.61904	-14.24531	471.5	Sample	On	0	Active	Rice	Rice: Mature & Grasses: Tall	Agricultural Land	Boundary - tall grass on the southern side.
7	LULC_157	34.6058	-14.2559	493.5	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	Visible water present

8	LULC_158	34.585	-14.2549	500.8	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	Point taken from a bund
9	LULC_159	34.595	-14.2521	496.6	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	Visible water present. Rice not as tightly planted
10	LULC_160	34.5864	-14.2594	501.7	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	Adjacent field has visible standing water; noting planted yet
11	LULC_161	34.6268	-14.2393	481.0	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	Adjacent field has visible dark standing water
12	LULC_162	34.6213	-14.2414	483.1	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	Transition between two fields. One is at a slightly earlier growth stage
13	LULC_163	34.6086	-14.2524	491.9	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	
14	LULC_164	34.5798	-14.2666	504.5	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	Some visible standing water between plantings.
15	LULC_17	34.61735	-14.24621	471.2	Sample	On	0	Active	Rice	Rice: Early Growth w/ Visible Water & Grasses	Agricultural Land	Boundary: Tall grass grown on the southern part and some trees.

16	LULC_18	34.61707	-14.24602	474.5	Sample	On	0	Active	Rice	Rice: Mature w/ Dried Grasses	Agricultural Land	Grasses lining non functioning tertiary canal
17	LULC_2	34.63451	-14.23507	468.7	Sample	On	0	Fallow	Grasses	Grasses: Tall	Agricultural Land	Tall grasses lining non functioning tertiary canal
18	LULC_20	34.61568	-14.24639	475.4	Sample	On	0	Active	Rice	Rice: Mature w/ Dried Grasses	Agricultural Land	Ridge on tertiary canal between rice fields running from NW to SW.
19	LULC_21	34.61462	-14.24774	472.1	Sample	On	0	Active	Rice	Rice: Mature & Grasses: Tall	Agricultural Land	Boundary. Tall grasses on other side.
20	LULC_22	34.61443	-14.24745	475.1	Sample	On	0	Fallow	Grasses	Grasses: Tall	Agricultural Land	Tall grasses lining non functioning tertiary canal
21	LULC_23	34.61422	-14.24756	477.0	Sample	On	0	Active	Rice	Rice: Mature & Grasses: Tall	Agricultural Land	Grass walkway between plots (one plot away from boundary (on a strip of 4 plots cultivate).
22	LULC_28	34.61056	-14.2495	477.0	Sample	On	0	Active	Maize	Maize: Mature	Agricultural Land	Boundary of scheme. Maize is growing on the upland here.

23	LULC_29	34.61005	-14.25092	478.5	Sample	On	0	Active	Mixed Cropping	Rice: Mature & Maize: Mature	Agricultural Land	Scheme edge. Road to west rice planted in fields. Maize on upland with a small border ~1ft of tall grasses
24	LULC_3	34.63435	-14.23691	468.7	Sample	On	0	Active	Sweet Potato	Sweet Potato: Young	Agricultural Land	Within the scheme 1 field of sweet potatoes on the upland.
25	LULC_32	34.57975	-14.25081	488.5	Sample	On	0	Active	Rice	Rice: Mature & Grasses: Tall	Agricultural Land	Boundary - rice paddy field on SE and tall grass grown on NE. Several trees next to grass on NE.
26	LULC_37	34.57704	-14.25372	489.2	Sample	On	0	Active	Maize	Maize: Past Maturity	Agricultural Land	Almost 1 acre of maize field within the scheme near the boundary.
27	LULC_39	34.57596	-14.25475	500.1	Sample	On	0	Fallow	Grasses	Grasses: Tall & Standing Water	Agricultural Land	Diversion point from the drain to the scheme fields.
28	LULC_4	34.63375	-14.23818	466.3	Sample	On	0	Active	Rice	Rice: Flooded Field w/	Agricultural Land	Boundary

										Dried Grasses		
29	LULC_41	34.57477	-14.25682	496.8	Sample	On	0	Active	Mixed Cropping	Rice: Mature & Maize: Mature	Agricultural Land	Within the scheme. On the ridge between the maize (grown next to the drain - strip running from east to west (see diagram in notebook) field and rice
30	LULC_5	34.63121	-14.23965	469.0	Sample	On	0	Active	Rice	Rice: Mature & Grasses: Tall	Agricultural Land	Tertiary canal downstream not functional.
31	LULC_50	34.57161	-14.26163	498.0	Sample	On	0	Active	Maize	Maize: Mature	Agricultural Land	On the footpath in the maize field. The maize field is located between the drain and rice paddy field supplied with drainage water.
32	LULC_53	34.57055	-14.26251	494.9	Sample	On	0	Active	Mixed Cropping	Rice: Mature & Maize: Mature	Agricultural Land	Rice grown in the main drain and there is maize grown on the upland between

												the drain and the rice paddy fields.
33	LULC_58	34.56821	-14.26424	506.8	Sample	On	0	Active	Maize	Maize: Mature	Agricultural Land	Maize field
34	LULC_6	34.62929	-14.24205	470.3	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	Boundary
35	LULC_60	34.5672	-14.26503	502.9	Sample	On	0	Active	Mixed Cropping	Sweet Potato: Young w/ Rice: Mature	Agricultural Land	Drain running from west to east there is rice cultivated within the drain and sweet potatoes on the side.
36	LULC_63	34.59582	-14.26065	485.8	Sample	On	0	Ag Infrastructure	Irrigation Structure	Concrete Canal w Flowing Water & Emergent Grasses	Agricultural Land	drainage meets canal
37	LULC_64	34.59565	-14.26084	488.2	Sample	On	0	Active	Maize	Maize: Past Maturity	Agricultural Land	maize middle od drain and old canal used as drain
38	LULC_65	34.59061	-14.25986	505.0	Sample	Offset	25	Trees	Trees	Trees: Green foliage on flooded rice plot	Agricultural Land	Original point is a large tree shading most of a farmers field. Point taken on road.
39	LULC_66	34.59708	-14.25299	492.2	Sample	On	0	Trees	Trees	Trees: Green Foliage on Roadway	Agricultural Land	Tree between canal and village

												along roadway
40	LULC_67	34.60095	-14.25116	488.2	Sample	On	0	Ag Infrastructure	Human Influence	Road	Agricultural Land	Point taken on roadway. Village adjacent
41	LULC_68	34.60478	-14.24897	474.2	Sample	On	0	Active	Sweet Potato	Sweet Potato & Emergent Shrubbery	Agricultural Land	Not rice; taller unmanaged weeds one rice field to the east. Two plots past the end of irrigation canal.
42	LULC_69	34.55937	-14.27472	499.2	Sample	On	0	Active	Sweet Potato	Sweet Potato: Mature	Agricultural Land	sweet potato rice on all sides
43	LULC_7	34.62824	-14.2424	472.4	Sample	On	0	Active	Rice	Rice: Mature & Grasses: Tall	Agricultural Land	Boundary next to the main drain.
44	LULC_70a	34.568199	-14.2657	498.0	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	
45	LULC_70	34.56821	-14.26569	498.0	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	Point is within rice paddy filed; great deal of standing H20. Almost to the top of boots ~7ft from bund (to east).
46	LULC_72	34.58018	-14.2568	487.3	Sample	On	0	Active	Rice	Rice: Mature w/ Dried Grasses	Agricultural Land	Point just off the road immediatel y adjacent to rice paddies. This point

												has mounded up grasses.
47	LULC_73	34.57882	-14.25982	488.2	Sample	On	0	Active	Rice	Rice: Flooded Field	Agricultural Land	field ponded with excess water
48	LULC_74	34.57863	-14.26104	491.6	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	Taken from bund. Original point is inside rice paddy. Bund has tall grasses. Taller than Willy.
49	LULC_75a	34.5774	-14.2617	494.3	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	
50	LULC_75	34.57745	-14.26167	494.3	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	Taken on a bund point is inside of a rice field. Bund = mounded grasses.
51	LULC_76	34.57612	-14.26408	493.4	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	Rice paddies potentially the bund separating two fields.
52	LULC_77	34.57581	-14.26449	496.8	Sample	Offset	1	Ag Infrastructure	Irrigation Structure	Concrete Canal w/ Flowing Water, Bare Earth & Dried Grasses	Agricultural Land	
53	LULC_78	34.57601	-14.2642	500.4	Sample	On	0	Active	Sweet Potato	Sweet Potato: Young	Agricultural Land	Exposed bare earth (for sweet potatoes) adjacent to flooded

												rice paddies. More water and this area could be flooded too
54	LULC_79	34.57528	-14.26512	498.6	Sample	Offset	10	Ag Infrastructure	Human Influence	Straw structure on Bare Soil	Agricultural Land	Straw structure
55	LULC_80	34.568	-14.26469	496.8	Sample	On	0	Active	Rice	Rice: Mid-Growth w/ Visible Light Standing Water	Agricultural Land	Rice adjacent to unintended maize to the north seeming the northern boundary of the scheme.
56	LULC_81	34.56274	-14.27414	501.7	Sample	On	0	Active	Rice	Rice: Early Growth w/ Visible Light Standing Water	Agricultural Land	Used point: 3-6-2017 @ 3:18 pm. 14.27349, 34.55320, maize
57	LULC_83	34.6022	-14.2573	485.8	Sample	On	0	Active	Maize	Maize: Mature	Agricultural Land	Three rows of maize planted immediatel y adjacent to the road in upland area.
58	LULC_84	34.6073	-14.2508	482.4	Sample	On	0	Active	Rice	Rice: Varied Growth Stages	Agricultural Land	At almost the corner of the last section of fields and a tertiary canal. Located in the rice

												fields immediately adjacent to a bund.
59	LULC_85	34.60962	-14.25091	473.0	Sample	On	0	Active	Rice	Rice: Mature	Agricultural Land	Cluster of unmanaged taller grasses immediately adjacent to these rice fields. Maize planted two fields to the west.
60	LULC_86	34.61084	-14.25165	477.9	Sample	Offset	5	Active	Rice	Rice: Flooded Field	Agricultural Land	Water is too deep to get to the point. Up to thighs. Rice is growing surrounded by the road to the east and maize to the west. See 360 degree on Nikon.
61	LULC_88	34.62309	-14.2388	471.5	Sample	Offset	2	Ag Infrastructure	Irrigation Structure	Concrete Canal w Flowing Water & Emergent Grasses	Agricultural Land	Point is between the roa and the canal. Immediately adjacent to the canal. Small patch of weeds growing.
62	LULC_9	34.6265	-14.24317	472.1	Sample	Offset	15	Active	Rice	Rice: Flooded Field w/	Agricultural Land	Tertiary canal downstrea

										Dried Grasses		m on the scheme boundary.
63	LULC_97	34.57532	-14.26512	499.5	Sample	On	0	Active	Maize	Maize: Mature	Agricultural Land	Small outcrop of maize on the upland tree adjacent and straw
64	AA_104.jpg	34.5888	-14.2622	-9999	AA	On	0	Fallow	Grasses	Grasses: Tall & Standing Water	Agricultural Land	
65	AA_110.jpg	34.5957	-14.2608	-9999	AA	On	0	Active	Maize	Maize: Past Maturity	Agricultural Land	
66	AA_123.jpg	34.5583	-14.274516	-9999	AA	On	0	Ag Infrastructure	Irrigation Structure	Dirt Canal w/ Standing Water & Mature Rice	Agricultural Land	
67	AA_127.jpg	34.5584	-14.2746	-9999	AA	On	0	Active	Rice	Rice: Mature	Agricultural Land	
68	AA_13.jpg	34.6267	-14.237001	-9999	AA	On	0	Active	Rice	Rice: Varied Growth Stages	Agricultural Land	
69	AA_137.jpg	34.5592	-14.2747	-9999	AA	On	0	Active	Sweet Potato	Mature	Agricultural Land	
70	AA_141.jpg	34.5713	-14.2688	-9999	AA	On	0	Active	Mixed Cropping	Sweet Potato: Mature, Maize: Mature, & Rice: Mature	Agricultural Land	
71	AA_142.jpg	34.5736	-14.268601	-9999	AA	On	0	Active	Mixed Cropping	Sweet Potato: Young & Mature Rice	Agricultural Land	
72	AA_144.jpg	34.5738	-14.2668	-9999	AA	On	0	Active	Rice	Rice: Early Growth w/ Visible Dark Standing Water	Agricultural Land	
73	AA_148.jpg	34.6344	-14.2326	-9999	AA	On	0	Active	Rice	Rice: Mature	Agricultural Land	
74	AA_150.jpg	34.6103	-14.2436	-9999	AA	On	0	Active	Rice	Rice: Mid-Growth w/ visible Dark	Agricultural Land	

										Standing Water		
75	AA_154.jpg	34.6162	-14.2416	-9999	AA	On	0	Active	Rice	Rice: Mature	Agricultural Land	
76	AA_162.jpg	34.61	-14.2506	-9999	AA	On	0	Active	Mixed Cropping	Rice: Mature & Maize: Mature	Agricultural Land	
77	AA_165.jpg	34.6107	-14.2493	-9999	AA	On	0	Active	Mixed Cropping	Rice: Mature & Maize: Mature	Agricultural Land	
78	AA_167.jpg	34.612	-14.2491	-9999	AA	On	0	Active	Rice	Rice: Early Growth w/ Visible Dark Standing Water	Agricultural Land	
79	AA_171.jpg	34.6231	- 14.239033	-9999	AA	On	0	Active	Rice	Rice: Mature	Agricultural Land	
80	AA_19.jpg	34.6333	-14.2331	-9999	AA	On	0	Ag Infrastructure	Irrigation Structure	Concrete Canal w/ Emergent Grasses & Dried Grasses	Agricultural Land	
81	AA_2.jpg	34.6243	-14.2382	-9999	AA	On	0	Ag Infrastructure	Irrigation Structure	Concrete Canal w/ Emergent Grasses & Dried Grasses	Agricultural Land	
82	AA_29.jpg	34.6231	-14.2388	-9999	AA	On	0	Fallow	Grasses	Grasses: Tall	Agricultural Land	
83	AA_31.jpg	34.6093	-14.2506	-9999	AA	On	0	Active	Rice	Rice: Mature & Grasses: Tall	Agricultural Land	
84	AA_33.jpg	34.6099	-14.251	-9999	AA	On	0	Active	Sweet Potato	Sweet Potato & Grasses	Agricultural Land	
85	AA_43.jpg	34.6072	-14.2508	-9999	AA	On	0	Active	Rice	Rice: Mature	Agricultural Land	
86	AA_59.jpg	34.5687	-14.2647	-9999	AA	On	0	Active	Rice	Rice: Mature	Agricultural Land	
87	AA_6.jpg	34.625	-14.2378	-9999	AA	On	0	Ag Infrastructure	Irrigation Structure	Concrete Canal w/ Flowing Water &	Agricultural Land	

										Emergent Grasses		
88	AA_62.jpg	34.5688	-14.2649	-9999	AA	On	0	Active	Rice	Rice: Mature w/ Dried Grass	Agricultural Land	This is actually a tertiary canal
89	AA_7.jpg	34.6256	-14.2376	-9999	AA	On	0	Active	Rice	Rice: Mature	Agricultural Land	
90	AA_70.jpg	34.5753	-14.2651	-9999	AA	On	0	Ag Infrastructure	Human Influence	Straw Structure on Bare Soil	Agricultural Land	
91	AA_73.jpg	34.5753	-14.265	-9999	AA	On	0	Ag Infrastructure	Irrigation Structure	Dirt Canal w/ Standing Water & Dried Grasses	Agricultural Land	
92	AA_75.jpg	34.5784	-14.2609	-9999	AA	On	0	Active	Rice	Rice: Mature	Agricultural Land	
93	AA_77.jpg	34.5787	-14.2601	-9999	AA	On	0	Ag Infrastructure	Irrigation Structure	Concrete Canal w/ Emergent Grasses & Dried Grasses	Agricultural Land	
94	AA_91.jpg	34.5799	-14.264	-9999	AA	On	0	Active	Rice	Rice: Early Growth w/ Visible Water & Grasses	Agricultural Land	
95	AA_97.jpg	34.5837	-14.2632	-9999	AA	On	0	Active	Rice	Rice: Mid-Growth w/ Visible Dark Standing Water	Agricultural Land	

Rainy Season BVIS Analysis Classes

Class Name	Samples in Class	Land Cover
2	4	Rice
3	6	Rice
4	8	Rice
5	3	Rice
6	4	Rice
7	12	Rice
8	8	Non-Vegetated
9	26	Rice
10	25	Non-Vegetated

Class 2: Rice (Panicle)

NAME	CLASS	SUBCLASS	LAND COVER
LULC_161	Active	Rice	Rice: Panicle
LULC_144	Active	Rice	Rice: Panicle & Tall Grasses
LULC_163	Active	Rice	Rice: Panicle
LULC_158	Active	Rice	Rice: Panicle

Class 3: Rice (Panicle)

NAME	CLASS	SUBCLASS	LAND COVER
LULC_5	Active	Rice	Rice: Panicle & Tall Grasses
AA_162	Active	Mixed Cropping	Mixed Cropping: Rice: Panicle & Maize: Panicle
LULC_159	Active	Rice	Rice: Panicle
LULC_83	Active	Maize	Maize: Panicle
LULC_42	Active	Mixed Cropping	Mixed Cropping: Rice: Panicle & Maize: Panicle
LULC_75	Active	Rice	Rice: Panicle

Class 4: Rice (Panicle or Past Maturity)

NAME	CLASS	SUBCLASS	LAND COVER
AA_148	Active	Rice	Rice: Panicle
LULC_4	Active	Rice	Flooded Field w/ Dried Grass
LULC_23	Active	Rice	Rice: Panicle & Tall Grasses
LULC_86	Active	Rice	Flooded Field
LULC_75	Active	Rice	Rice: Panicle
LULC_80	Active	Rice	Rice: Early Growth w/ Visible Light Standing Water
AA_142	Active	Mixed Cropping	Mixed Cropping: Sweet Potato: Young & Rice: Panicle
LULC_81	Active	Rice	Rice: Early Growth w/ Visible Light Standing Water

Class 5: Rice (Panicle)

NAME	CLASS	SUBCLASS	LAND COVER
LULC_22	Fallow	Grasses	Grasses: Tall
LULC_85	Active	Rice	Rice: Panicle
LULC_157	Active	Rice	Rice: Panicle

Class 6: Rice (Panicle & Dried Grasses)

NAME	CLASS	SUBCLASS	LAND COVER
LULC_2	Fallow	Grasses	Grasses: Tall
AA_165	Active	Mixed Cropping	Mixed Cropping: Rice: Panicle & Maize: Panicle
AA_62	Active	Rice	Rice: Panicle & Dried Grasses

Class 7: Rice

NAME	CLASS	SUBCLASS	LAND COVER
LULC_9	Active	Rice	Rice: Flooded Field w/ Dried Grasses
LULC_18	Active	Rice	Rice: Panicle w/ Dried Grasses
LULC_67	Ag. Inf.	Human Influence	Road
AA_33	Active	Sweet Potato	Sweet Potato & Grasses
LULC_36	Active	Maize	Maize: Panicle
LULC_37	Active	Maize	Maize: Past Maturity
LULC_39	Fallow	Grasses	Grasses: Tall
LULC_74	Active	Rice	Rice: Panicle
AA_97	Active	Rice	Rice: Mid-Growth w/ Visible Dark Standing Water
AA_91	Active	Rice	Rice: Early Growth w/ Visible Water & Grasses
AA_59	Active	Rice	Rice: Panicle
AA_144	Active	Rice	Rice: Early Growth w/ Visible Dark Standing Water

Class 8: Non-Vegetated

NAME	CLASS	SUBCLASS	LAND COVER
AA_7	Active	Rice	Rice: Panicle
AA_6	Ag. Inf.	Ag. Inf.	Concrete Canal w/ Flowing Water & Emergent Grasses
LULC_73	Active	Rice	Rice: Flooded Field
LULC_160	Active	Rice	Rice: Panicle
AA_77	Ag. Inf.	Ag. INf.	Concrete Canal w/ Flowing Water, Emergent Grasses & Dried Grasses
LULC_70	Active	Rice	Rice: Panicle
AA_127	Active	Rice	Rice: Panicle
AA_123	Ag. Inf.	Ag. Inf.	Dirt Canal w/ Standing Water & Panicle Rice

Class 9: Rice

NAME	CLASS	SUBCLASS	LAND COVER
LULC_3	Active	Sweet Potato	Sweet Potato: Young
AA_13	Active	Rice	Rice: Varied Growth Stages
AA_171	Active	Rice	Rice: Panicle
LULC_162	Active	Rice	Rice: Panicle
LULC_6	Active	Rice	Rice: Panicle
LULC_7	Active	Rice	Rice: Panicle & Grasses: Tall
LULC_10	Active	Rice	Rice: Panicle & Grasses: Tall
AA_150	Active	Rice	Rice: Mid-Growth w/ Visible Standing Water
LULC_11	Active	Rice	Rice: Early Growth w/ Visible Standing Water and Grasses
LULC_20	Active	Rice	Rice: Panicle w/ Dried Grasses
LULC_21	Active	Rice	Rice: Panicle w/ Tall Grasses
LULC_28	Active	Maize	Maize: Panicle
AA_167	Active	Rice	Rice: Early Growth w/ Visible Dark Standing Water
LULC_32	Active	Rice	Rice: Panicle & Tall Grasses
LULC_63	Ag. Inf.	Ag. Inf.	Concrete Canal w/ Flowing Water & Emergent Grasses
AA_75	Active	Rice	Rice: Panicle
LULC_53	Active	Mixed Cropping	Mixed Cropping: Rice: Panicle & Maize Panicle
LULC_76	Active	Rice	Rice: Panicle
LULC_58	Active	Maize	Maize: Panicle
LULC_77	Ag. Inf.	Ag. Inf.	Concrete Canal w/ Flowing Wtaer, Bare Earth, & Dried Grasses
LULC_70	Active	Rice	Rice: Panicle
LULC_60	Active	Mixed Cropping	Mixed Cropping: Sweet Potato: Young & Rice: Panicle
LULC_164	Active	Rice	Rice: Panicle
AA_137	Active	Sweet Potato	Sweet Potato: Panicle

Class 10: Non-Vegetated

NAME	CLASS	SUBCLASS	LAND COVER
AA_19	Ag. Inf.	Ag. Inf.	Concrete Canal w/ Flowing Water, Emergent Grasses, & Dried Grasses
LULC_1	Fallow	Grasses	Grasses: Tall
AA_2	Ag. Inf.	Ag. Inf.	Concrete Canal w/ Flowing Water, Emergent Grasses, & Dried Grasses
LULC_88	Ag. Inf.	Ag. Inf.	Concrete Canal w/ Flowing Water & Emergent Grasses
AA_29	Fallow	Grasses	Grasses: Tall
AA_154	Active	Rice	Rice: Panicle
LULC_17	Active	Rice	Rice: Early Growth w/ Visible Water & Grasses
LULC_68	Active	Pumpkin	Pumpkin: Intermediate Growth Stage & Grasses
AA_31	Active	Rice	Rice: Panicle & Grasses: Tall
LULC_84	Active	Active	Rice: Varied Growth Stages
LULC_29	Active	Mixed Cropping	Mixed Cropping: Rice: Panicle & Maize: Panicle
AA_43	Active	Rice	Rice: Panicle
LULC_66	Trees	Trees	Trees: Green Foliage over Roadway
LULC_72	Active	Rice	Rice: Panicle w/ Dried Grasses
LULC_65	Trees	Trees	Trees: Green Foliage on Flooded Rice Plot
LULC_64	Active	Maize	Maize: Past Maturity
AA_110	Active	Maize	Maize: Past Maturity
LULC_50	Active	Maize	Maize: Panicle
AA_104	Fallow	Grasses	Grasses: Tall & Standing Water
LULC_78	Active	Sweet Potato	Sweet Potato: Young
AA_73	Ag. Inf.	Ag. Inf.	Dirt Canal w/ Standing Water & Tall Grasses
LULC_97	Active	Maize	Maize: Panicle
LULC_79	Ag. Inf.	Human Influence	Straw Structure on Bare Soil
AA_70	Ag Inf.	Human Influence	Straw Structure on Bare Soil
LULC_69	Active	Pumpkin	Sweet Potato: Panicle

APPENDIX B:

Dry Season LULC Data: BVIS

Dry Season BVIS LULC Classification Table

	BVIS		TOTAL
Class Descriptions	*Sample*	*AA*	
I. AGRICULTURAL LAND			
I. ACTIVE			
Maize			
Mature	9	7	**16**
Young	4	0	**4**
Young & Dense Shrubbery	2	0	**2**
Beans			
Mature	2	1	**3**
Mature & Emergent Weeds	2	0	**2**
Young	5	1	**6**
Cowpea			
Mature	2	1	**3**
Cowpea & Shrubbery	2	1	**3**
Young	3	0	**3**
General Agriculture			
Intercrop: Young Maize & Beans	1	1	**2**
Mature Maize & Beans	1	0	**1**
Mustard Greens	0	1	**1**
II. FALLOW			
Bare Earth			
Dark Soil	7	0	**7**
Dark Soil w/ Straw	14	2	**16**
Dark Soil w/ Straw & Ridging	0	2	**2**
Light Soil	2	0	**2**
Light Soil w/ Straw & Ridging	3	0	**3**
Medium Soil w/ Straw & Ridging	3	0	**3**
Charred Ground			
Charred Ground w/ Beans	1	0	**1**
Charred Ground w/ Cowpea	2	0	**2**
Charred Ground w/ Emergent Weeds	3	2	**5**
Charred Ground w/ Shrubbery	1	0	**1**
Charred Ground on Bare Earth	1	0	**1**
Dried Fields			
Dried Grass	10	3	**13**
Dried Grass & Emergent c3 Vegetation	6	0	**6**
Vertical Rice Straw w/ Little Vegetation	4	0	**4**
Vertical Rice Straw w/ Emergent Weeds	7	10	**17**
Vertical Rice Straw w/ Green Tops	1	0	**1**
Horizontal Rice Straw w/ Emergent Weeds	31	0	**31**
II. FALLOW (CONT.)			
Shrubbery			
Dense	30	5	**35**
Sparse	15	2	**17**
Dense & Emergent Red Weeds	2	2	**4**
Blackjack w/ Emergent Weeds	1	1	**2**
Dense Shrubbery w/ Medium Soil & Straw	1	0	**1**
III. AGRICULTURAL INFRASTRUCTURE			
Irrigation Canal			
Concrete	1	2	**3**
Human Influence			
Road	0	3	**3**
IV. TREES			
Banana Trees & Dried Grass	2	0	**2**
Banana Trees & Dense Shrubbery	0	1	**1**
Green Foliage on Active Agricultural Land	1	0	**1**
Green Foliage on Fallow Field	3	1	**4**
Green Foliage on Fallow Land w/ Green Vegetation	0	1	**1**

Dry Season BVIS LULC Classification Photos

I. AGRICULTURAL LAND

II. ACTIVE

Maize

Mature

Sample Photos:

2_57

5_52

4_53

5_53

1_39

3_39

5_39

4_45

1_3

Accuracy Assessment Photos:

BVIS_AA_108

BVIS_AA_109

BVIS_AA_116

BVIS_AA_15

BVIS_AA_16

BVIS_AA_80

	 BVIS_AA_86

I. AGRICULTURAL LAND

II. ACTIVE

Maize

Young

Sample Photos:

9_38

2_12

1_9

2_3

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND		
	II. ACTIVE	
		Maize
		Young w Dense Shrubbery
		Sample Photos:  5_33  5_38
		Accuracy Assessment Photos None

I. AGRICULTURAL LAND

II. ACTIVE

Beans

Mature

Sample Photos:

1_18

6_36

Accuracy Assessment Photos:

BVIS_AA_131

I. AGRICULTURAL LAND
II. ACTIVE
Beans
Mature & Emergent Weeds
Sample Photos:  3_31  1_24
Accuracy Assessment Photos None

I. AGRICULTURAL LAND
II. ACTIVE
Beans
Young

Sample Photos:


3_38


4_38


2_19


2_18


1_6

Accuracy Assessment Photos:


BVIS_AA_132

I. AGRICULTURAL LAND
II. ACTIVE
Cowpea
Mature
Sample Photos:


2_10


1_15

Accuracy Assessment Photos:


BVIS_AA_123

I. AGRICULTURAL LAND

II. ACTIVE

Cowpea

Cowpea & Shrubbery

Sample Photos:


2_15


3_15

Accuracy Assessment Photo:


BVIS_AA_128

I. AGRICULTURAL LAND

II. ACTIVE

Cowpea

Young

Sample Photos:

2_23

1_10

7_21

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND

II. ACTIVE

General Agriculture

Intercrop: Young Maize & Beans

Sample Photos:

2_38

Accuracy Assessment Photos

BVIS_AA_144

I. AGRICULTURAL LAND

II. ACTIVE

General Agriculture

Mature Maize & Beans

Sample Photos:

4_39

Accuracy Assessment Photos

None

I. AGRICULTURAL LAND
II. ACTIVE
General Agriculture
Mustard Greens
Sample Photos: None
Accuracy Assessment Photos:  BVIS_AA_151

I. AGRICULTURAL LAND

II. FALLOW

Bare Earth

Dark Soil

Sample Photos:


1_58


1_50


3_50


7_53


3_49


3_47


2_49

Accuracy Assessment Photos:
None

I. AGRICULTURAL LAND
II. FALLOW
Bare Earth
Dark Soil w Straw

Sample Photos:

6_7

1_47

2_47

4_47

2_46

5_46

6_46

1_45

2_45a

2_40

1_51

1_52

1_55

4_57

Accuracy Assessment Photos:

BVIS_AA_5

BVIS_AA_47

I. AGRICULTURAL LAND

II. FALLOW

Bare Earth

Bare Earth: Dark Soil w Straw and Ridging

Sample Photos:

None

Accuracy Assessment Photos:

BVIS_AA_158

BVIS_AA_163

I. AGRICULTURAL LAND

II. FALLOW

Bare Earth

Bare Earth: Light Soil

Sample Photos:

1_1

4_2

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND
II. FALLOW
Bare Earth
Light Soil w Straw and Ridging

Sample Photos:

2_1

3_2

3_6

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND
II. FALLOW
Bare Earth
Medium Soil w Straw and Ridging

Sample Photos:

1_2

2_2

7_7

Accuracy Assessment Photos:
None

I. AGRICULTURAL LAND
II. FALLOW
Charred Ground
Charred Ground w Beans

Sample Photos:

5_19

Accuracy Assessment Photos:
None

I. AGRICULTURAL LAND	
	II. FALLOW
	Charred Ground
	Charred Ground w Cowpea
	Sample Photos:  2_9  3_10
	Accuracy Assessment Photos: None

I. AGRICULTURAL LAND

II. FALLOW

Charred Ground

Charred Ground w Emergent Weeds

Sample Photos:

4_52

2_31

4_25

Accuracy Assessment Photos:

BVIS_AA_138

BVIS_AA_75

I. AGRICULTURAL LAND

II. FALLOW

Charred Ground

Charred Ground w Shrubbery

Sample Photos:

2_22

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND

II. FALLOW

Charred Ground

Charred Ground on Bare Earth

Sample Photos:

1_21

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND

II. FALLOW

Dried Fields

Dried Grass

Sample Photos:

3_57b

3_57

1_54

1_46

6_16

1_23

2_51

4_27

3_46

1_29

Accuracy Assessment Photos:

BVIS_AA_28

BVIS_AA_68

BVIS_AA_67

I. AGRICULTURAL LAND

II. FALLOW

Dried Fields

Dried Grass & Emergent c3 Vegetation

Sample Photos:

2_56

1_42

1_38

1_19

1_12

7_16

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND

II. FALLOW

Dried Fields

Vertical Rice Straw w/ Little Vegetation

Sample Photos:


1_25


1_40


1_17


4_51

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND

II. FALLOW

Dried Fields

Vertical Rice Straw w Emergent Weeds

Sample Photos:

1_56

1_53

5_51

6_53

1_49

3_22

3_20

Accuracy Assessment Photos:


BVIS_AA_103


BVIS_AA_104


BVIS_AA_34


BVIS_AA_72


BVIS_AA_71


BVIS_AA_76


BVIS_AA_77


BVIS_AA_148


BVIS_AA_156


BVIS_AA_35

I. AGRICULTURAL LAND
II. FALLOW
Dried Fields
Vertical Rice Straw w Green Tops
Sample Photos:  1_8
Accuracy Assessment Photos: None

I. AGRICULTURAL LAND

II. FALLOW

Dried Fields

Horizontal Rice Straw w/ Emergent Weeds

Sample Photos:

2_55

3_51

10_53

1_48

3_44

3_48

2_37

6_38

4_46

10_38

4_48

5_48


6_48


2_36


4_36


3_40


5_36


1_35

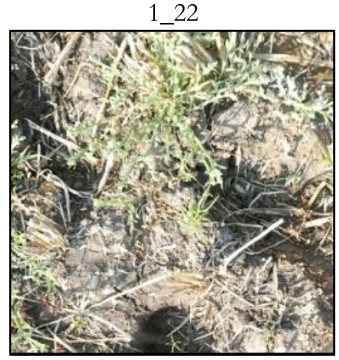

1_28


2_28


1_22


7_22


3_28


4_28


5_28


2_21


2_7


3_21


4_21


6_21


2_52

Accuracy Assessment Photos:
None

I. AGRICULTURAL LAND

II. FALLOW

Shrubbery

Shrubbery: Dense

Sample Photos:


7_25


3_8


2_27


3_27


3_7


4_7


2_20


4_20


2_6


1_14


7_44


1_43


2_33


3_33


1_26


4_33


1_31


2_25


1_36


5_31


1_30


3_36


3_52


1_44


4_31


3_16


1_11


2_44


8_38


4_19

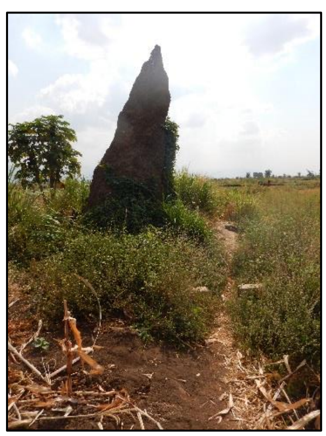
Accuracy Assessment Photos:


BVIS_AA_133


BVIS_AA_4


BVIS_AA_166


BVIS_AA_100


BVIS_AA_134

I. AGRICULTURAL LAND

II. FALLOW

Shrubbery

Sparse

Sample Photos:


2_48

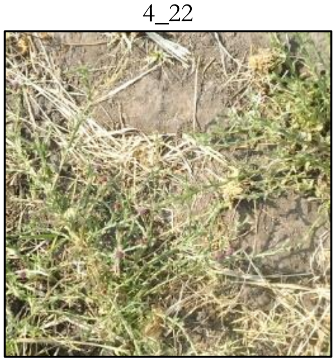

1_33


2_16


4_22


5_22


3_23


6_22


1_27


5_7


5_21


5_2


4_44

 5_44	 6_44	 2_8

Accuracy Assessment Photos:

 BVIS_AA_58	 BVIS_AA_99

I. AGRICULTURAL LAND

II. FALLOW

Shrubbery

Dense & Emergent Red Weeds

Sample Photos:

5_25

6_25

Accuracy Assessment Photos:

BVIS_AA_125

BVIS_AA_126

I. AGRICULTURAL LAND

II. FALLOW

Shrubbery

Blackjack w Emergent Weeds

Sample Photos:

4_9

Accuracy Assessment Photos:

BVIS_AA_145

I. AGRICULTURAL LAND		
	II. FALLOW	
		Shrubbery
		Dense Shrubbery w Medium Soil & Straw
		Sample Photos:  3_19
		Accuracy Assessment Photos: None

I. AGRICULTURAL LAND

III. AGRICULTURAL INFRASTRUCTURE

Irrigation Canal

Concrete

Sample Photos:

3_25

Accuracy Assessment Photos:

BVIS_AA_118

BVIS_AA_147

I. AGRICULTURAL LAND

III. AGRICULTURAL INFRASTRUCTURE

Human Influence

Road

Sample Photos:

None

Accuracy Assessment Photos:

BVIS_AA_124

BVIS_AA_149

BVIS_AA_97

I. AGRICULTURAL LAND

IV: TREES

Banana Trees & Dried Grass

Sample Photos:

1_7

1_5

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND

IV: TREES

Banana Trees & Dense Shrubbery

Sample Photos:

None

Accuracy Assessment Photos:

BVIS_AA_159

I. AGRICULTURAL LAND

IV: TREES

Green Foliage on Active Agricultural Land

Sample Photos:

2_4

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND

IV: TREES

Green Foliage on Fallow Land

Sample Photos:

7_46

11_38

2_5

Accuracy Assessment Photos:

BVIS_AA_164

I. AGRICULTURAL LAND

IV: TREES

Green Foliage on Fallow Land w/ Green Vegetation

Sample Photos:

None

Accuracy Assessment Photos:

BVIS_AA_122

Dry Season BVIS Data

ID	Name	X	Y	Elev	Date_ Time	Pnt_type	Pnt_Acq	Offset_Dis	Class	SubClass	Land_Co ver	Land_Use	Notes
0	1_58	34.6331	-14.229	456.8	8/16/ 2016 13:44	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil	Agricultural Land	Bare earth. Straw to the east north & south. Bare earth to the west. No evidence of standing water.
6	4_57	34.636	-14.233	455.3	8/16/ 2016 14:46	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw	Agricultural Land	Bare. To the south and west bare with dried grasses. To the east is bare.
10	1_55	34.628	-14.233	456.5	8/16/ 2016 15:30	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw	Agricultural Land	Dry harvested rice field. To the North are Baobab trees. Active animal grazing occurring here.
25	7_53	34.634	-14.238	461.1	8/16/ 2016 17:21	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil	Agricultural Land	Bare. To the North are Trees. To the South are trees and dried grass. To the West is maize and to the East is dried grass.
41	1_50	34.632	-14.24	466.3	8/17/ 2016 11:41	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil	Agricultural Land	Dark Soil. Bare earth. To the north, grass, shrubs, maize and a drain. To the South, grass and trees. To the west, grass shrubs, drain and maize field To the East, grass and trees.
46	3_50	34.632	-14.241	463.6	8/17/ 2016 12:23	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil	Agricultural Land	Bare earth. Trees and grass located to the East and South. Grass to the West. Shrubs and Grass to the North.

48	2_49	34.63	-14.242	465.4	8/17/ 2016 12:46	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil	Agricultural Land	Bare earth. To the north are shrubs and trees. To the south is bare with burned grasses. To the West and East there are shrubs.
50	3_49	34.628	-14.243	462.0	8/17/ 2016 13:00	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil	Agricultural Land	Dry harvested rice field. Maize field & drain to the north. Drain is covered in grass and shrubs. Shrubs in a drain to the West. Harvested rice fields to the south and east.
59	3_47	34.627	-14.246	466.3	8/17/ 2016 13:48	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil	Agricultural Land	Bare Earth. Surrounding fields have trees and grass.
181	6_7	34.562	-14.268	500.1	8/20/ 2016 10:51	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw	Agricultural Land	Out.
54	1_47	34.629	-14.244	466.9	8/17/ 2016 13:24	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw	Agricultural Land	Dry harvested rice field. Trees to the south and east. Dry rice fields to the north and west.
57	2_47	34.627	-14.245	464.5	8/17/ 2016 13:38	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw	Agricultural Land	Dry rice field. All surrounding fields are dry rice fields. To the South and East are trees.
60	4_47	34.626	-14.246	465.7	8/17/ 2016 13:57	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw	Agricultural Land	Bare earth. Trees and grass located to the West and East. Bare to the North. To the South is grass.

64	2_46	34.624	-14.247	468.1	8/17/2016 14:17	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw	Agricultural Land	Bare earth. Bare and trees to the north. Trees and grass in all other directions.
68	5_46	34.625	-14.244	467.5	8/18/2016 11:06	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw	Agricultural Land	Bare / Harvested maize field. Harvested maize field to the North and East. Grass and harvested maize to the south. Grass to the west.
69	6_46	34.624	-14.244	471.5	8/18/2016 11:13	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw	Agricultural Land	Harvested maize fields to the North and East. Grass to the West and Grass and Harvested Maize to the South.
76	1_45	34.621	-14.245	471.2	8/18/2016 11:46	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw	Agricultural Land	Harvested rice field. To the north, west and east are rice fields. To the south there is a maize between rice fields and grasses.
79	2_45a	34.618	-14.244	471.2	8/18/2016 12:11	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw	Agricultural Land	
107	2_40	34.598	-14.248	481.8	8/18/2016 15:44	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw	Agricultural Land	Trees and shrubs to the north and west. To the east there are dry harvested rice fields. To the south are rice fields.
13	1_51	34.625	-14.236	464.5	8/16/2016 15:54	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw	Agricultural Land	Dry harvest fields but the soil here is no longer cracked

12	1_52	34.626	-14.235	462.9	8/16/2016 15:45	Sample	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw	Agricultural Land	Dry harvested rice field. To the south is dry irrigation canal.
190	1_1	34.55	-14.273	507.1	8/20/2016 11:31	Sample	On	0	Fallow	Bare Earth	Bare Earth: Light Soil	Agricultural Land	Bare earth. Harvested maize field where only straw remains.
187	4_2	34.552	-14.272	504.4	8/20/2016 11:20	Sample	On	0	Fallow	Bare Earth	Bare Earth: Light Soil	Agricultural Land	Bare earth. Harvested Cotton Field.
191	2_1	34.549	-14.274	507.1	8/20/2016 11:34	Sample	On	0	Fallow	Bare Earth	Bare Earth: Light Soil w Straw & Ridging	Agricultural Land	Dry, harvested maize field.
174	3_2	34.556	-14.272	500.7	8/20/2016 10:18	Sample	On	0	Fallow	Bare Earth	Bare Earth: Light Soil w Straw & Ridging	Agricultural Land	Bare field covered only by straw and spiney plants
179	3_6	34.559	-14.268	500.7	8/20/2016 10:42	Sample	On	0	Fallow	Bare Earth	Bare Earth: Light Soil w Straw & Ridging	Agricultural Land	
159	1_2	34.553	-14.273	505.3	8/19/2016 16:15	Sample	On	0	Fallow	Bare Earth	Bare Earth: Medium Soil w Straw & Ridging	Agricultural Land	Dry harvested maize field. Bare earth.
160	2_2	34.552	-14.273	503.2	8/19/2016 16:18	Sample	On	0	Fallow	Bare Earth	Bare Earth: Medium Soil w Straw & Ridging	Agricultural Land	Bare earth with sporadic spiked weeds.
183	7_7	34.563	-14.266	501.7	8/20/2016 10:57	Sample	On	0	Fallow	Bare Earth	Bare Earth: Medium Soil w Straw & Ridging	Agricultural Land	

110	1_18	34.585	-14.265	487.9	8/18/ 2016 16:02	Sample	On	0	Active	Beans	Beans: Mature	Agricultural Land	Beans are nearly mature. No evidence of beans on plants yet though. Other fields are covered in shrubs with nothing planted.
113	6_36	34.594	-14.25	483.7	8/18/ 2016 16:11	Sample	On	0	Active	Beans	Beans: Mature	Agricultural Land	Peas. Trees to the north and east. To the west is grass. To the south is trees and peas.
108	1_24	34.592	-14.261	485.2	8/18/ 2016 15:46	Sample	On	0	Active	Beans	Beans: Mature & Emergent Weeds	Agricultural Land	Newly planted bean field. Bean field to the immediate south, otherwise all other fields are shrubs
83	3_31	34.597	-14.257	480.6	8/18/ 2016 12:36	Sample	On	0	Active	Beans	Beans: Mature & Emergent Weeds	Agricultural Land	Edge of a bean field. Mature beans on the vines. Mixture of weeds present.
61	3_38	34.605	-14.253	475.1	8/17/ 2016 13:57	Sample	On	0	Active	Beans	Beans: Young	Agricultural Land	Newly turned bean field surrounded by shrubbery and fallow land.
62	4_38	34.6034	-14.252	476.0	8/17/ 2016 14:08	Sample	On	0	Active	Beans	Beans: Young	Agricultural Land	Newly turned bean field. Maize planted adjacent.
93	2_19	34.591	-14.265	482.8	8/18/ 2016 13:41	Sample	On	0	Active	Beans	Beans: Young	Agricultural Land	Young bean field. To the north is bare. Trees to the west.
112	2_18	34.587	-14.266	487.0	8/18/ 2016 16:09	Sample	On	0	Active	Beans	Beans: Young	Agricultural Land	Maize planted with beans immediately east. To the West, a field intercropped with maize and sweet potato and another field with maize and beans.

170	1_6	34.56	-14.271	500.4	8/20/ 2016 10:01	Sample	On	0	Active	Beans	Beans: Young	Agricultural Land	
137	4_9	34.571	-14.271	490.7	8/19/ 2016 13:45	Sample	On	0	Fallow	Shrubbery	Blackjack w Emergent Weeds	Agricultural Land	Full field of blackjack. Maize located along the periphery.
161	1_21	34.579	-14.259	484.6	8/20/ 2016 9:29	Sample	On	0	Fallow	Charred Ground	Charred Ground on Bare Earth	Agricultural Land	Ash in the center of a harvested rice field. Rice fields in all directions.
96	5_19	34.59	-14.263	484.0	8/18/ 2016 13:55	Sample	On	0	Fallow	Charred Ground	Charred Ground w Beans	Agricultural Land	Young bean fields. Adjacent plots are all beans.
133	2_9	34.574	-14.269	490.1	8/19/ 2016 13:25	Sample	On	0	Fallow	Charred Ground	Charred Ground w Cowpea	Agricultural Land	Cow pea field. In the center is a burned area. Surroundings are all cowpea with one plot of maize.
149	3_10	34.578	-14.269	486.4	8/19/ 2016 14:54	Sample	On	0	Fallow	Charred Ground	Charred Ground w Cowpea	Agricultural Land	In the center of a cowpea field directly in the charred area. Surrounded by cowpea. Fields to the south are barren.
20	4_52	34.629	-14.238	463.2	8/16/ 2016 16:41	Sample	Offset	4	Fallow	Charred Ground	Charred Ground w Emergent Weeds	Agricultural Land	Ash circle located in the center of a harvest field with green grasses growing. To the North and West are dry rice fields. To the South and East are maize fields.
82	2_31	34.596	-14.256	481.8	8/18/ 2016 12:28	Sample	On	0	Fallow	Charred Ground	Charred Ground w Emergent Weeds	Agricultural Land	Inside of a barren field covered with shrubbery. Specifically in a burned central circle. Field is otherwise covered

													in low vegetative shrubbery.
90	4_25	34.595	-14.261	482.4	8/18/ 2016 13:13	Sample	On	0	Fallow	Charred Ground	Charred Ground w Emergent Weeds	Agricultural Land	Dry, harvested rice field. Low shrubbery including red burned grass and charring in the center.
125	2_22	34.582	-14.259	488.5	8/19/ 2016 12:41	Sample	Offset	3	Fallow	Charred Ground	Charred Ground w Shrubbery	Agricultural Land	Dry harvested rice fields. There is evidence of ash here.
186	2_15	34.575	-14.263	496.2	8/20/ 2016 11:18	Sample	On	0	Active	Cowpea	Cowpea & Shrubbery	Agricultural Land	Cowpea fields completely surrounding this one.
188	3_15	34.574	-14.264	494.6	8/20/ 2016 11:23	Sample	On	0	Active	Cowpea	Cowpea & Shrubbery	Agricultural Land	Cow pea field surrounded by other cowpea fields.
146	2_10	34.576	-14.271	491.9	8/19/ 2016 14:38	Sample	On	0	Active	Cowpea	Cowpea: Mature	Agricultural Land	Cowpea field surrounded by other cowpea fields.
184	1_15	34.573	-14.263	498.0	8/20/ 2016 11:11	Sample	On	0	Active	Cowpea	Cowpea: Mature	Agricultural Land	Cowpea fields completely surrounding this plot.
135	2_23	34.586	-14.262	485.8	8/19/ 2016 13:37	Sample	On	0	Active	Cowpea	Cowpea: Young	Agricultural Land	Cow pea field surrounded by other cow pea fields.
145	1_10	34.575	-14.271	489.8	8/19/ 2016 14:32	Sample	On	0	Active	Cowpea	Cowpea: Young	Agricultural Land	Primarily bare dirt. Cowpea field but young and barely sprouted. Surrounding fields are all cowpea.
182	7_21	34.577	-14.262	492.5	8/20/ 2016 10:53	Sample	On	0	Active	Cowpea	Cowpea: Young	Agricultural Land	Cowpea fields to the south and east. Dry harvested rice fields to the north and west.

94	3_19	34.59	-14.266	478.5	8/18/ 2016 13:46	Sample	On	0	Fallow	Shrubbery	Dense Shrubbery w/ Medium Soil & Straw	Agricultural Land	Division mound between fields. Field to the south is turned for new planting. Surrounding fields are shrubbery.
2	3_57b	34.638	-14.232	458.7	8/16/ 2016 14:15	Sample	On	0	Fallow	Dried Fields	Dried Grass	Agricultural Land	To the north and east are maize. Dried grasses and brush are located to the south and west
3	3_57	34.638	-14.232	458.4	8/16/ 2016 14:17	Sample	On	0	Fallow	Dried Fields	Dried Grass	Agricultural Land	To the north and east are maize. Dried grasses and brush are located to the south and west
5	1_54	34.637	-14.235	457.1	8/16/ 2016 14:37	Sample	On	0	Fallow	Dried Fields	Dried Grass	Agricultural Land	To the north, east, and west are dried grasses. To the south are grasses but it is also bare here.
63	1_46	34.625	-14.247	466.9	8/17/ 2016 14:08	Sample	Offset	6	Fallow	Dried Fields	Dried Grass	Agricultural Land	Bare field. Termite mound about 2m from point. Grass to the North. Trees and grass in all other directions.
8	2_56	34.632	-14.234	457.1	8/16/ 2016 15:08	Sample	On	0	Fallow	Dried Fields	Dried Grass & Emergent c3 Vegetation	Agricultural Land	To the north is the road. Dry harvested fields surround this entire area
39	1_42	34.607	-14.248	475.4	8/17/ 2016 11:30	Sample	On	0	Fallow	Dried Fields	Dried Grass & Emergent c3 Vegetation	Agricultural Land	Out. Shrubs amid grassland that backs up to a village. There is a pump nearby with standing water.

45	1_38	34.607	-14.250	475.4	8/17/ 2016 12:14	Sample	On	0	Fallow	Dried Fields	Dried Grass & Emergent c3 Vegetation	Agricultural Land	Dried grasses along the roadway. Fields to the north were planted with rice. Now beans and maize and growing in the field. Maize is planted closest to the village.
92	1_19	34.593	-14.264	487.0	8/18/ 2016 13:34	Sample	On	0	Fallow	Dried Fields	Dried Grass & Emergent c3 Vegetation	Agricultural Land	Tall, dried grasses along the scheme periphery
116	1_12	34.586	-14.267	488.2	8/18/ 2016 16:46	Sample	On	0	Fallow	Dried Fields	Dried Grass & Emergent c3 Vegetation	Agricultural Land	Division between crops. Beans to the east, sweet potatoes to the north. Maize to the west and east and south, enveloping this field.
129	7_16	34.58	-14.266	488.8	8/19/ 2016 12:57	Sample	On	0	Fallow	Dried Fields	Dried Grass & Emergent c3 Vegetation	Agricultural Land	Dry, mounded grasses separating dry, harvested rice fields.
18	2_52	34.627	-14.239	466.0	8/16/ 2016 16:29	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Division mound between plots. Green maize growing to the west. All other surrounding plots are dry harvested maize.
11	2_55	34.626	-14.234	461.4	8/16/ 2016 15:38	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	To the north are Baobab Trees along the periphery of the scheme. Otherwise all other fields are

													dry, harvested fields.
15	3_51	34.623	-14.239	468.4	8/16/ 2016 16:10	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Mounded division between two fields nearby. Dry canal with creeping grass. To the north is an irrigation canal and road. Other fields nearby are dry harvested rice.
26	10_53	34.635	-14.237	459.3	8/16/ 2016 17:33	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Bare earth. Maize fields to the north and west. Dried grasses to the south and east.
27	1_48	34.623	-14.24	466.0	8/17/ 2016 10:30	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Harvested rice field. Canal to the north. All surrounding fields are harvested rice fields.
30	3_44	34.616	-14.245	475.4	8/17/ 2016 10:44	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Dry harvested rice field. Canal to the right. Maize to the southeast.
33	3_48	34.625	-14.24	470.9	8/17/ 2016 10:55	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Dark Soil. Dry harvested rice field surrounded by the same.
49	2_37	34.6	-14.253	480.9	8/17/ 2016 12:53	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Dark Soil. Harvested, dry rice field with emergent weeds.
66	6_38	34.606	-14.252	477.0	8/17/ 2016 14:26	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Harvested rice fields. Can see planted maize closer to the roadway

73	4_46	34.623	-14.245	470.9	8/18/ 2016 11:32	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Dark Soil. Harvested rice field. Surrounding fields are a combination of harvested rice and grasses.
74	10_38	34.61	-14.252	478.5	8/18/ 2016 11:36	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Bare field surrounded by planted maize. Trees located to the southwest
85	4_48	34.622	-14.243	467.5	8/18/ 2016 12:44	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Dark Soil. Dry harvested rice fields completely surrounding this plot.
88	5_48	34.625	-14.243	465.7	8/18/ 2016 13:08	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	To the North and West are grass. Maize to the south and east.
91	6_48	34.624	-14.242	467.2	8/18/ 2016 13:18	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Dry harvested rice field.
99	2_36	34.597	-14.251	479.1	8/18/ 2016 14:59	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Harvested rice fields. Rice fields and brush.
102	4_36	34.598	-14.25	480.3	8/18/ 2016 15:21	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Dark Soil. Rice fields and brush. All surrounding areas and rice fields
109	3_40	34.597	-14.248	482.4	8/18/ 2016 15:52	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Creeping grass. To the north is a termite mound and shrubs. To the west, east, and south are trees.

111	5_36	34.595	-14.25	483.7	8/18/ 2016 16:04	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Out. Dark Soil. TO the north are trees. To the south are trees and grass. To the west is a tilled field. To the east is a rice field.
114	1_35	34.589	-14.252	486.7	8/18/ 2016 16:30	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Green peas growing here. Elephant grass to the west. East and South to the peas
119	1_28	34.581	-14.255	488.2	8/19/ 2016 12:08	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	All surrounding fields are dry harvested rice
121	2_28	34.581	-14.256	492.2	8/19/ 2016 12:21	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	A canal to the North, east, and West. Dry irrigated rice fields surround.
123	1_22	34.582	-14.258	489.2	8/19/ 2016 12:33	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Dry irrigated rice fields.
143	7_22	34.583	-14.258	486.1	8/19/ 2016 14:15	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Trees to the north. Dry harvested rice in all other directions
144	3_28	34.584	-14.256	483.7	8/19/ 2016 14:31	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Dark Soil. Dry harvested rice fields.
148	4_28	34.582	-14.254	476.7	8/19/ 2016 14:49	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Dry harvested rice field

150	5_28	34.581	-14.253	479.1	8/19/ 2016 14:58	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Dry harvested rice field. Medium soil.
163	2_21	34.577	-14.259	484.	8/20/ 2016 9:37	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Harvested rice field with brush. The plots immediately surrounding this one are all the same.
164	2_7	34.566	-14.268	494.6	8/20/ 2016 9:42	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	
166	3_21	34.575	-14.258	488.5	8/20/ 2016 9:47	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Cowpeas to the north. Dry harvested rice in all other directions.
169	4_21	34.576	-14.259	487.9	8/20/ 2016 9:57	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Brush beginning to grow along dry harvested rice field. All surrounding fields appear similar.
180	6_21	34.576	-14.261	493.7	8/20/ 2016 10:48	Sample	On	0	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds	Agricultural Land	Dry harvested rice field with horizontal straw. Lots of straw.
43	4_39	34.606	-14.251	475.1	8/17/ 2016 12:07	Sample	On	0	Active	General Agriculture	Intercrop: Mature Maize & Beans	Agricultural Land	Bund separating a maize field to the north and a field planted with beans to the south.
47	2_38	34.603	-14.252	476.7	8/17/ 2016 12:36	Sample	On	0	Active	General Agriculture	Intercrop: Young Maize & Beans	Agricultural Land	Division between two plots. To the south, young maize is planted. To the north, beans are planted through to the

													northern edge of the scheme.
89	3_25	34.594	-14.261	485.8	8/18/ 2016 13:10	Sample	Offset	2	Ag Infrast ructure	Irrigation Canal	Irrigation Canal: Concrete	Infrastructu re	Irrigation Canal. No water present.
1	2_57	34.635	-14.230	458.4	8/16/ 2016 14:02	Sample	On	0	Active	Maize	Maize: Mature	Agricultural Land	Plots nearby are a mixture between bare and dried grasses.
21	5_52	34.629	-14.239	465.1	8/16/ 2016 16:48	Sample	Offset	8	Active	Maize	Maize: Mature	Agricultural Land	From this vantage point (mounded division) maize fields in all directions.
22	4_53	34.631	-14.239	464.2	8/16/ 2016 17:01	Sample	On	0	Active	Maize	Maize: Mature	Agricultural Land	Inside of a maize field. From this vantage point, maize fields in all directions.
23	5_53	34.631	-14.238	464.8	8/16/ 2016 17:05	Sample	On	0	Active	Maize	Maize: Mature	Agricultural Land	Inside of a maize field. From this vantage point, maize fields in all directions.
40	1_39	34.607	-14.25	476.4	8/17/ 2016 11:40	Sample	On	0	Active	Maize	Maize: Mature	Agricultural Land	Maize field. Maize to the North. Small outcrop of maize to the south but then fields turn to dry harvested rice.
42	3_39	34.605	-14.251	477.3	8/17/ 2016 12:03	Sample	On	0	Active	Maize	Maize: Mature	Agricultural Land	Maize field. No intercropping. Field to the immediate south is newly planted maize field. Adjacent field to the west is beans.
75	5_39	34.609	-14.252	479.4	8/18/ 2016 11:43	Sample	On	0	Active	Maize	Maize: Mature	Agricultural Land	Located in maize field. Tallest maize in the area; adjacent to canal.

80	4_45	34.617	-14.245	468.1	8/18/2016 12:22	Sample	On	0	Active	Maize	Maize: Mature	Agricultural Land	Field is divided in half. From this vantage point, all areas around are maize.
158	1_3	34.5597	-14.274	501.0	8/19/2016 16:03	Sample	Offset	10	Active	Maize	Maize: Mature	Agricultural Land	Irrigated maize fields. First signs of flowing water.
72	9_38	34.608	-14.252	479.7	8/18/2016 11:28	Sample	On	0	Active	Maize	Maize: Young	Agricultural Land	Young maize growth. One plot to the east is beans. The rest are maize.
117	2_12	34.585	-14.268	492.8	8/18/2016 16:51	Sample	On	0	Active	Maize	Maize: Young	Agricultural Land	Edge of maize field. Bounded up dirt covered in vegetation that is low to the ground. Termite mound is present here. There are signs of water here, but no water in the irrigation canal.
132	1_9	34.572	-14.269	494.3	8/19/2016 13:19	Sample	Offset	10	Active	Maize	Maize: Young	Agricultural Land	Young, planted maize field immediately adjacent to a tertiary canal/
176	2_3	34.559	-14.272	500.7	8/20/2016 10:28	Sample	On	0	Active	Maize	Maize: Young	Agricultural Land	irrigated maize fields.
58	5_33	34.605	-14.255	472.4	8/17/2016 13:48	Sample	On	0	Active	Maize	Maize: Young w Dense Shrubbery	Agricultural Land	Planted, young maize field. Young maize all around and shrubbery / grasses growing among the maize
65	5_38	34.607	-14.253	474.2	8/17/2016 14:19	Sample	On	0	Active	Maize	Maize: Young w Dense Shrubbery	Agricultural Land	Newly turned maize field mixed with shrubbery

70	8_38	34.609	-14.251	477.9	8/18/ 2016 11:23	Sample	On	0	Active	Maize	Shrubbery: Dense	Agricultural Land	Newly planted maize fields covered in shrubbery and low vegetation. Surrounding fields are the same with some maize in various stages of growth.
151	1_11	34.581	-14.268	485.8	8/19/ 2016 15:06	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Division between two dry, harvested rice fields that are covered in red shrubbery.
106	7_25	34.592	-14.258	485.2	8/18/ 2016 15:34	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Dry, harvested maize area covered in low shrub growth
142	3_8	34.569	-14.271	493.7	8/19/ 2016 14:09	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Out. Overgrowth of vegetation with an irrigation canal
154	2_27	34.578	-14.256	486.4	8/19/ 2016 15:34	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Dry harvested rice field. Dry harvested rice fields completely surrounding this one.
155	3_27	34.577	-14.257	488.2	8/19/ 2016 15:42	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Dry harvested rice field. Cowpea fields to the north. Dry rice plots to the south and west. Dry rice field with cowpea growing to the east.
165	3_7	34.565	-14.268	493.4	8/20/ 2016 9:44	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	
167	4_7	34.564	-14.268	495.6	8/20/ 2016 9:48	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	

171	2_20	34.573	-14.26	487.6	8/20/2016 10:07	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Dry harvested rice fields in all directions. Canal located to the east.
175	4_20	34.575	-14.261	491.3	8/20/2016 10:26	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Dry harvested rice fields with shrubbery in all directions.
177	2_6	34.56	-14.27	500.7	8/20/2016 10:34	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	
192	1_14	34.57	-14.266	499.5	8/20/2016 11:49	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Dry harvested rice field. Dry grass to the north and south. To the west has been cultivated. To the East are sweet potato and cowpeas intercropped.
28	1_44	34.615	-14.244	472.7	8/17/2016 10:34	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Division mound between plots. To the North are dry harvested rice fields, brush and weeds on all sides.
84	4_31	34.596	-14.257	481.2	8/18/2016 12:41	Sample	Offset	4	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Edge of bean field. All barren to the north.
122	3_16	34.576	-14.266	491.0	8/19/2016 12:25	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Division between plots marked with lots of rice straw. Surrounding fields are fallow.
29	2_44	34.616	-14.244	475.4	8/17/2016 10:40	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Footpath along a canal. Located in a dry harvested field.
37	7_44	34.612	-14.247	474.2	8/17/2016 11:09	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Medium Soil. Dry, harvested rice field with a plot division located directly behind.

38	1_43	34.609	-14.248	473.6	8/17/2016 11:17	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Medium Soil. Bare earth along the roadway and canal. Dry, harvested fields to the south. Evidence of more brush cover now in addition to the presence of children in the field. Village to North.
52	2_33	34.6	-14.255	482.8	8/17/2016 13:08	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Harvested rice fields covered in shrubbery. Burned areas in the center of the field. Low growing red vegetation growing sporadically.
53	3_33	34.603	-14.257	477.0	8/17/2016 13:20	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Harvested rice field with shrubbery and cracked, dry soil. Presence of red vegetation to the east.
55	1_26	34.604	-14.258	476.4	8/17/2016 13:25	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Harvested, dry field covered in red and green shrubbery. Maize growing along the south of the field.
56	4_33	34.603	-14.256	479.4	8/17/2016 13:33	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Harvest field. Red and green shrubbery growing. No other crops growing in view.
81	1_31	34.597	-14.255	481.2	8/18/2016 12:23	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Barren field covered in low, red hued vegetation.

87	2_25	34.597	-14.258	481.2	8/18/ 2016 12:58	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Cleared field. Beans to the immediate south. Otherwise fields in various states from cleared to turned for beans
97	1_36	34.595	-14.252	473.9	8/18/ 2016 14:49	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Dry harvested rice field. Grass and trees to the north. Dry harvested rice fields to the south, west, and east.
98	5_31	34.594	-14.254	477.6	8/18/ 2016 14:49	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Dry, harvest field. All surrounding fields are planted.
100	1_30	34.591	-14.256	480.6	8/18/ 2016 15:04	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Dry, harvested rice fields. Considerable overgrowth here. Large trees nearby
101	3_36	34.597	-14.25	475.7	8/18/ 2016 15:12	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Dry harvested rice fields and brush. Dry harvested rice fields all around.
19	3_52	34.628	-14.237	463.6	8/16/ 2016 16:36	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	Harvested field with green grasses growing. To the north are shrubs on a harvested field. In all other directions there are dry harvested fields.
103	5_25	34.594	-14.258	485.8	8/18/ 2016 15:24	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense & Emergent Red Weeds	Agricultural Land	Harvested rice field with red weeds. Maize planted to the west.
104	6_25	34.592	-14.259	485.2	8/18/ 2016 15:30	Sample	On	0	Fallow	Shrubbery	Shrubbery: Dense & Emergent Red Weeds	Agricultural Land	Dry, harvested rice field covered in red weeds. Everything to the south of this point appears similar.

32	4_44	34.614	-14.246	473.3	8/17/ 2016 10:53	Sample	On	0	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	Medium Soil. Dry harvest rice field surrounded by the same.
34	5_44	34.614	-14.247	474.8	8/17/ 2016 10:56	Sample	Offset	1	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	Dark Soil. Grasses to the North and West. Maize to the South and East.
35	6_44	34.612	-14.246	476.0	8/17/ 2016 11:05	Sample	Offset	3	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	Medium Soil. Grasses. Dry harvested rice fields.
140	2_8	34.568	-14.271	494.9	8/19/ 2016 14:05	Sample	On	0	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	Mounded division between fields. The straw is hard packed.
31	2_48	34.624	-14.24	468.4	8/17/ 2016 10:45	Sample	On	0	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	Harvested rice field covered in brush. Dry harvested rice fields surrounding
51	1_33	34.601	-14.254	480.9	8/17/ 2016 13:03	Sample	On	0	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	Harvested rice field with small, sparse shrubs growing across the plot. Barren fields all around.
120	2_16	34.576	-14.265	491.9	8/19/ 2016 12:19	Sample	On	0	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	Small triangular plot with dirt turned and ready for planting. Low vegetative growth.
130	4_22	34.581	-14.261	486.4	8/19/ 2016 12:58	Sample	On	0	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	Dry harvested rice fields surrounding.
131	5_22	34.58	-14.262	496.2	8/19/ 2016 13:05	Sample	On	0	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	Dark Soil. Dry harvested rice fields.
138	3_23	34.585	-14.258	485.5	8/19/ 2016 13:54	Sample	On	0	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	To the north are grasses growing on dry harvest rice fields. To the south is rice.

141	6_22	34.584	-14.258	483.7	8/19/ 2016 14:09	Sample	On	0	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	Dry irrigated rice fields.
152	1_27	34.577	-14.254	485.5	8/19/ 2016 15:24	Sample	On	0	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	Dry harvested rice field. Trees and grass to the north. Bean to the south. More harvested rice to the west. Trees and grass to the east.
168	5_7	34.563	-14.269	496.8	8/20/ 2016 9:52	Sample	On	0	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	
178	5_21	34.576	-14.262	492.2	8/20/ 2016 10:34	Sample	On	0	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	Field is divided in half. Half is cow peas and half is dry harvested rice. Plots to the immediate south and west are the same. In other directions, plots are dry harvested rice.
189	5_2	34.553	-14.272	506.2	8/20/ 2016 11:23	Sample	On	0	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	Bare earth covered in spiked plants.
14	2_51	34.625	-14.237	463.9	8/16/ 2016 16:00	Sample	On	0	Fallow	Dried Fields	Dried Grass	Agricultural Land	Some minor cracks in the soil. There are dry harvest rice fields here.
128	6_16	34.579	-14.265	488.5	8/19/ 2016 12:52	Sample	On	0	Fallow	Dried Fields	Dried Grass	Agricultural Land	Mounded dried grasses and rice straw
134	1_23	34.585	-14.261	486.4	8/19/ 2016 13:28	Sample	On	0	Fallow	Dried Fields	Dried Grass	Agricultural Land	Dry harvested rice fields
147	1_29	34.585	-14.255	482.4	8/19/ 2016 14:38	Sample	On	0	Fallow	Dried Fields	Dried Grass	Agricultural Land	Dry harvested rice fields with straw.
157	4_27	34.576	-14.257	487.3	8/19/ 2016 15:50	Sample	On	0	Fallow	Dried Fields	Dried Grass	Agricultural Land	Mounded rice straw in a dry, harvested rice

													field. Cowpea planted to the north and west. Dry rice to the south and east.
67	3_46	34.622	-14.246	466.0	8/17/ 2016 14:33	Sample	On	0	Fallow	Dried Fields	Dried Grass	Agricultural Land	Surrounding fields are dried rice fields with grasses
95	4_19	34.59	-14.265	484.6	8/18/ 2016 13:49	Sample	On	0	Ag Infrast ructure	Irrigation Canal	Shrubbery: Dense	Infrastructu re	Cement gate to field along tertiary canal/ Large termite mound is also present here. Surround maize along the canal line.
162	1_7	34.565	-14.266	491.9	8/20/ 2016 9:36	Sample	Offset	15	Trees	Trees	Trees: Banana Trees & Dried Grass	Agricultural Land	
172	1_5	34.555	-14.271	498.6	8/20/ 2016 10:12	Sample	Offset	10	Trees	Trees	Trees: Banana Trees & Dried Grass	Agricultural Land	
156	2_4	34.564	-14.274	498.6	8/19/ 2016 15:48	Sample	Offset	15	Trees	Trees	Trees: Green Foliage on Active Agricultur al Land	Agricultural Land	Tree located along the scheme periphery (road)
71	7_46	34.622	-14.244	471.2	8/18/ 2016 11:25	Sample	Offset	8	Trees	Trees	Trees: Green Foliage on Fallow Field	Agricultural Land	Bare with a tree present. Patches of grass in the North, South, and West. Grass in the East.
77	11_38	34.6102	-14.2509	478.2	8/18/ 2016 11:54	Sample	On	0	Trees	Trees	Trees: Green Foliage on Fallow Field	Agricultural Land	Trees located along the periphery of the scheme

185	2_5	34.553	-14.269	505.3	8/20/ 2016 11:13	Sample	Offset	40	Trees	Trees	Trees: Green Foliage on Fallow Field	Agricultural Land	
7	1_56	34.634	-14.233	457.1	8/16/ 2016 14:54	Sample	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	To the south, east, and west are dry, harvested rice fields. Termite mound north
9	1_53	34.632	-14.235	456.2	8/16/ 2016 15:16	Sample	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	Plot surrounded by dry harvested rice fields.
17	5_51	34.625	-14.239	464.8	8/16/ 2016 16:20	Sample	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	Dry harvested rice fields. All surrounding plots are the same.
24	6_53	34.631	-14.237	462.3	8/16/ 2016 17:11	Sample	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	Harvested rice field. To the North and West are harvested rice fields. To the South and East are Maize fields.
36	1_49	34.627	-14.24	466.0	8/17/ 2016 11:06	Sample	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	Harvested rice field. To the North is evidence of rice straw. All surrounding areas are dry harvested rice fields.
127	3_22	34.58	-14.259	487.0	8/19/ 2016 12:49	Sample	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	To the north is a termite mound. Surrounding fields are all dry harvested rice.
173	3_20	34.573	-14.261	488.8	8/20/ 2016 10:16	Sample	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	All surrounding fields are dry harvested rice

139	1_8	34.568	-14.27	491.9	8/19/ 2016 14:00	Sample	On	0	Fallow	Dried Fields	Vertical Rice Straw w Green Tops	Agricultural Land	Former rice fields. Green rice tops are still exposed but bare earth turned for new plantings (holes dug).
86	1_25	34.595	-14.259	481.8	8/18/ 2016 12:50	Sample	On	0	Fallow	Dried Fields	Vertical Rice Straw w Little Vegetation	Agricultural Land	Dried rice field with straw collected. Beans to the immediate east. Remaining fields are dried rice.
105	1_40	34.6	-14.247	481.5	8/18/ 2016 15:33	Sample	On	0	Fallow	Dried Fields	Vertical Rice Straw w Little Vegetation	Agricultural Land	Dry harvested rice field. Surrounding areas are dry and harvested.
115	1_17	34.582	-14.266	491.0	8/18/ 2016 16:32	Sample	On	0	Fallow	Dried Fields	Vertical Rice Straw w Little Vegetation	Agricultural Land	Dry harvested rice field with little other ground cover. Mostly dark soil.
16	4_51	34.624	-14.239	466.9	8/16/ 2016 16:17	Sample	On	0	Fallow	Dried Fields	Vertical Rice Straw w Little Vegetation	Agricultural Land	Plot is surrounded by dry harvested rice fields.
34	BVIS_ AA_15 9	34.562	-14.268	449	8/20/ 2016	Accuracy	Offset	40	Trees	Trees	Banana Trees & Dense Shrubbery	Agricultural Land	
46	BVIS_ AA_5	34.6318	-14.2303	395	8/16/ 2016	Accuracy	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw	Agricultural Land	
33	BVIS_ AA_15 8	34.5585	-14.2678		8/16/ 2016	Accuracy	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw & Ridging	Agricultural Land	
37	BVIS_ AA_16 3	34.5622	-14.267	448	8/20/ 2016	Accuracy	On	0	Fallow	Bare Earth	Bare Earth: Dark Soil	Agricultural Land	

											w Straw & Ridging		
16	BVIS_AA_131	34.5953	-14.2585	424	8/18/2016	Accuracy	On	0	Active	Beans	Beans: Mature	Agricultural Land	
17	BVIS_AA_132	34.5953	-14.2585	437	8/18/2016	Accuracy	On	0	Active	Beans	Beans: Young	Agricultural Land	
22	BVIS_AA_145	34.5667	-14.2655	455	8/19/2016	Accuracy	On	0	Fallow	Shrubbery	Blackjack w Emergent Weeds	Agricultural Land	
20	BVIS_AA_138	34.5927	-14.257	442	8/18/2016	Accuracy	Offset	25	Fallow	Charred Ground	Charred Ground w Emergent Weeds	Agricultural Land	
55	BVIS_AA_75	34.6274	-14.2382	410	8/16/2016	Accuracy	On	0	Fallow	Charred Ground	Charred Ground w Emergent Weeds	Agricultural Land	Lots of straw is heaped up around this circle
15	BVIS_AA_128	34.597	-14.2571	421	8/18/2016	Accuracy	On	0	Active	Cowpea	Cowpea & Shrubbery	Agricultural Land	
11	BVIS_AA_123	34.6101	-14.2519	407	8/18/2016	Accuracy	On	0	Active	Cowpea	Cowpea: Mature	Agricultural Land	
40	BVIS_AA_28	34.637	-14.235	396	8/16/2016	Accuracy	On	0	Fallow	Dried Fields	Dried Grass	Agricultural Land	
21	BVIS_AA_144	34.5865	-14.2658	450	8/18/2016	Accuracy	On	0	Active	General Agriculture	Intercrop: Young Maize & Beans	Agricultural Land	
8	BVIS_AA_118	34.5966	-14.253	398	8/18/2016	Accuracy	On	0	Ag Infrastructure	Irrigation Canals	Irrigation Canal: Concrete	Infrastructure	Concrete tertiary canal. Charred ground & straw
24	BVIS_AA_147	34.5741	-14.2718	459	8/19/2016	Accuracy	On	0	Ag Infrastructure	Irrigation Canals	Irrigation Canal: Concrete	Infrastructure	Surrounded by green grasses and shrubbery
45	BVIS_AA_47	34.6281	-14.233	401	8/16/2016	Accuracy	On	0	Ag Infrastructure	Irrigation Canals	Bare Earth: Dark Soil w Straw	Infrastructure	

5	BVIS_AA_108	34.6069	-14.2482	404	8/17/2016	Accuracy	On	0	Active	Maize	Maize: Mature	Agricultural Land	Emergent vegetation growing between rows; not intercropped
6	BVIS_AA_109	34.607	-14.25	404	8/17/2016	Accuracy	On	0	Active	Maize	Maize: Mature	Agricultural Land	Field is adjacent to a fallow field covered in emergernt vegetation
7	BVIS_AA_116	34.6061	-14.25	403	8/17/2016	Accuracy	On	0	Active	Maize	Maize: Mature	Agricultural Land	Potentially an intercropped field
27	BVIS_AA_15	34.6351	-14.2308	394	8/16/2016	Accuracy	On	0	Active	Maize	Maize: Mature	Agricultural Land	On dark soil. No intercropping
35	BVIS_AA_16	34.635	-14.2304	395	8/16/2016	Accuracy	On	0	Active	Maize	Maize: Mature	Agricultural Land	No intercropping. Emergent weeds present.
58	BVIS_AA_80	34.629	-14.2389	405	8/16/2016	Accuracy	On	0	Active	Maize	Maize: Mature	Agricultural Land	No intercropping or emergent weeds
60	BVIS_AA_86	34.6311	-14.2381	404	8/16/2016	Accuracy	On	0	Active	Maize	Maize: Mature	Agricultural Land	No intercropping w little emergent weeds
29	BVIS_AA_151	34.552	-14.2734	470	8/19/2016	Accuracy	On	0	Active	General Agriculture	Mustard Greens	Agricultural Land	What crop is this?
12	BVIS_AA_124	34.5981	-14.2578	416	8/18/2016	Accuracy	Offset	10	Ag Infrastructure	Human Influence	Road	Infrastructure	
26	BVIS_AA_149	34.564	-14.2742	469	8/19/2016	Accuracy	On	0	Ag Infrastructure	Human Influence	Road	Infrastructure	
64	BVIS_AA_97	34.613	-14.253	387	8/17/2016	Accuracy	On	0	Ag Infrastructure	Human Influence	Road	Agricultural Land	Looking out toward drain at southwest corner of irrigation scheme
18	BVIS_AA_133	34.591	-14.2648	436	8/18/2016	Accuracy	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	

39	BVIS_AA_166	34.5529	-14.272	455	8/20/2016	Accuracy	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	
0	BVIS_AA_100	34.6161	-14.2439	385	8/17/2016	Accuracy	On	0	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	
44	BVIS_AA_4	34.6332	-14.2331	400	8/16/2016	Accuracy	Offset	3	Fallow	Shrubbery	Shrubbery: Dense	Agricultural Land	
19	BVIS_AA_134	34.59	-14.265	438	8/18/2016	Accuracy	Offset	10	Fallow	Shrubbery	Shrubbery: Dense	Infrastructure	
13	BVIS_AA_125	34.5981	-14.2578	414	8/18/2016	Accuracy	On	0	Fallow	Shrubbery	Shrubbery: Dense & Emergent red weeds	Agricultural Land	
14	BVIS_AA_126	34.597	-14.255	411	8/18/2016	Accuracy	On	0	Fallow	Shrubbery	Shrubbery: Dense & Emergent red weeds	Agricultural Land	
47	BVIS_AA_58	34.625	-14.2359	405	8/16/2016	Accuracy	On	0	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	
65	BVIS_AA_99	34.6151	-14.2437	379	8/17/2016	Accuracy	On	0	Fallow	Shrubbery	Shrubbery: Sparse	Agricultural Land	
50	BVIS_AA_67	34.6248	-14.2366	404	8/16/2016	Accuracy	On	0	Fallow	Dried Fields	Dried Grass	Agricultural Land	
51	BVIS_AA_68	34.625	-14.237	405	8/16/2016	Accuracy	On	0	Fallow	Dried Fields	Dried Grass	Agricultural Land	
10	BVIS_AA_122	34.609	-14.2517	405	8/18/2016	Accuracy	Offset	45	Trees	Trees	Trees: Green Foliage on Fallow Land w Green Vegetation	Agricultural Land	
38	BVIS_AA_164	34.553	-14.269	452	8/20/2016	Accuracy	Offset	40	Trees	Trees	Trees: Green foliage on Fallow Field	Agricultural Land	
2	BVIS_AA_103	34.612	-14.247	393	8/17/2016	Accuracy	On	0	Fallow	Dried Fields	Vertical Rice Straw w	Agricultural Land	

											Emergent Weeds		
3	BVIS_AA_104	34.6112	-14.247	393	8/17/2016	Accuracy	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	~15ft away is a charred circle
25	BVIS_AA_148	34.581	-14.2679	458	8/19/2016	Accuracy	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	Charred circle roughly 20ft away
32	BVIS_AA_156	34.5599	-14.27	449	8/20/2016	Accuracy	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	
42	BVIS_AA_34	34.6352	-14.2329	396	8/16/2016	Accuracy	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	
43	BVIS_AA_35	34.6339	-14.233	398	8/16/2016	Accuracy	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	
53	BVIS_AA_71	34.623	-14.2392	407	8/16/2016	Accuracy	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	Charred cirlce roughly 15ft away
54	BVIS_AA_72	34.6248	-14.2392	408	8/16/2016	Accuracy	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	
56	BVIS_AA_76	34.6273	-14.2378	409	8/16/2016	Accuracy	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	

57	BVIS_ AA_77	34.6278	-14.2368	406	8/16/ 2016	Accuracy	On	0	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds	Agricultural Land	

Dry Season BVIS Analysis Classes

Class Name	Samples in Class	# Crop Samples	Land Cover
1	18	1	Dry Season Fallow
2	20	5	Dry Season Fallow
3	43	4	Dry Season Fallow
4	13	2	Dry Season Fallow
5	19	6	Dry Season Fallow
6	35	10	Active Agriculture
7	3	0	Not Vegetated
8	10	4	Active Agriculture
9	12	3	Not Vegetated
10	7	3	Not Vegetated
11	33	8	Not Vegetated

Class 1: Dry Season Fallow

NAME	CLASS	SUBCLASS	LAND COVER
1_10	Active	Cowpea	Cowpea: Young
1_22	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
1_30	Fallow	Shrubbery	Shrubbery: Dense
1_44	Fallow	Shrubbery	Shrubbery: Dense
1_54	Fallow	Dried Fields	Dried Grass
2_46	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw
2_48	Fallow	Shrubbery	Shrubbery: Sparse
3_10	Fallow	Charred Ground	Charred Ground w Cowpea
3_22	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds
4_36	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
4_52	Fallow	Charred Ground	Charred Ground w Emergent Weeds
6_53	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds
7_16	Fallow	Dried Fields	Dried Grass & Emergent c3 Vegetation
7_44	Fallow	Shrubbery	Shrubbery: Dense
BVIS_AA_103	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds
BVIS_AA_104	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds
BVIS_AA_28	Fallow	Dried Fields	Dried Grass
BVIS_AA_34	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds

Class 2: Dry Season Fallow

NAME	CLASS	SUBCLASS	LAND COVER
2_57	Active	Maize	Maize: Mature
3_57b	Fallow	Dried Fields	Dried Grass
3_57	Fallow	Dried Fields	Dried Grass
1_56	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds
1_53	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds
10_53	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
5_53	Active	Maize	Maize: Mature
2_52	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
5_28	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
2_28	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
4_27	Fallow	Dried Fields	Dried Grass
6_22	Fallow	Shrubbery	Shrubbery: Sparse
7_22	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
1_21	Fallow	Charred Ground	Charred Ground on Bare Earth
2_20	Fallow	Shrubbery	Shrubbery: Dense
4_22	Fallow	Shrubbery	Shrubbery: Sparse
7_21	Active	Cowpea	Cowpea: Young
5_21	Fallow	Shrubbery	Shrubbery: Sparse
BVIS_AA_16	Active	Maize	Maize: Mature
BVIS_AA_15	Active	Maize	Maize: Mature

Class 3: Dry Season Fallow

NAME	CLASS	SUBCLASS	LAND COVER
1_58	Fallow	Bare Earth	Bare Earth: Dark Soil
4_57	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw
3_52	Fallow	Shrubbery	Shrubbery: Dense
2_51	Fallow	Dried Fields	Dried Grass
7_53	Fallow	Bare Earth	Bare Earth: Dark Soil
4_53	Active	Maize	Maize: Mature
4_51	Fallow	Dried Fields	Vertical Rice Straw w Little Vegetation
3_48	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
3_44	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
2_47	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw
3_46	Fallow	Dried Fields	Dried Grass
1_40	Fallow	Dried Fields	Vertical Rice Straw w Little Vegetation
2_36	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
5_31	Fallow	Shrubbery	Shrubbery: Dense
3_28	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
2_27	Fallow	Shrubbery	Shrubbery: Dense
3_33	Fallow	Shrubbery	Shrubbery: Dense
7_25	Fallow	Shrubbery	Shrubbery: Dense
2_22	Fallow	Charred Ground	Charred Ground w Shrubbery
6_21	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
1_18	Active	Beans	Beans: Mature
4_19	Ag Inf	Irrigation Canal	Shrubbery: Dense
6_16	Fallow	Dried Fields	Dried Grass
1_11	Fallow	Shrubbery	Shrubbery: Dense
4_7	Fallow	Shrubbery	Shrubbery: Dense
2_10	Active	Cowpea	Cowpea: Mature
BVIS_AA_47	Ag Inf	Irrigation Canals	Bare Earth: Dark Soil w Straw
BVIS_AA_4	Fallow	Shrubbery	Shrubbery: Dense
BVIS_AA_35	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds
BVIS_AA_67	Fallow	Dried Fields	Dried Grass
BVIS_AA_77	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds
BVIS_AA_68	Fallow	Dried Fields	Dried Grass
BVIS_AA_75	Fallow	Charred Ground	Charred Ground w/ Emergent Weeds
BVIS_AA_86	Active	Maize	Maize: Mature
BVIS_AA_71	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds
BVIS_AA_72	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds
BVIS_AA_99	Fallow	Shrubbery	Shrubbery: Sparse
BVIS_AA_134	Fallow	Shrubbery	Shrubbery: Dense
BVIS_AA_156	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds

Class 4: Dry Season Fallow

NAME	CLASS	SUBCLASS	LAND COVER
1_55	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw
1_52	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw
5_51	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds
1_48	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
1_49	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds
3_50	Fallow	Bare Earth	Bare Earth: Dark Soil
3_36	Fallow	Shrubbery	Shrubbery: Dense
3_27	Fallow	Shrubbery	Shrubbery: Dense
3_31	Active	Beans	Beans: Mature & Emergent Weeds
3_23	Fallow	Shrubbery	Shrubbery: Sparse
4_20	Fallow	Shrubbery	Shrubbery: Dense
BVIS_AA_5	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw
BVIS_AA_128	Active	Cowpea	Cowpea & Shrubbery

Class 5: Dry Season Fallow

NAME	CLASS	SUBCLASS	LAND COVER
2_55	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
5_52	Active	Maize	Maize: Mature
3_51	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
1_50	Fallow	Bare Earth	Bare Earth: Dark Soil
6_48	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
3_47	Fallow	Bare Earth	Bare Earth: Dark Soil
1_29	Fallow	Dried Fields	Dried Grass
3_21	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
4_25	Fallow	Charred Ground	Charred Ground w Emergent Weeds
2_23	Active	Cowpea	Cowpea: Young
1_14	Fallow	Shrubbery	Shrubbery: Dense
7_7	Fallow	Bare Earth	Bare Earth: Medium Soil w Straw & Ridging
2_12	Active	Maize	Maize: Young
1_6	Active	Beans	Beans: Young
2_1	Fallow	Bare Earth	Bare: Earth: Light Soil w Straw & Ridging
BVIS_AA_76	Fallow	Dried Fieds	Vertical Rice Straw w Emergent Weeds
BVIS_AA_80	Active	Maize	Maize: Mature
BVIS_AA_100	Fallow	Shrubbery	Shrubbery: Dense
BVIS_AA_144	Active	Gen Ag	Intercrop: Young Maize & Beans

Class 6: Active Agriculture

NAME	CLASS	SUBCLASS	LAND COVER
3_49	Fallow	Bare Earth	Bare Earth: Dark Soil
7_46	Trees	Trees	Trees: Green Foliage on Fallow Field
1_47	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw
6_46	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw
1_45	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw
4_47	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw
6_44	Fallow	Shrubbery	Shrubbery: Sparse
3_39	Active	Maize	Maize: Mature
6_38	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
9_38	Active	Maize	Maize: Young
3_38	Active	Beans	Beans: Young
5_38	Active	Maize	Maize: Young w Dense Shrubbery
4_28	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
1_33	Fallow	Shrubbery	Shrubbery: Sparse
4_33	Fallow	Shrubbery	Shrubbery: Dense
2_31	Fallow	Charred Ground	Charred Ground w Emergent Weeds
4_31	Fallow	Shrubbery	Shrubbery: Dense
4_21	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
6_25	Fallow	Shrubbery	Shrubbery: Dense & Emergent Red Weeds
3_20	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds
1_15	Active	Cowpea	Cowpea: Mature
5_19	Fallow	Charred Ground	Charred Ground w Beans
1_19	Fallow	Dried Fields	Dried Grass & Emergent c3 Vegetation
3_19	Fallow	Shrubbery	Dense Shrubbery w/ Medium Soil & Straw
1_17	Fallow	Dried Fields	Vertical Rice Straw w Little Vegetation
1_12	Fallow	Dried Fields	Dried Grass & Emergent c3 Vegetation
2_7	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
1_9	Active	Maize	Maize: Young
2_8	Fallow	Shrubbery	Shrubbery: Sparse
2_3	Active	Maize	Maize: Young
BVIS_AA_116	Active	Maize	Maize: Mature
BVIS_AA_122	Trees	Trees	Trees: Green foliage on fallow land w green vegetation
BVIS_AA_138	Fallow	Charred Ground	Charred Ground w Emergent Weeds
BVIS_AA_131	Active	Beans	Beans: Mature
BVIS_AA_132	Active	Beans	Beans: Young

Class 7: Not Vegetated

NAME	CLASS	SUBCLASS	LANDCOVER
2_56	Fallow	Dried Fields	Dried Grass & Emergent c3 Vegetation
2_40	Fallow	Bare Earth	Bare Earth: Dark Soil w Soil
1_35	Fallow	Dried fields	Horizontal Rice Straw w Emergent Weeds

Class 8: Active Agriculture

NAME	CLASS	SUBCLASS	LAND COVER
2_38	Active	General Ag	Intercrop: Young Maize & Beans
5_39	Active	Maize	Maize: Mature
2_37	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
2_33	Fallow	Shrubbery	Shrubbery: Dense
2_21	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
1_23	Fallow	Dried Fields	Dried Grass
1_24	Active	Beans	Beans: Mature & Emergent Weeds
3_7	Fallow	Shrubbery	Shrubbery: Dense
2_9	Fallow	Charred Ground	Charred Ground w Cowpea
BVIS_AA_133	Fallow	Shrubbery	Shrubbery: Dense

Class 9: Not Vegetated

NAME	CLASS	SUBCLASS	LAND COVER
2_49	Fallow	Bare Earth	Bare Earth: Dark Soil
1_28	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
3_25	Ag Inf	Irrigation Canal	Irrigation Canal: Concrete
3_15	Active	Cowpea	Cowpea & Shrubbery
2_16	Fallow	Shrubbery	Shrubbery: Sparse
1_8	Fallow	Dried Fields	Vertical Rice Straw w Green Tops
3_8	Fallow	Shrubbery	Shrubbery: Dense
1_3	Active	Maize	Maize: Mature
BVIS_AA_58	Fallow	Shrubbery	Shrubbery: Sparse
BVIS_AA_123	Active	Cowpea	Cowpea: Mature
BVIS_AA_124	Ag Inf	Human Influence	Road
BVIS_AA_125	Fallow	Shrubbery	Shrubbery: Dense & Emergent Red Weeds

Class 10: Not Vegetated

NAME	CLASS	SUBCLASS	LAND COVER
1_51	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw
1_39	Active	Maize	Maize: Mature
1_38	Fallow	Dried Fields	Dried Grass & Emergent c3 Vegetation
10_38	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
BVIS_AA_108	Active	Maize	Maize: Mature
BVIS_AA_109	Active	Maize	Maize: Mature
BVIS_AA_147	Ag Inf	Irrigation Canals	Irrigation Canal: Concrete

Class 11: Not Vegetated

NAME	CLASS	SUBCLASS	LAND COVER
4_48	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
5_48	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
5_46	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw
2_44	Fallow	Shrubbery	Shrubbery: Dense
2_45A	Fallow	Bare Earth	Bare Earth: Dark Soil w Straw
4_46	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
4_45	Active	Maize	Maize: Mature
4_44	Fallow	Shrubbery	Shrubbery: Sparse
1_46	Fallow	Dried Fields	Dried Grass
5_44	Fallow	Shrubbery	Shrubbery: Sparse
1_43	Fallow	Shrubbery	Shrubbery: Dense
4_39	Active	Gen Ag	Intercrop: Mature Maize & Beans
8_38	Active	Maize	Shrubbery: Dense
1_36	Fallow	Shrubbery	Shrubbery: Dense
4_38	Active	Beans	Beans: Young
1_27	Fallow	Shrubbery	Shrubbery: Sparse
1_31	Fallow	Shrubbery	Shrubbery: Dense
5_33	Active	Maize	Maize: Young w Dense Shrubbery
2_25	Fallow	Shrubbery	Shrubbery: Dense
5_25	Fallow	Shrubbery	Shrubbery: Dense & Emergent Red Weeds
1_26	Fallow	Shrubbery	Shrubbery: Dense
1_25	Fallow	Dried Fields	Vertical Rice Straw w Little Vegetation
5_22	Fallow	Shrubbery	Shrubbery: Sparse
2_15	Active	Cowpea	Cowpea & Shrubbery
2_19	Active	Beans	Beans: Young
3_16	Fallow	Shrubbery	Shrubbery: Dense
2_18	Active	Beans	Beans: Young
5_7	Fallow	Shrubbery	Shrubbery: Sparse
2_6	Fallow	Shrubbery	Shrubbery: Dense
4_9	Fallow	Shrubbery	Blackjack w Emergent Weeds
BVIS_AA_126	Fallow	Shrubbery	Shrubbery: Dense & Emergent Red Weeds
BVIS_AA_145	Fallow	Shrubbery	Blackjack w Emergent Weeds
BVIS_AA_148	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds

APPENDIX C:

Dry Season LULC Data: Bwanje Valley

Bwanje Valley Dry Season Classification Table

	Study Area		TOTAL
Class Descriptions	***Sample***	***AA***	
I. AGRICULTURAL LAND			
II. ACTIVE			
Maize			
Young	1	0	**1**
Cowpea			
Cowpea & Shrubbery	2	0	**2**
Cotton			
Cotton	0	1	**1**
II. FALLOW			
Bare Earth			
Dark Soil	2	0	**2**
Dark Soil w/ Straw	0	1	**1**
Dark Soil w/ Straw & Ridging	0	1	**1**
Light Soil	1	0	**1**
Light Soil w/ Straw	1	1	**2**
Light Soil w/ Straw & Ridging	8	4	**12**
Light Soil w/ Ridging	2	5	**7**
Medium Soil w/ Ridging & Emergent Weeds	3	0	**3**
Charred Ground			
Charred Ground on Bare Earth	1	1	**2**
Dried Fields			
Vertical Rice Straw w/ Emergent Weeds	1	4	**5**
Horizontal Rice Straw w/ Emergent Weeds	0	1	**1**
Dried Grass	1	0	**1**
Long Term Fallow			
Medium Soil w/ Ridging & Dried Vegetation	1	1	**2**
Shrubbery			
Dense	2	3	**5**

	Study Area		TOTAL
Class Descriptions	***Sample***	***AA***	
IV. TREES			
Green Foliage on Bare Soil	1	0	**1**
Green Foliage on Dry Harvested Agricultural Land w Ridging	3	2	**5**
I. NON-AGRICULTURAL LAND			
Bare Earth			
Dark Soil w/ Straw	2	1	**3**
Light Soil	5	1	**6**
Light Soil w/ Green Vegetation	3	4	**7**
Charred Ground			
Charred Ground w/ Dry Vegetation	3	1	**4**
Dried Grass			
Dried Grass	0	5	**5**
Trees			
Green Foliage & Dry Undergrowth	2	1	**3**
Green Foliage on Bare Soil	3	1	**4**
Little Green Foliage w/ Dry Undergrowth	4	7	**11**
Mostly Dried Leaves	0	3	**3**
Dried Trees on Bare Rock	1	0	**1**
Human Influence			
Road	1	0	**1**
Human Dwellings	1	1	**2**
Riverbed			
Riverbed	0	3	**3**

Bwanje Valley Dry Season Classification Photos

I. AGRICULTURAL LAND

II. ACTIVE

Maize

Young

Sample Photos:

3_31

Accuracy Assessment Photos:
None

I. AGRICULTURAL LAND

II. ACTIVE

Cowpea

Cowpea & Shrubbery

Sample Photos:

3_43

Other_3

Accuracy Assessment Photos:
None

I. AGRICULTURAL LAND

II. ACTIVE

Cotton

Cotton

Sample Photos:
None

Accuracy Assessment Photos:

SA_AA_35

I. AGRICULTURAL LAND

II. FALLOW

Bare Earth

Dark Soil

Sample Photos:

2_87

4_34

Accuracy Assessment Photos:
None

I. AGRICULTURAL LAND

II. FALLOW

Bare Earth

Dark Soil w Straw

Sample Photos:
None

Accuracy Assessment Photos:

SA_AA_137

I. AGRICULTURAL LAND

II. FALLOW

Bare Earth

Dark Soil w Straw & Ridging

Sample Photos:
None

Accuracy Assessment Photos:

SA_AA_114

I. AGRICULTURAL LAND

II. FALLOW

Bare Earth

Light Soil

Sample Photos:

1_18

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND

II. FALLOW

Bare Earth

Light Soil w/ Straw

Sample Photos:

1_17

Accuracy Assessment Photos:

SA_AA_23

I. AGRICULTURAL LAND

II. FALLOW

Bare Earth

Light Soil w Straw & Ridging

Sample Photos:


1_34


1_18a


1_56


1_82


3_64


1_64


2_22


1_22

Accuracy Assessment Photos:


SA_AA_41


SA_AA_48


SA_AA_49


SA_AA_111

I. AGRICULTURAL LAND

II. FALLOW

Bare Earth

Light Soil w Ridging

Sample Photos:


2_82

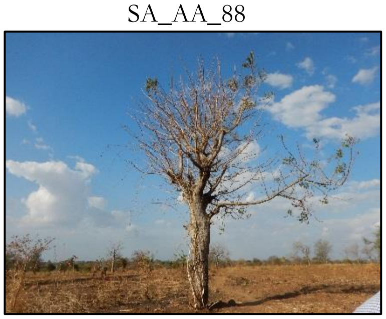

1_32

Accuracy Assessment Photos:


SA_AA_88


SA_AA_89


SA_AA_108


SA_AA_112


SA_AA_6

I. AGRICULTURAL LAND

II. FALLOW

Bare Earth

Medium Soil w Ridging & Emergent Weeds

Sample Photos:


1_58


1_81


2_32

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND

II. FALLOW

Charred Ground

Charred Ground on Bare Earth

Sample Photos:


1_100

Accuracy Assessment Photos:


SA_AA_69

I. AGRICULTURAL LAND
II. FALLOW
Dried Fields
Vertical Rice Straw w Emergent Weeds

Sample Photos:

1_37

Accuracy Assessment Photos:

SA_AA_17

SA_AA_18

SA_AA_135

SA_AA_158

I. AGRICULTURAL LAND

II. FALLOW

Dried Fields

Horizontal Rice Straw w Emergent Weeds

Sample Photos:

None

Accuracy Assessment Photos:

SA_AA_157

I. AGRICULTURAL LAND

II. FALLOW

Dried Fields

Dried Grass

Sample Photos:

1_20

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND		
	II. FALLOW	
		Long Term Fallow
		Medium Soil w Ridging & Dried Vegetation
		Sample Photos:  1_3
		Accuracy Assessment Photos:  SA_AA_110

I. AGRICULTURAL LAND

II. FALLOW

Shrubbery

Shrubbery: Dense

Sample Photos:

2_56

3_56

Accuracy Assessment Photos:

SA_AA_162

SA_AA_163

SA_AA_164

I. AGRICULTURAL LAND

IV. TREES

Green Foliage on Bare Soil

Sample Photos:

1_33

Accuracy Assessment Photos:

None

I. AGRICULTURAL LAND

IV. TREES

Green Foliage on Dry Harvested Agricultural Land w Ridging

Sample Photos:


1_27


1_87


2_64

Accuracy Assessment Photos:


SA_AA_50


SA_AA_118

II. NON-AGRICUTURAL LAND

Bare Earth

Dark Soil w Straw

Sample Photos:

1_61

2_14

Accuracy Assessment Photos:

SA_AA_61

II. NON-AGRICUTURAL LAND

Bare Earth

Light Soil

Sample Photos:

1_93

2_95

2_100

1_49

1_74

Accuracy Assessment Photos:

SA_AA_103

II. NON-AGRICUTURAL LAND

Bare Earth

Light Soil w Green Vegetation

Sample Photos:

1_36

3_79

2_61

Accuracy Assessment Photos:

SA_AA_51

SA_AA_52

SA_AA_119

SA_AA_120

II. NON-AGRICUTURAL LAND

Charred Ground

Charred Ground & Dry Vegetation

Sample Photos:


3_34


3_77


1_31

Accuracy Assessment Photos:


SA_AA_30

II. NON-AGRICUTURAL LAND

Dried Grass

Dried Grass

Sample Photos:

None

Accuracy Assessment Photos:

SA_AA_60

SA_AA_78

SA_AA_73

SA_AA_74

SA_AA_75

II. NON-AGRICUTURAL LAND		
	Trees	
		Green Foliage & Dry Undergrowth
		Sample Photos:  2_20  1_24
		Accuracy Assessment Photos:  SA_AA_2

II. NON-AGRICUTURAL LAND

Trees

Green Foliage on Bare Soil

Sample Photos:

1_14

2_36

4_91

Accuracy Assessment Photos:

SA_AA_5

II. NON-AGRICUTURAL LAND

Trees

Little Green Foliage w Dry Undergrowth

Sample Photos:

2_24

1_8

2_77

1_35

Accuracy Assessment Photos:

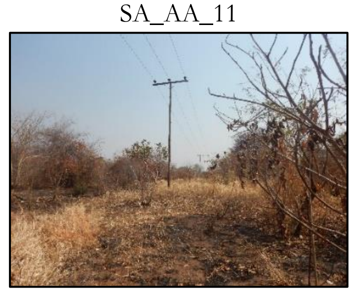
SA_AA_9

SA_AA_10

SA_AA_11

SA_AA_28

SA_AA_29



SA_AA_38

SA_AA_39

II. NON-AGRICUTURAL LAND

Trees

Mostly Dried Leaves

Sample Photos:

None

Accuracy Assessment Photos:

SA_AA_37

SA_AA_40

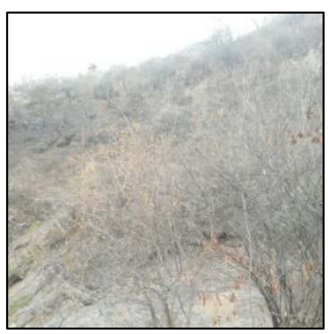
SA_AA_64

II. NON-AGRICUTURAL LAND

Trees

Dried Trees on Bare Rock

Sample Photos:



2_31

Accuracy Assessment Photos:

None

II. NON-AGRICUTURAL LAND

Human Influence

Road

Sample Photos:

2_34

Accuracy Assessment Photos:

II. NON-AGRICUTURAL LAND

Human Influence

Human Dwellings

Sample Photos:

2_3

Accuracy Assessment Photos:

SA_AA_36

II. NON-AGRICULTURAL LAND

IV. TREES

Riverbed

Sample Photos:

None

Accuracy Assessment Photos:


SA_AA_92


SA_AA_155


SA_AA_156

Bwanje Valley Dry Season Data

ID	Name	X	Y	Elev	Date_ Time	Pnt_type	Pnt_Acq	Offset_ Dist	Land_Use_ ANA	Land_ Cover	Land_Use	Notes
56	3_43	34.56	-14.27	498.6	8/25/2016 13:50	Sample	On	0	Agriculture	Cowpea & Shrubbery	Agricultural Land	Inside the scheme within a cowpea field with weeds. Harvested rice field in between cow pea field and a maize field to the south. Cowpea fields to the E, N & W.
26	2_87	34.615	-14.222	462.6	8/23/2016 13:08	Sample	On	0	Agriculture	Bare Earth: Dark Soil	Agricultural Land	Charred former cropland under the canopy of trees Same to the ENW & South. Open dry land.
6	4_34	34.561	-14.292	503.5	8/22/2016 11:57	Sample	On	0	Agriculture	Bare Earth: Dark Soil	Agricultural Land	Open dirt field. Appears to at one time been used for agriculture (maize?)
52	1_61	34.657	-14.26	468.7	8/25/2016 10:15	Sample	On	0	Non-Agriculture	Bare Earth: Dark Soil w Straw	Unsure	Trees in the middle of a mostly open landscape dotted with sporadic trees and dried grasses.
17	2_14	34.675	-14.286	461.7	8/22/2016 16:58	Sample	On	0	Non-Agriculture	Bare Earth: Dark soil w Straw	Unsure	
35	2_100	34.598	-14.195	465.7	8/23/2016 16:09	Sample	On	0	Non-Agriculture	Bare Earth: Light soil	Unsure	Open, barren land covered in dried grass. A small village to the west and southeast.
28	2_95	34.611	-14.208	465.1	8/23/2016 13:59	Sample	On	0	Non-Agriculture	Bare Earth: Light soil	Unsure	Dry grassland with a few sporadic trees. The soil is dark grey.
51	1_49	34.661	-14.273	471.5	8/25/2016 10:02	Sample	On	0	Non-Agriculture	Bare Earth: Light soil	Unsure	Bare land with sporadic palm trees and baobab trees. Houses located to the immediate south
33	1_93	34.582	-14.204	471.5	8/23/2016 15:38	Sample	On	0	Non-Agriculture	Bare Earth: Light soil	Unsure	Dry, barren area. A few homes to the

												south and a few sporadic trees. Otherwise a traditional looking savannah landscape.
15	1_18	34.662	-14.309	486.4	8/22/2016 16:03	Sample	On	0	Agriculture	Bare Earth: Light Soil	Agricultural Land	Open field. Soils are more red and sandy. Adjacent to a village. Covered in tall, dried reeds. Evidence of some type of cropping here. Maize (?)
46	1_74	34.515	-14.238	537.0	8/24/2016 14:23	Sample	On	0	Non-Agriculture	Bare Earth: Light Soil	Built Up	Torn down house surrounded by open land with sporadic tree cover. Soccer field to the immediate south.
1	1_32	34.537	-14.297	519.0	8/24/2016 13:21	Sample	On	0	Agriculture	Bare Earth: Light soil w ridging	Agricultural Land	Dry, harvested maize fields. Homes to the immediate north. Fields in the direction of the road and homes to the west.
10	1_36	34.586	-14.29	486.7	8/22/2016 13:36	Sample	On	0	Non-Agriculture	Bare Earth: Light Soil w Green Vegetation	Unsure	
23	3_79	34.619	-14.228	465.1	8/23/2016 12:09	Sample	On	0	Non-Agriculture	Bare Earth: Light Soil w Green Vegetation	Unsure	
53	2_61	34.655	-14.253	465.7	8/25/2016 10:30	Sample	On	0	Non-Agriculture	Bare Earth: Light Soil w Green Vegetation	Infrastructure	Inside a dried river bed surrounded by open land with sporadic tree and grasses. This is a diversion weir for another rice scheme further down. Namboona River.

48	2_82	34.523	-14.222	506.2	8/24/2016 14:59	Sample	On	0	Agriculture	Bare Earth: Light soil w ridging	Agricultural Land	Dry, harvested field left fallow. Sporadic trees but mainly dry fields and a few houses.
14	1_17	34.636	-14.313	484.9	8/22/2016 15:30	Sample	On	0	Agriculture	Bare Earth: Light soil w Straw	Agricultural Land	
24	1_18a	34.625	-14.23	462.3	8/23/2016 12:23	Sample	On	0	Agriculture	Bare Earth: Light soil w straw & ridging	Agricultural Land	
2	1_34	34.562	-14.289	503.5	8/22/2016 11:33	Sample	On	0	Agriculture	Bare Earth: Light soil w straw & ridging	Agricultural Land	Dry, harvested maize field. To the north is a village. To the south is open land. Grey-Brown soil.
57	1_56	34.561	-14.267	497.4	8/25/2016 14:06	Sample	On	0	Agriculture	Bare Earth: Light soil w straw & ridging	Agricultural Land	Harvested field of maize but outside o the scheme. Banana and sugarcane on the SE. Nsangu trees on western side and a main farm road on the north.
43	1_64	34.512	-14.256	551.3	8/24/2016 13:51	Sample	On	0	Agriculture	Bare Earth: Light soil w straw & ridging	Agricultural Land	Drainage canal surrounded by dry maize fields that have been harvested and left fallow.
47	1_82	34.52	-14.217	497.7	8/24/2016 14:41	Sample	On	0	Agriculture	Bare Earth: Light soil w straw & ridging	Agricultural Land	Dry field. Irrigated maize field closer to the road. Village to the east.
45	3_64	34.517	-14.25	535.2	8/24/2016 14:11	Sample	On	0	Agriculture	Bare Earth: Light soil w straw & ridging	Agricultural Land	Dry, harvested maize field immediately adjacent to homes. Sporadic trees to the east and some to the west.

50	2_22	34.537	-14.306	531.2	8/24/2016 15:43	Sample	On	0	Agriculture	Bare Earth: Light Soil w Straw & Ridging	Agricultural Land	Dry, harvested field. Sporadic trees in all directions.
49	1_22	34.535	-14.304	528.8	8/24/2016 15:34	Sample	On	0	Agriculture	Bare Earth: Light Soil w Straw & Ridging	Agriculture	Dry, harvested land covered in grasses with sporadic trees dotting the landscape
60	1_81	34.639	-14.235	464.2	8/26/2016 9:31	Sample	On	0	Agriculture	Bare Earth: Medium Soil w Ridging & Emergent Weeds	Agriculture	Appearance of previous harvested rice field. Now this area is left fallow and covered in dried grasses.
61	2_32	34.536	-14.288	519.6	8/26/2016 10:26	Sample	On	0	Agriculture	Bare Earth: Medium Soil w Ridging & Emergent Weeds	Agriculture	Dry, harvested maize field. Tree immediately to the E. Sporadic trees dot the landscape where most maize fields have been left fallow and are covered in weeds and tall grasses
5	3_34	34.564	-14.293	501.7	8/22/2016 11:51	Sample	On	0	Non-Agriculture	Charred Ground & Dry Vegetation	Unsure	Charred ground. Dark grey soil. Surrounded by random grasses and trees
31	3_77	34.573	-14.232	483.1	8/23/2016 14:54	Sample	On	0	Non-Agriculture	Charred Ground & Dry Vegetation	Unsure	Charred ground surrounded by grasses that are dry. Outside of a small tree grove. To the north are more grasses and larger trees.
37	1_31	34.514	-14.286	557.1	8/24/2016 10:02	Sample	On	0	Non-Agriculture	Charred Ground & Dry Vegetation	Unsure	
34	1_100	34.602	-14.191	459.9	8/23/2016 15:54	Sample	On	0	Agriculture	Charred Ground on Bare Earth	Agricultural Land	Charred ground amidst open fields. A few palms in the

												area. A few homes nearby just off the lake.
55	Other_3	34.562	-14.27	495.6	8/25/2016 13:38	Sample	On	0	Agriculture	Cowpea & Shrubbery	Agricultural Land	
39	1_20	34.496	-14.295	615.0	8/24/2016 10:33	Sample	On	0	Agriculture	Dried Grass	Agriculture	Small tree adjacent to a channel for water. Maize plots with nothing planted located here. Tall, dry grasses dominate.
38	2_31	34.5131	-14.2867	555.6	8/24/2016 10:09	Sample	On	0	Non-Agriculture	Dried Trees on Bare Rock	Unsure	Bare rock along a cliff face. Former perineal river.
22	1_58	34.601	-14.259	482.8	8/23/2016 11:00	Sample	On	0	Agriculture	Bare Earth: Medium Soil w Ridging & Emergent Weeds	Agriculture	Harvested maize field. Spiny grasses. Weeds to the south and west. To the E, low grasses. N- Line of trees, then the scheme. Right at this point are two small banana trees.
20	2_3	34.561	-14.337	525.1	8/23/2016 9:30	Sample	On	0	Non-Agriculture	Human Dwellings	Built Up	Housing compound. Point is at the outhouse structure. Made of dried grasses adjacent to cotton fields. In a village with grasses to the north in the direction of the scheme.
42	3_31	34.5251	-14.292	516.3	8/24/2016 13:32	Sample	On	0	Agriculture	Maize: Young	Agricultural Land	Irrigated maize field. Point taken from a small road between fields. To the south are houses. A few large trees dot the scheme. All maize is green.
18	1_3	34.558	-14.339	532.7	8/23/2016 9:17	Sample	On	0	Agriculture	Medium Soil w Ridging &	Agriculture	Bare maize field overgrown with

										Dried Vegetation		weeds adjacent to the railway lines.
3	2_34	34.566	-14.289	493.1	8/22/2016 11:40	Sample	On	0	Non-Agriculture	Road	Infrastructure	Dirt road through to a village surrounded by dead, drying vegetation.
58	2_56	34.571	-14.263	489.5	8/25/2016 14:29	Sample	On	0	Agriculture	Shrubbery: Dense	Agricultural Land	Inside the scheme. Cleared field covered with red and green shrubs. Barren field as well on the N, E, & W but green maize fields to the south.
59	3_56	34.587	-14.255	484.3	8/25/2016 15:03	Sample	On	0	Agriculture	Shrubbery: Dense	Agricultural Land	Inside the scheme. Harvested rice field surrounded by harvested rice fields with some grass and dry vegetation. There is a green maize plot almost 50m on the eastern side.
8	1_24	34.579	-14.296	491.6	8/22/2016 12:33	Sample	On	0	Non-Agriculture	Trees: Green Foliage & Dry Undergrowth	Unsure	Small cluster of trees surrounded by open, bare land
40	2_20	34.505	-14.31	629.1	8/24/2016 10:58	Sample	On	0	Non-Agriculture	Trees: Green Foliage & Dry Undergrowth	Unsure	Thick tree and vegetative growth. Tall grass undergrowth. Adjacent to a road. House located to the south.
11	2_36	34.592	-14.288	481.2	8/22/2016 13:50	Sample	On	0	Non-Agriculture	Trees: Green Foliage on Bare Soil	Unsure	
36	4_91	34.553	-14.20	491.0	8/23/2016 16:26	Sample	On	0	Non-Agriculture	Trees: Green Foliage on Bare Soil	Built Up	Taller clustering of grasses and low trees. To the E is a grouping of homes. This point is located within a village.

												Some of the homes have tin roofs.
0	1_33	34.55	-14.292	515.7	8/22/2016 11:18	Sample	On	0	Agriculture	Trees: Green Foliage on Bare Soil	Agriculture	
16	1_14	34.664	-14.296	478.5	8/22/2016 16:28	Sample	On	0	Non-Agriculture	Trees: Green Foliage on Bare Soil	Unsure	
13	1_27	34.624	-14.308	479.4	8/22/2016 15:03	Sample	On	0	Agriculture	Trees: Green Foliage on Dry Harvested Agricultural Land w Ridging	Agriculture	Tall tree cover amidst a field of changing brush to barren lots surrounded by tall trees. We have not seen these types of trees elsewhere. Brush is almost to our waists. It looks like a prairie.
27	1_87	34.61	-14.223	460.2	8/23/2016 13:25	Sample	On	0	Agriculture	Trees: Green Foliage on Dry Harvested Agricultural Land w Ridging	Agriculture	Grey, dry ground surrounded by green trees and small shrubs. Dead leaves and dry grasses cover the floor.
44	2_64	34.514	-14.251	542.5	8/24/2016 14:02	Sample	On	0	Agriculture	Trees: Green Foliage on Dry Harvested Agricultural Land w Ridging	Agriculture	Mango tree sitting within a dry harvested maize field.
7	1_35	34.581	-14.292	487.9	8/22/2016 12:24	Sample	On	0	Non-Agriculture	Trees: Little foliage w Dry Undergrowth	Unsure	Open, dry area covered in sticks. Houses to the E
21	1_8	34.549	-14.327	534.9	8/23/2016 9:42	Sample	On	0	Non-Agriculture	Trees: Little foliage w Dry Undergrowth	Unsure	Small grouping of trees with dried orange leaves. Adjacent to powerlines with dried grasses below.

9	2_24	34.572	-14.298	495.3	8/22/2016 12:48	Sample	On	0	Non-Agriculture	Trees: Little foliage w Dry Undergrowth	Unsure	Clustering of small trees surrounded by dry grasses.
30	2_77	34.575	-14.233	476.0	8/23/2016 14:47	Sample	On	0	Non-Agriculture	Trees: Little foliage w Dry Undergrowth	Unsure	Charred ground surrounded by grasses that are dried out. We're outside of a small tree grove now. To the north are more grasses and larger trees.
12	1_37	34.612	-14.284	474.5	8/22/2016 14:14	Sample	On	0	Agriculture	Vertical Rice Straw w Emergent Weeds	Agricultural Land	Harvested dry rice field adjacent to maize planted to the east.
4	SA_AA_10	34.5790	-14.296	453	2016:08:22	Accuracy	On	0	Non-Agriculture	Trees: Little Green Foliage with Dry Undergrowth	Unsure	
37	SA_AA_103	34.5169	-14.250	466	2016:08:24	Accuracy	Offset	5	Non-Agriculture	Bare Earth: Light Soil	Built up	
38	SA_AA_108	34.5227	-14.222	441	2016:08:24	Accuracy	On	0	Agriculture	Bare Earth: Light soil w Ridging	Agriculture	
5	SA_AA_11	34.576	-14.296	459	2016:08:22	Accuracy	On	0	Non-Agriculture	Trees: Little Green Foliage with Dry Undergrowth	Unsure	
39	SA_AA_110	34.5350	-14.304	468	2016:08:24	Accuracy	On	0	Agriculture	Medium Soil w Ridging & Dried Vegetation		
40	SA_AA_111	34.5350	-14.304	468	2016:08:24	Accuracy	On	0	Agriculture	Bare Earth: Light Soil w Straw & Ridging	Agriculture	Trees with green foliage present across the area. Spotty.

41	SA_AA_112	34.5350	-14.304	466	2016:08:24	Accuracy	On	0	Agriculture	Bare Earth: Light soil w Ridging	Agriculture	One tree located here. No foliage.
42	SA_AA_114	34.5350	-14.304	466	2016:08:24	Accuracy	On	0	Agriculture	Bare Earth: Dark soil w straw & ridging	Agriculture	
46	SA_AA_118	34.5343	-14.306	473	2016:08:24	Accuracy	On	0	Agriculture	Trees: Green Foliage on Dry Harvested Agricultural Land w Ridging	Agriculture	There is a pathway here flanked by trees. Otherwise trees are only sporadic.
47	SA_AA_119	34.5343	-14.306	396	2016:08:24	Accuracy	On	0	Non-Agriculture	Light Soil w Green Vegetation	Unsure	
48	SA_AA_120	34.5343	-14.306	396	2016:08:24	Accuracy	On	0	Non-Agriculture	Light Soil w Green Vegetation	Unsure	
52	SA_AA_135	34.6616	-14.249	380	2016:08:25	Accuracy	On	0	Agriculture	Vertical Rice Straw w Emergent Weeds	Agriculture	Nambuona Irrigation Scheme: 200ha
54	SA_AA_137	34.6616	-14.249	378	2016:08:25	Accuracy	On	0	Agriculture	Bare Earth: Dark Soil w Straw	Agriculture	Active cultivation going on nearby.
55	SA_AA_155	34.5452	-14.279	394	2016:08:25	Accuracy	On	0	Non-Agriculture	Riverbed	Unsure	This is the end of available water from Namikokwe
56	SA_AA_156	34.5452	-14.279	394	2016:08:25	Accuracy	On	0	Non-Agriculture	Riverbed	Unsure	
57	SA_AA_157	34.5452	-14.279	395	2016:08:25	Accuracy	On	0	Agriculture	Horizontal Rice Straw w Emergent Weeds	Agriculture	
58	SA_AA_158	34.5452	-14.279	395	2016:08:25	Accuracy	On	0	Agriculture	Vertical Rice Straw w Emergent Weeds	Agricultures	
60	SA_AA_162	34.536	-14.288	426	2016:08:26	Accuracy	On	0	Agriculture	Shrubbery: Dense	Agriculture	With ridging
61	SA_AA_163	34.5360	-14.288	426	2016:08:26	Accuracy	On	0	Agriculture	Shrubbery: Dense	Agriculture	Without ridging

62	SA_AA_164	34.5360	-14.288	427	2016:08:26	Accuracy	On	0	Agriculture	Shrubbery: Dense	Agriculture	Ridging. Fallow field. Trees with green foliage present.
6	SA_AA_17	34.6119	-14.284	450	2016:08:22	Accuracy	On	0	Agriculture	Vertical Rice Straw w Emergent Weeds	Agriculture	Charred circle in the center of the plot. Maize planted nearby
7	SA_AA_18	34.612	-14.284	451	2016:08:22	Accuracy	On	0	Agriculture	Vertical Rice Straw w Emergent Weeds	Agriculture	
1	SA_AA_2	34.5162	-14.275	487	2016:08:20	Accuracy	On	0	Non-Agriculture	Trees: Green Foliage & Dry Undergrowt h	Unsure	
9	SA_AA_23	34.6242	-14.307	462	2016:08:22	Accuracy	On	0	Agriculture	Bare Earth: Light Soil w Straw & Ridging	Agriculture	Tree with green foliage about 75ft away
10	SA_AA_28	34.6639	-14.296	461	2016:08:22	Accuracy	On	0	Non-Agriculture	Trees: Little Green Foliage with Dry Undergrowt h	Unsure	
11	SA_AA_29	34.6639	-14.296	460	2016:08:22	Accuracy	On	0	Non-Agriculture	Trees: Little Green Foliage with Dry Undergrowt h	Unsure	
12	SA_AA_30	34.6701	-14.284	451	2016:08:22	Accuracy	On	0	Non-Agriculture	Charred Ground & Dry Vegetation	Unsure	
13	SA_AA_35	34.5612	-14.337	466	2016:08:23	Accuracy	On	0	Agriculture	Cotton	Agriculture	
14	SA_AA_36	34.5612	-14.337	466	2016:08:23	Accuracy	On	0	Non-Agriculture	Human Dwellings	Built up	
15	SA_AA_37	34.5611	-14.337	475	2016:08:23	Accuracy	On	0	Non-Agriculture	Trees: Mostly Dried Leave	Unsure	
16	SA_AA_38	34.5489	-14.327	474	2016:08:23	Accuracy	On	0	Non-Agriculture	Trees: Little Green	Unsure	

										Foliage with Dry Undergrowt h		
17	SA_AA_39	34.5489	-14.327	473	2016:08:23	Accuracy	On	0	Non-Agriculture	Trees: Little Green Foliage with Dry Undergrowt h	Unsure	
18	SA_AA_40	34.5489	-14.327	475	2016:08:23	Accuracy	On	0	Non-Agriculture	Trees: Mostly Dried Leave	Unsure	
19	SA_AA_41	34.5489	-14.327	423	2016:08:23	Accuracy	On	0	Agriculture	Bare Earth: Light Soil w Straw & Ridging	Agriculture	
20	SA_AA_48	34.625	-14.23	414	2016:08:23	Accuracy	On	0	Agriculture	Bare Earth: Light soil w Straw & Ridging	Agriculture	
21	SA_AA_49	34.6250	-14.23	414	2016:08:23	Accuracy	On	0	Agriculture	Bare Earth: Light soil w Straw & Ridging	Agriculture	Fallow field. Green wild vegetation growing in plots nearby.
2	SA_AA_5	34.5639	-14.293	459	2016:08:22	Accuracy	On	0	Non-Agriculture	Trees: Green Foliage on Bare Soil	Unsure	
22	SA_AA_50	34.6250	-14.23	414	2016:08:23	Accuracy	On	0	Agriculture	Trees: Green Foliage on Dry Harvested Agricutural Land w Ridging	Agriculture	
23	SA_AA_51	34.6151	-14.222	406	2016:08:23	Accuracy	On	0	Non-Agriculture	Light Soil w Green Vegetation	Unsure	
24	SA_AA_52	34.6150	-14.222	407	2016:08:23	Accuracy	On	0	Non-Agriculture	Light Soil w Green Vegetation	Unsure	Trees with green foliage
0	SA_AA_6	34.5617	-14.292	464	2016:08:22	Accuracy	On	0	Agriculture	Bare Earth: Light soil w Ridging	Agriculture	Large mound of dirt in the distance. The ridging is not very

												high here, but is evident.
25	SA_AA_60	34.6238	-14.217	412	2016:08:23	Accuracy	On	0	Non-Agriculture	Dried Grass	Unsure	
26	SA_AA_61	34.6236	-14.216	412	2016:08:23	Accuracy	On	0	Non-Agriculture	Bare Earth: Dark Soil w Straw	Unsure	
27	SA_AA_64	34.5750	-14.233	435	2016:08:23	Accuracy	On	0	Non-Agriculture	Trees: Mostly Dried Leave	Unsure	
28	SA_AA_69	34.602	-14.191	417	2016:08:23	Accuracy	On	0	Agriculture	Charred Ground on Bare Earth	Agriculture	
29	SA_AA_73	34.6037	-14.191	417	2016:08:23	Accuracy	On	0	Non-Agriculture	Dried Grass	Agriculture	
30	SA_AA_74	34.6038	-14.191	418	2016:08:23	Accuracy	On	0	Non-Agriculture	Dried Grass	Agriculture	
31	SA_AA_75	34.6038	-14.191	417	2016:08:23	Accuracy	On	0	Non-Agriculture	Dried Grass	Unsure	
32	SA_AA_78	34.5980	-14.194	421	2016:08:23	Accuracy	On	0	Non-Agriculture	Dried Grass	Unsure	
33	SA_AA_88	34.5371	-14.296	443	2016:08:24	Accuracy	On	0	Agriculture	Bare Earth: Light soil w Ridging	Agriculture	
34	SA_AA_89	34.5371	-14.296	445	2016:08:24	Accuracy	On	0	Agriculture	Bare Earth: Light soil w Ridging	Agriculture	Large dirt mound located here in the center of the field
3	SA_AA_9	34.5760	-14.29	450	2016:08:22	Accuracy	On	0	Non-Agriculture	Trees: Little Green Foliage with Dry Undergrowt h	Unsure	Lots of sticks mounded up here for later gathering (?)
36	SA_AA_92	34.52273	-14.291	449	2016:08:24	Accuracy	On	0	Non-Agriculture	Riverbed	Unsure	Point taken from bridge

Bwanje Valley Dry Season Analysis Classes

Class Name	Samples in Class	Land Cover
29	4	Fallow Agriculture
32	2	Fallow Agriculture
33	2	Fallow Agriculture
40	3	Fallow Agriculture
41	6	Fallow Agriculture
50	10	Fallow Agriculture
56	6	Mixed Foliage
59	7	Fallow Agriculture
63	1	Mixed Forest
69	3	Mixed Foliage
70	5	Mixed Forest
75	6	Mixed Foliage
77	6	Bare Earth
80	4	Mixed Foliage
85	2	Bare Earth
90	29	Mixed Foliage

Class 29: Fallow Agriculture

NAME	LAND USE	CLASS	SUBCLASS	LAND COVER
2_95		Fallow	Bare Earth	Light Soil
1_61		Fallow	Bare Earth	Dark Soil w Straw
2_32		Fallow	Bare Earth	Medium Soil w Ridging & Emergent Reeds
3_31		Active	Maize	Young

Class 32: Fallow Agriculture

NAME	LAND USE	CLASS	SUBCLASS	LAND COVER
1_100		Fallow	Charred Ground	Charred Ground on Bare Earth
1_87		Trees	Trees	Trees: Green Foliage on Dry Harvested Agricultural Land w Ridging
1_27		Trees	Trees	Trees: Green Foliage on Dry Harvested Agricultural Land w Ridging
SA_AA_69	AG	Fallow	Charred Ground	Charred Ground on Bare Earth

Class 33: Fallow Agriculture

NAME	LAND USE	CLASS	SUBCLASS	LAND COVER
SA_AA_164	Ag	Fallow	Shrubbery	Dense
SA_AA_162	Ag	Fallow	Shrubbery	Dense

Class 40: Fallow Agriculture

NAME	LAND USE	CLASS	SUBCLASS	LAND COVER
SA_AA_35	Ag	Active	Cotton	Cotton
SA_AA_36	Non Ag	Human Inf	Human Inf	Human Dwellings
SA_AA_37	Non Ag	Trees	Trees	Mostly Dried Leaves

Class 41: Fallow Agriculture

NAME	LAND USE	CLASS	SUBCLASS	LAND COVER
1_81		Fallow	Bare Earth	Medium Soil w Riding & Emergent Weeds
3_64		Fallow	Bare Earth	Light Soil w Straw & Ridging
1_37		Fallow	Long Term Fallow	Medium Soil w Ridging & Dried Vegetation
SA_AA_74	Ag	Fallow	Dried Fields	Dried Grass
SA_AA_17	Ag	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds
SA_AA_18	Ag	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds

Class 50: Fallow Agriculture

NAME	LAND USE	CLASS	SUBCLASS	LAND COVER
4_34		Fallow	Bare Earth	Dark Soil
2_3		Non-Ag	Human Inf	Human Dwellings
1_3		Fallow	Long Term Fallow	Medium Soil w Ridging & Dried Vegetation
SA_AA_108	Ag	Fallow	Bare Earth	Light Soil w Ridging
SA_AA_137	Ag	Fallow	Bare Earth	Dark Soil w Straw
SA_AA_135	Ag	Fallow	Dred Fields	Vertical Rice Straw w Emergent Weeds
SA_AA_103	Non Ag	Bare Earth	Bare Earth	Light Soil
SA_AA_9	Non Ag	Trees	Trees	Little Green Foliage w Dry Undergrowth
Sa_AA_89	Ag	Fallow	Bare Earth	Light Soil w Ridging
Sa_AA_11	Non Ag	Trees	Trees	Little Green Foliage w Dry Undergrowth

Class 56: Mixed Foliage

NAME	LAND USE	CLASS	SUBCLASS	LAND COVER
3_77	Non-Ag	Charred Ground	Charred Ground	Charred Ground w/ Dry Vegetation
2_61	Non-Ag	Bare Earth	Bare Earth	Light Soil w/ Green Vegetation
2_24	Non-Ag	Trees	Trees	Little Foliage w Dry Undergrowth
1_14	Non-Ag	Trees	Trees	Green Foliage on Bare Soil
SA_AA_64	Non-Ag	Trees	Trees	Mostly Dried Leaves
SA_AA_28	Non-Ag	Trees	Trees	Little Green Foliage w Dry Undergrowth

Class 59: Fallow Agriculture

NAME	LAND USE	CLASS	SUBCLASS	LAND COVER
SA_AA_112	Ag	Fallow	Bare Earth	Light Soil w Ridging
SA_AA_111	Ag	Fallow	Bare Earth	Light Soil w Straw & Ridging
SA_AA_110	Ag	Fallow	Bare Earth	Medium Soil w Ridging & Dried Vegetation
SA_AA_114	Ag	Fallow	Bare Earth	Dark soil w Straw & Ridging
2_82	Ag	Fallow	Bare Earth	Light Soil w Ridging
1_58	Ag	Fallow	Bare Earth	Medium Soil w Ridging & Emergent Weeds
2_22	Ag	Fallow	Bare Earth	Light Soil w Straw & Ridging

Class 63: Mixed Forest

NAME	LAND USE	CLASS	SUBCLASS	LAND COVER
1_31	Non-Ag	Charred Ground	Charred Ground	Charred Ground & Dry Vegetation

Class 69: Mixed Foliage

NAME	LAND USE	CLASS	SUBCLASS	LAND COVER
2_64	Ag	Trees	Trees	Green Foliage on Dry Harvested Agricultural Land w/ Ridging
1_20	Ag	Fallow	Dried Fields	Dried Grass
1_22	Ag	Fallow	Bare Earth	Light Soil w Straw & Ridging

Class 70: Mixed Forest

NAME	LAND USE	CLASS	SUBCLASS	LAND COVER
3_34	Non-Ag	Charred Ground	Charred Ground	Charred Ground & Dry Vegetation
SA_AA_5	Non-Ag	Trees	Trees	Green Foliage on Bare Soil
SA_AA_39	Non-Ag	Trees	Trees	Little Green Foliage w Dry Undergrowth
SA_AA_40	Non-Ag	Trees	Trees	Mostly Dried Leaves
SA_AA_41	Ag	Fallow	Bare Earth	Light Soil w Straw & Ridging

Class 75: Mixed Foliage

NAME	LAND USE	CLASS	SUBCLASS	LANDCOVER
2_31	Non-Ag	Trees	Trees	Dried trees on bare rock
1_35	Non-Ag	Trees	Trees	Little Foliage w Dry Undergrowth
2_36	Non-Ag	Trees	Trees	Green Foliage on Bare Soil
1_24	Non-Ag	Trees	Trees	Green Foliage & Dry Undergrowth
SA_AA_10	Non-Ag	Trees	Trees	Little Green Foliage w Dry Undergrowth
SA_AA_29	Non-Ag	Trees	Trees	Little Green Foliage w Dry Undergrowth

Class 77: Bare Earth

NAME	LAND USE	CLASS	SUBCLASS	LANDCOVER
2_100	Non-Ag	Bare Earth	Bare Earth	Light Soil
2_87	Ag	Fallow	Bare Earth	Dark Soil
SA_AA_78	Non-Ag	Dried Grass	Dried Grass	Dried Grass
SA_AA_60	Non-Ag	Dried Grass	Dried Grass	Dried Grass
SA_AA_61	Non-Ag	Bare Earth	Bare Earth	Dark Soil w Straw
SA_AA_30	Non-Ag	Charred Ground	Charred Ground	Charred Ground & Dry Vegetation

Class 80: Mixed Foliage

NAME	LAND USE	CLASS	SUBCLASS	LAND COVER
2_34	Non-Ag	Human Inf	Human Inf	Road
1_33	Ag	Trees	Trees	Green Foliage on Bare Soil
1_8	Non-Ag	Trees	Trees	Little Foliage w Dry Undergrowth
SA_AA_38	Non-Ag	Trees	Trees	Little Foliage w Dry Undergrowth

Class 85: Bare Earth

NAME	LAND USE	CLASS	SUBCLASS	LANDCOVER
3_79	Non-Ag	Human Inf	Human Inf	Road
SA_AA_52	Non-Ag	Bare Earth	Bare Earth	Little Soil w Green Vegetation

Class 90: Mixed Foliage

NAME	LAND USE	CLASS	SUBCLASS	LANDCOVER
1_93	Non-Ag	Bare Earth	Bare Earth	Light Soil
4_91	Non-Ag	Trees	Trees	Green Foliage on Bare Soil
1_82	Ag	Fallow	Bare Earth	Light Soil w Straw & Ridging
1_18a	Ag	Fallow	Bare Earth	Light Soil w Straw & Ridging
2_77	Non-Ag	Trees	Trees	Little Foliage w Dry Undergrowth
1_74	Non-Ag	Bare Earth	Bare Earth	Light Soil
1_64	Ag	Fallow	Bare Earth	Light Soil w Straw & Ridging
1_49	Non-Ag	Bare Earth	Bare Earth	Light Soil
1_34	Ag	Fallow	Bare Earth	Light Soil w Straw & Ridging
2_14	Non-Ag	Bare Earth	Bare Earth	Dark Soil w Straw
1_36	Non-Ag	Bare Earth	Bare Earth	Light Soil w Green Vegetation
1_32	Ag	Fallow	Bare Earth	Bare Earth w ridging
1_18	Ag	Fallow	Bare Earth	Light Soil
2_20	Non-Ag	Trees	Trees	Green Foliage & Dry undergrowth
1_17	Ag	Fallow	Bare Earth	Light Soil w Straw
SA_AA_51	Non-Ag	Bare Earth	Bare Earth	Little Soil w Green Vegetation
SA_AA_49	Ag	Fallow	Bare Earth	Light Soil w Straw & Ridging
SA_AA_48	Ag	Fallow	Bare Earth	Light Soil w Straw & Ridging
SA_AA_50	Ag	Trees	Trees	Green Foliage on Dry Harvested Agricultural Land w Ridging
SA_AA_2	Ag	Trees	Trees	Green Foliage & Dry Undergrowth
SA_AA_155	Non Ag	Riverbed	Riverbed	Riverbed
SA_AA_157	Ag	Fallow	Dried Fields	Horizontal Rice Straw w Emergent Weeds
SA_AA_158	Ag	Fallow	Dried Fields	Vertical Rice Straw w Emergent Weeds
SA_AA_6	Ag	Fallow	Bare Earth	Light Soil w Ridging
SA_AA_92	Non-Ag	Riverbed	Riverbed	Riverbed
SA_AA_88	Ag	Fallow	Bare Earth	Light Soil w Ridging
SA_AA_118	Ag	Trees	Trees	Green Foliage on Dry Harvested Ag Land w Ridging
SA_AA_23	Ag	Fallow	Bare Earth	Light Soil w Straw & Ridging
SA_AA_119	Non-Ag	Bare Earth	Bare Earth	Light Soil w Green Vegetation

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