Investigation of the impacts of land use activities on wetlands along Dzindi River

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ABSTRACT

The threat posed by anthropogenic activities on wetlands remains a major concern throughout the world. A series of wetlands along the Dzindi River are subjected to extensive cultivation of maize crops, sand and clay mining as well as afforestation. This has negatively impacted on ecological processes within the wetlands. The maize crops are planted on a continuous basis during summer seasons on both seasonal and temporary wet zones of all the hydrogeomorphic (HGM) units assessed along the Dzindi River. The Dzindi River wetlands Present Ecological Status (PES) is considered to be poor, however some very basic ecological functioning still exist. The ecosystem services provided by these HGM units have diminished because the wetlands are cleared of all the natural wetlands vegetation at both temporary and seasonal zones. The high level wetlands assessment study called National Fresh Water Ecosystem Priority Areas (NFEPA) which covered the whole of South Africa identified Dzindi River as a fresh water ecosystem priority area (SANBI) (2011). A series of smaller wetlands responsible for maintenance of this river system were not assessed as part of this program. Valuable information to guide the rehabilitation and protection of these important ecosystems can be obtained through intensive assessments, recording, storing and continuous evaluation of relevant data. Therefore, there is an urgent need for interventions to protect Dzindi River wetlands from further degradation. These interventions can include education and awareness, alien plants control, rehabilitation activities and a detailed assessment of available wetlands.

Key words: Hydrogeomorphic Unit, Present Ecological Status, Ecosystems Goods and Services, Subsistence Farming.

DECLARATION

I declare that this research is my own work. It is being submitted for the Master's degree in Environmental Sciences with Hydrology and Geohydrology, Faculty of Natural and Agricultural Sciences within the North-West University, Potchefstroom. It has not been submitted before for any degree or any examination to any other University.

Signature: Date:

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ABBREVIATIONS

AVHRR	**Advanced Very High Resolution Radiometer**
C.A.P.E	**Cape Action for People and the Environment**
CARA	**Conservation of Agricultural Resource Act**
CBA	**Critical Biodiversity Areas**
CBD	**Convention on Biological Diversity**
CMA	**Catchment Management Agency**
CoJ	**City of Johannesburg**
DAFF	**Department of Agriculture, Forestry and Fisheries**
DEA	**Department of Environmetal Affairs**
DEM	**Digital Elevation Models**
DRIFT	**Downstream Response to Imposed Flow Transformations**
DWA	**Department of Water Affairs**
DWAF	**Department of Water Affairs and Forestry**
DWS	**Department of Water and Sanitation**
EIA	**Environmental Impact Assessment**
EIR	**Environmenat Impact Report**
EWR	**Environmental Water Requirements**
GDE	**Groundwater Dependent Ecosystem**
GIS	**Geographic Information System**
Ha	**Hectares**
HGM	**Hydrogeomorphic**
IDP	**Integrated Development Plan**
IBI	**Indices of Biological Integrity**
IRS	**Indian Remote Sensing satellite**
IUSS	**International Union of Soil Science**
IWMI	**International Water Management Institute**
MEA	**Millennium Ecosystem Assessment**
MODIS	**Moderate Resolution Imaging Spectroradiometer**
NAEHMP	**National Aquatic Ecosystem Health Monitoring Programme**
NBA	**National Biodiversity Assessment**
NDVI	**Normalised Difference Vegetation Index**
NEMA	**National Environmental Management Act**
NFEPA	**National Fresh Water Ecosystems Priority Areas**
NGO	**Non-Govermental Organisation**

NLC	**National Land Cover**
NWA	**National Water Act**
NWI	**National Wetlands Invetories**
PES	**Present Ecological State**
PHI	**Post-Harvest Innovation**
REC	**Recommended Ecological Category**
RQOs	**Resource Quality Objectives**
SANBI	**South African National Biodiversity Institute**
SPOT	**Systeme Pour l'Observation de la Terre**
SAWCS	**South African Wetlands Classification System**
STATSSA	**Statistics South Africa**
USA	**United States of America**
TG	**Trillion grams**
WETLAND-IHI	**Wetland Index of Habitat Integrity**
WUL	**Water Use Licence**
WMA	**Water Management Area**
WRB	**World Reference Base for Soil Resources**
WRC	**Water Research Commission**

CHAPTER 1 : INTRODUCTION

1. BACKGROUND

1.1 Problem Statement

Wetlands along the Dzindi River face major challenges due to various land use practices by communities. Subsistence and commercial farming practices, sand and clay mining as well as afforestation are the main threats to the wetlands along the Dzindi River. As a result of these activities, the benefits derived from these wetlands by the surrounding communities, which include flood attenuation, fresh water supply, medicinal plants supply are under severe threat.

The Water Research Commission of South Africa completed an important wetlands assessment study called National Fresh Water Ecosystem Priority Areas (NFEPA) (Nel *et al*., 2011). The GIS data set from this study has been used to develop a NFEPA wetland layer. Though Dzindi is identified as a NFEPA River, smaller wetlands responsible for maintenance of this river system are not part of this program. This program involved mapping the distribution, extent and diversity of freshwater ecosystems in South Africa. For maintenance of this river system and the ecosystem at large, these wetlands must be mapped and protected.

In the South African context, local government must develop their own wetland inventories that will be included in the national working for wetlands program that is part of the broader national wetlands inventory program. There are major institutional problems with regards to wetlands management and protection, particularly in rural municipal areas. Wetland management and protection programmes are ignored and in some cases non-existent. This exposes the surrounding wetland systems to degradation by means of various land use practices. The Dzindi River wetlands are no exception as they are located in similar rural settings with various local challenges threatening their existence.

The main research questions that this study seeks to answer were:

- What wetland types did exist along the Dzindi River?
- What data regarding wetlands did exist at the local level?
- To what extent were the land use practices impacting the wetlands along Dzindi River and how could the conditions of the wetlands along the Dzindi River be improved?

1.2 Research Objectives

The objectives of the research were to come up with answers to research questions and were designed within the context of water resource ecosystem management of the Dzindi River System. The objectives of the research were as follows:

- To assess the data available on the Dzindi River wetlands and protection measures in place by local authorities;
- To determine the nature and types of wetlands along the Dzindi River using the Hydrogeomorphic (HGM) classification system;
- To ascertain the ecological integrity and functioning of the Dzindi River wetlands using Wet-EcoServices, Wetland Index of Habitat Integrity (Wetland -IHI) and WET Health tools;
- To ascertain the land use impacts affecting the wetlands; and
- To recommend measures to improve the condition of the wetlands along the Dzindi River.

1.3 Justification

Wetlands along the Dzindi River are under severe pressure from anthropogenic activities. Regulation of flow by subsistence farmers through river diversion, and clearing of wetland vegetation as well as pollution from fertilisers breakdown the natural biogeographical barriers in wetlands thereby impacting on the ecological condition of wetlands ecosystems (MacFarlane and Bredin, 2017). The end result is the complete destruction of these important ecosystems along with the benefits currently being derived from these wetlands. It is therefore imperative to investigate the levels of impacts directed to these wetlands so that necessary preventative and rehabilitation measures can be employed in order to avoid further degradation of these resources. Government agencies and Non-Governmental Organisation (NGOs) responsible for the wetlands management should consider the Present Ecological State (PES) of a wetland, when making decisions in order to have a balance between sustainable use and protection of wetlands (Ollis and Malan, 2014). It is therefore important to ensure that appropriate methods are used for wetland PES assessments. Wetlands/aquatic assessments and the associated PES are also part of Environmental Impact Assessment (EIA) process. The PES also forms part of classification of an area, determination of the Reserve and setting Resource Quality Objectives (RQOs) (Ollis and Malan, 2014).

The above-mentioned activities threaten the water resources within the catchment, particularly wetlands which are being converted to agricultural lands mainly along the river systems. Gumbo *et al*. (2016) pointed out that urban runoff, urbanization and poor agricultural practices threaten the suitability of the water quality in the Luvuvhu River Catchment. Irrespective of the status of pollution in parts of the catchment, the Luvuvhu River and its tributaries including Dzindi River are the main sources of water for agriculture and domestic uses, in some part of Makhado and Thohoyandou Municipalities (Edokpayi et al., 2014).

Water quality is becoming a serious environmental challenge due to population growth and socio-economic developments within the catchment area (Edokpayi *et al*., 2014). The communities subject the river to various uses such as subsistence and commercial farming, brick industries, formal and informal settlements, garages and wastewater treatment works (Edokpayi *et al*., 2014).

This study is imperative because it generates information and data pertaining to wetlands along the Dzindi River. These research products will be shared with relevant authorities including SANBI, the Department of Water and Sanitation (DWS) and the Thulamela Local Municipality and Vhembe District Municipality. The research outcomes will also help in managing the existing wetlands ecosystem by determining the PES and Recommended Ecological Category (REC). This will facilitate the development of necessary protection and management measures by the responsible authorities.

1.4 Delimitations of the Study

The study only focused on selected wetlands along the Dzindi River, in quaternary catchment A91E.

1.5 Hypothesis

The wetlands along the Dzindi River are deteriorating due to land use activities. They can therefore no longer offer the required ecosystem benefits to the surrounding communities.

CHAPTER 2 : LITERATURE REVIEW

2.1 Wetlands Defined

The Department of Water Affairs and Forestry (DWAF, 1999), defines a wetland as the transitional land between aquatic and terrestrial in which the water table is near the surface, or the land is occasionally covered with water, and in normal conditions that particular land would favour hydrophytes. Wetland consist of a diverse range of ecosystems, which include marshy areas, swamps, peatlands, which could be artificial or natural, temporary or permanent, with flowing or static water that is fresh, salty or brackish, and this may include marine areas where the water depth of less than ten meters at low tides (Ewart-Smith *et al*., 2006). Wetlands are formed around the areas of prolonged or repeated inundation or saturation of soils. Water availability in these environments therefore is the determining factor with regards to the soil formation processes and the types of organisms thriving in that environment (Ewart-Smith *et al*., 2006).

McCartney *et al*. (2010) found that wetlands ecosystems constituted critical areas of groundwater-surface water interaction from the surrounding catchment. Wetland soils are considered rich in nutrients under high moisture conditions usually targeted by smallholder farmers without irrigating the crops (Sieben *et al*., 2017). Water is the key driver in wetlands, and it determines their ecosystem structure and functioning (Downard and Endter-Wada, 2013). Flooding regime of a particular wetland potentially affects the occurrence of particular plant species in the wetland (Lou *et al*., 2016). Global changes such as flooding events, extended droughts, and drainage activities of wetlands to farmlands are likely to exert significant threats on wetland ecosystems in the future (Lou *et al*., 2016).

Permanent wet conditions in valley bottoms influenced by high groundwater tables promote the formation of peat materials (Grundling *et al*., 2013). According to Grundling *et al*. (2013), these wetlands are considered permanent since they have a relatively fixed boundary. Grassland wetlands which occur on deep sandy soil associated with highly fluctuating water table do not support the development of peat. These kinds of environments give rise to the development of short-term wetlands, which are characterised by fluctuating boundaries during wet or dry periods. The fluctuating nature of wetland boundaries may cause the wetland area to be understated in dry periods. Wetland ecosystems are comprised of large number of living organisms, plants and animals interacting with each other in complex food webs. These interactions also occur with their non-living environments (earth, climate, weather, soil, sun and atmosphere).

2.2 State of Wetlands in South Africa

South Africa has a variety of unique wetlands which supply the surrounding communities with a variety of benefits. These wetlands occur in different landscapes and biomes, however, they are endangered due to various human activities. The functionality of grassland wetlands in South Africa is impacted by poor protection measures and unsustainable and badly managed burning regimes, damming by farmers and reclamation of wetlands. The increase in conversion of grassland to afforestation through plantation of alien pine and Eucalyptus species, which reduces the catchment runoff, is concerning (Turpie *et al*., 2007).

Mpumalanga Highveld grassland wetlands face significant degradation due to coal mining activities. The unique South Africa coastal peat swamp forests of Maputaland support unusual plant and animal communities and also play a special role in maintaining other aquatic ecosystems such as the Maputaland freshwater lakes and Lake St Lucia (Dada *et al*., 2007). Many rural areas of South Africa depend on wetlands for small scale subsistence farming, but it is critical that farming practices are conducted in a way that does not degrade wetlands by inhibiting their functioning. South African wetlands provide habitat for various important animal, birds and plants species that serve as sources of wild food, craft and medicinal products that are important for rural communities. Of the 7921 total wetlands found in the Limpopo basin, about 99% of them are 1 km^2 or less in size (McCarthy *et al*., 2011). These small wetlands are often left out in the regional and national wetland assessment projects leaving them susceptible to destruction from human activities. In Limpopo the Nile River floodplain, which is a Ramsar site, supports a variety of plants and birds species and it demonstrates a case of proper management of these important national assets (McCarthy *et al*., 2011). The Pongola floodplain in Kwazulu-Natal which has supported the surrounding communities with their craft materials and fish resources for decades faces major problems due to the low release of water from Jozini Dam. This situation impacts negatively on cattle farming and agricultural activities along the floodplain and harvesting of natural resources within the wetlands (Lankford *et al*., 2011).

Studies done by various researchers estimated more than 50% of South African wetlands have been lost (Ellery *et al*., 2010; Kotzé *et al*., 2008; Nel and Driver, 2012). DWS (2018) indicated that over 65% of wetlands in South Africa's are threatened while 48% of the wetlands are classified as critically endangered. Sieben *et al*. (2017) indicated that condition is exacerbated by the issue that humans often regarded wetlands as the cheapest source of irrigation water or areas of crop production which is readily available. Wetlands in South Africa are therefore currently considered the most threatened ecosystem types along with the related biodiversity habitats which are deteriorating at an alarming rate (Driver *et al*., 2012).

2.3 Wetlands and Groundwater

According to Dinar and Encarna (2016), the importance of groundwater resources has gained traction recently due to increasing evidence of the range of services it provides. Groundwater becomes a sole source of water supply under extremely scarce and variable conditions such as drought. Aquifers store water during high rainfalls and release it during drier periods. Groundwater supply wetland ecosystems with water particularly during dry season which creates links between society and nature. Most of the wetland systems are dependent on groundwater for their existence. The wetlands that are formed in these conditions along with other ecosystems dependent on groundwater have been referred to as groundwater dependent ecosystems (GDEs). GDEs refer to terrestrial environments that depend mainly on water seeping from aquifers (Münch and Conrad, 2007). In these ecosystems, groundwater seeping from aquifers remains critical for their existence, status and ecological processes (Dinar and Encarna, 2016). In this type of system, the level of ecosystem services provided to society is controlled by the characteristics of groundwater such as water pressure, water level, and quality.

Understanding wetlands, surface and groundwater interaction is the key in defining how these environments function as integrated and interrelated systems (Min *et al*., 2010). The Ecological Water Requirements (EWR) of wetlands systems that depend on groundwater is therefore critical to maintain healthy functioning (Eamus and Froend, 2006). The relationship between wetland and groundwater is an important component of biogeochemical cycling in constructed and natural wetlands ecosystems. During dry periods, wetland water level naturally decline influenced by evapotranspiration and reduced groundwater recharge (Min *et al*., 2010).

2.4 Wetland Ecosystem Services

The Millennium Ecosystem Assessment (MEA) (2005) defined ecosystem services as the benefits a particular community generate from a certain ecosystem including provisioning services (water, food, timber and fibre); regulation services (water quality, floods control, and waste removal; cultural services, (spiritual benefits, recreational, and aesthetic improvement); and support services (promote photosynthesis, nutrient cycling, and soil formation). Additionally, ecosystems also help in health maintenance, improved social relations and general well-being (MEA, 2005).

The MEA provides a detailed examination of the nature and relationship between the livelihood, general wellbeing of people and ecosystem services (McInnes and Everard, 2017; Tatu and Anderson, 2017; MEA, 2005; Pantaleo *et al*., 2011). The MEA (2005) guided assessments of status of the wetlands throughout the world since the year 2000. This assisted in taking stock of the extent at which human beings have damaged the wetland ecosystems and also how things look for the future. The MEA Report provided a clear description of ecosystem goods and services which became useful to scientists and other researchers. In addition to other resources derived from their biological diversity, wetlands provide distinctive habitats for diverse plants and animals (Daryadel and Talei, 2014; Pantaleo *et al*., 2011). Furthermore, wetlands contribute by providing other important ecosystem services such as the removal of pollutants, the regulation of floods, biodiversity support and carbon management (McInnes and Everard, 2017; Zhanga *et al*., 2017; Zedler and Kercher, 2005). Wetlands provide a favourable environment for formation of fertile soils which supports crop production by subsistence farmers (Matenga, 2019).

Wetland ecosystems have been referred to as ‘kidneys of the landscape’ because of the diversity of services and goods derived from them. Wetlands have also been named ‘biological supermarkets’ since they are characterised by a wide-range of food webs and contain high levels of biodiversity (Belle *et al*., 2018). Nasongo *et al*. (2015) indicated that harvesting wetlands resources has increased all over Africa.

As reported in An *et al*. (2007), wetlands especially peat lands, serve as major sinks of carbon thereby reducing accumulation of atmospheric pollutants such as carbon dioxide and methane. The study found that most of China’s peat lands had a mean carbon content of 28.2% in weight. China’s peat lands were deteriorating due to mining for uses as fertilisers and cement additives. About 5.0 Trillion grams (TG) of peat were mined annually and 4500 km^2 of peat lands were destroyed during the last 50 years which resulted in a carbon release of 1.48 TG per year (An *et al*., 2007).

Wetland ecosystems have the ability to accumulate rain water and runoffs when it rains and release it during periods of low flows, thereby allowing communities and farmers targeting these environments to grow their crops. This is regarded as a major contribution in safeguarding the food security and generation of income of these communities (Jogo and Hassan, 2010). Other important functions and values of wetlands in the landscape include fish production and carbon storage (Houlahan *et al*., 2006; MEA, 2005). Tatu and Anderson (2017) indicated that wetlands provide buffers by absorbing and storing flood waters or by reducing the velocities of flowing water. This reduces the amount of soil erosion. Scientists, researchers and other education entities benefit greatly from the wetlands and associated biodiversity. Wetlands help in climate change mitigation and adaptation. All services and benefits derived from wetlands strengthen the argument about the need to protect and conserve them.

Unfortunately, wetlands do not exist in isolation; they exist in complex catchment settings with conditions that are susceptible to change in various respects both spaciously and timeously with respect to their functioning and structural diversity. Assessment of the threats facing these wetlands is vital in determining the levels and nature of ecosystem change to inform the development of relevant management strategies (Malekmohammadi and Jahanishakib, 2017). The variety of wetlands goods and services will only be available to support the ever increasing population if ecosystem functioning is not severely impacted by human activities. In a nutshell, healthy ecosystems support thriving plants and animal communities capable of sustainably provide wetlands goods and services to the communities. This means that human have to find ways of using the wetlands ecosystems in a sustainable manner protecting them from deteriorating.

2.5 Threats to Wetlands: International Perspectives

Human interventions and environmental pressures remain the driving forces behind wetlands deterioration and losses (Jogo and Hassan, 2010). The dwindling spatial distribution and areal extent of the natural wetlands around the globe remains a critical issue of concern possibly caused by the dynamics of hydrologic systems, the adoption of different definitions of wetlands, and characteristics of seasonal vegetation (Serran and Creed, 2016). Humans have extensively converted the natural wetlands to croplands to expand their subsistence and economic gains. In most cases, the rapid population growth in combination with struggles to increase food production to feed these populations contributes greatly in increasing the pressure to encroach into the wetlands (Rebelo *et al*., 2010). Most of the natural ecosystems have been converted rapidly and continuously into farms or urban areas (Downard and Endter-Wada, 2013). Since the 1900 the world has lost about 64% (Ramsar Fact Sheet, 2014). Dixon *et al*. (2016) indicated that the 20th century losses of wetlands alone have been estimated at 64 to 71% of the area that was present in in the 1900s.

While there is a considerable amount of published reports for wetlands loss in some regions, Dixon *et al*. (2016) found that there was a lack of credible reports on wetland ecosystems loss for Africa which makes it difficult to assess the rate at which wetlands are being lost. Further attention must therefore be focussed on development of inventories of wetlands and analysis of wetland change particularly in the African region (Davidson, 2014). In other regions (especially, Asia) the loss is expected to be higher than Africa. Davidson (2014) found that inland wetlands were declining at a faster pace than coastal ones. Since the adoption of the Ramsar Convention in 1971 and also having a significant number of countries being party to it (127 by 2012), wetlands loss has not decreased particularly for Asia and possibly Africa. Only 19% of 127 countries reporting to Ramsar Convention indicated an improvement in their wetlands status compared with 28% which reported wetlands losses (Davidson, 2014; Ramsar Convention, 2012). Other countries have continued to drain, pollute, convert and impact wetlands in the name of economic advancement and development, poverty alleviation and to feed an ever-growing human population (McInnes, 2014).

The deterioration of wetlands and riparian zones increase sediment movement through stream flow, and as more and more sediment pile up in the wetland, it diminishes the habitat diversity and it destroys the ecological corridors in the landscape. Understanding of how the wetlands of the world are distributed can facilitate an understanding of wetland development, restoration and protection (Malekmohammadi and Jahanishakib, 2017). The use of herbicides and pesticides for agricultural production affect wetlands organisms in a variety of manners. Different types of damage may be caused by pollution of wetlands from agricultural pesticides, from reducing waterfowl reproduction to modifying the growth and development of aquatic organisms (Daryadel and Talaei, 2014).

The problem caused by pesticides on wetlands plants and animals is magnified and amplified over a period of time (Daryadel and Talaei, 2014). Pesticides induce changes in the functions of enzymes, cells, or organs in organisms. These changes how a plant or animal reproduces, competes for living space and food as well as avoiding predators. There are two ways in which the affected plants or animals show the signs of change including changed structure of the population or ecosystem structure or transformed community (Daryadel and Talei, 2014).

Environmental pressures that have detrimental impacts on wetland originating from human activities include agricultural water shortage, pollution from industrial and domestic wastewater into wetlands and transformed wetlands caused by unmanaged harvesting of wetland resources. These activities are more prevalent in developing countries, especially where the protection and management of wetland ecosystems is ignored by those intrusted with the responsibility of protecting these systems (Adekola and Mitchell, 2011; Kimmel *et al*., 2010). Commercial afforestation is also a major contributor in wetlands deterioration. Commercial forestry located at the headwater of the catchment contributed to decreasing stream flow resulting in wetland degradation, due to loss of base flow (Riddell *et al*., 2013).

Serran and Creed (2016) stressed that efficient management of wetlands to maintain the balance between the much needed socioeconomic benefits and the safeguarding of ecological biodiversity of wetlands was critical. However, appropriate wetlands protection and management program needs accurate and up to date wetland inventory which is useful in determining the available wetland numbers with associated spatial coverages. Researchers would experience difficulties to estimate the loss of wetland ecosystems when all this important data is unavailable (Behna *et al*., 2018; Serran and Creed, 2016). Wetlands with spatial coverage of <1 hectare (ha) are susceptible to damage by human activities mainly because they are normaly excluded in wetland inventories. Researchers require the need for a wetland mapping techniques that is able to identify small wetlands and that can estimate possible loss of all wetlands sizes is overdue. Researchers have had several challenges trying to develop an accurate and automated wetland inventory, including the lack of techniques to capture their size and shape because unstable nature of other types of wetlands (Tiner, 2003).

As reported in International Water Management Institute (IWMI, 2014), wetlands are continuously being transformed through sedimentation, erosion and coastal flooding. However, human activities still dominate with respect to wetlands transformation. The chief contributor remains the reclamation of wetlands for agricultural purposes. Wetland agriculture has increased dramatically in recent years and has damaged and degraded a significant amount of wetlands across the world (Kotzé and Treynor, 2011).

This is a concerning trend, because degraded wetlands fail to provide ecosystem services. Kotzé (2004) mentioned that a lost wetland is the one that is unable to provide ecosystem services owing to the fact that it no longer poses key properties and functioning. A suitable wetland classification system is a prerequisite for wetlands assessments conducted at National, Regional and Local levels (Lindenmayer *et al*., 2008; Ewart-Smith *et al*., 2006). Change in catchment land use has quantifiable impacts and correlations with freshwater systems (Mantel *et al*., 2010; Weitjers *et al*., 2009; Amis *et al*., 2007; Allan, 2004).

Wetlands found in populated areas have experienced significant degradation of ecological state (Jeppesen *et al*., 2017). In the context of catchment management, wetlands influences hydrological cycle process. The study concluded by Warburton *et al*. (2012) shows that changes in land use affect surface runoff and groundwater recharge. The degree of catchment modification from land use affects the hydrological response in the catchment.

Perhaps the more challenging threats facing wetlands throughout the world revolves around climate change and variability. Change in water regimes as a result of climate change and river regulation increase threats on wetlands (Fu *et al*., 2015). Some inland wetlands, particularly floodplains support high biodiversity that are dependent on flows from rivers. Climate change measured by a shift in temperatures and precipitation over a long time leads to reduced flow levels in rivers due to reduced rainfall and increased evaporation which may reduce the flooding episodes of floodplains. Change in climate increase water stress have considered as one of the factors contributing to the decline of wetlands (Palmer *et al*., 2008).

Climate change is expected to alter rainfall and temperatures and may present new and additional challenges in the future. More frequent or intense extreme events such as changes in drought and storms (DWA, 2013) are expected to increase. Impacts on wetlands may be exacerbated by changes in precipitation and its implications for water availability under the projected future climate (Roberts, 2008). Junk *et al*. (2012), reported that wetlands are not considered adequately in many climate change scenarios.

2.6 Wetland Classification, Inventory, Assessment and Monitoring: The International Perspective

In order to systematically manage the loss of wetlands, researchers have acknowledged the need for wetlands data and information. The methods for capturing these data often scale dependent, ranging from field surveying at local scale to regional estimations using predictive modelling or remote sensing classification (van Deventer *et al*., 2018). While the field surveying of inland wetland ecosystems offers the most spatially accurate and detailed understanding of these ecosystems, they become costly and impractical for regional to country-wide extents. Through field surveys, detailed information on the hydro period, soil and flow characteristics, functionality, condition and presence of species can be recorded. The use of remote sensing has enabled mapping and monitoring of ecosystems at a regional level, by compromising on detail and accuracy (van Deventer *et al*., 2018). Remote sensing also added the benefit of frequent revisit times which could inform wetland characteristics across multiple seasons and years.

Finalyson *et al*. (2005) emphasised the need for coherent wetlands management programs. Internationally, it has been argued that the main or critical requirement for developing the effective wetlands management framework is the establishment of a multi-layered classification system which defines different wetlands types and characteristics (Finlayson *et al*., 2005). Classification system guides the collection of data in the development of a wetland inventory. The purpose of a wetland inventory is to identify the location of wetlands and priority conservation sites and identify functions and values of individual wetlands.

Wetlands assessment and monitoring take the exercise to the next levels gathering more information for implementation of necessary protection and rehabilitation measures. The assessment of wetlands deals with the determination of the status and threats, to the wetlands in order to establish necessary monitoring activities. The wetland monitoring stage involves the collection of specific information for management purposes.

2.6.1 Wetlands Classification

A suitable wetland classification and structured health assessment procedure forms the basis for a sound wetland assessment at a regional scale (Ewart-Smith *et al*. 2006; Lindenmayer *et al*. 2008 (cited by Rivers-Moore and Cowden, 2012)). Wetlands classification is a key process that must be conducted to inform the mapping, data collection and management of these important systems. Once classification is concluded, it becomes clear as to what should assessments focus on by means of various techniques, i.e. unique characteristics of wetlands found in different land forms such as valleys, foothills, shorelines and floodplains. It is crucial to classify wetlands types according to their determining factors over and above the wetness conditions such as physiography and vegetation types. The availability of this information for particular wetlands facilitates the development of necessary protection and management measures.

For a national wetlands classification, the widely used methodology has been developed by Cowardin *et al*. (1979) for the United States Fish and Wildlife Service. In broader sense, Cowardin *et al*., (1979) identified five wetlands categories: (1) areas with hydrophytes and hydric soils, such as marsh, swamp, and bogs; (2) areas without hydrophytes but with hydric soils -; (3) areas with hydrophytes but non hydric soils, such as margins of impoundments; (4) areas without soils but with hydrophytes such as rocky shores; and (5) wetlands without soil and without hydrophytes, such as gravel beaches or rocky shores without vegetation.

The classification systems derived from the Cowardin system, has led to much confusion due to mixture of land form features, vegetation and soils and vast inconsistencies (Ollis *et al*., 2015). Geomorphological and hydrological driven wetland classification systems are accepted since they are vigorous and consistent than those based on structural criteria (Finlayson *et al*., 2002), since the two parameters are chiefly responsible for wetlands formation functioning (Jones, 2002; Kotzé *et al*., 2008; Ellery *et al*., 2010). Similar approach was followed in developing the wetlands classification in the United States of America (USA) (Brinson, 1993).

2.6.2 Wetlands Inventory

According to Finlayson & Rea (1999), inventory of wetlands is essentially about gathering and recording of basic wetland data. Inventorying of wetlands therefore includes recording the areal coverage of all wetlands, wetland types found in a defined area; location and characteristics of wetlands, and defining baseline conditions for measuring change.
Wetlands inventory is recognised internationally as an important tool that informs policy, conservation of wetlands and management practices since its adoption in the 8th Conference on Wetlands Convention. The Scientific and Technical Review Panel of the convention was requested to develop a comprehensive wetland inventorying program (Rebelo *et al*., 2009). In Europian countries and North America, the wetland inventories were started in the early 1950s. The USA has one of the most extensive wetland mapping programs which complies with many of the federal

legislations on wetland mapping (Lang and McCarty, 2008 (cited by Guidugli-Cook *et al*., 2017)). Kentucky State developed their wetland inventory some 35 years ago with data updated every 10 years. Inventories of wetlands guided by the classification and mapping are generally accepted in maintaining wetland ecological conditions and protection of the core benefits that wetlands provide globally (Finlayson and van der Valk 1995; Rebelo *et al*., 2009; Davidson and Finlayson, 2007). The process generates baseline maps which display the location, nature and extent of wetlands and can be carried out at any scale.

2.6.3 Wetlands Assessment and monitoring

Internationally, wetlands assessment has evolved over a number of decades following different approaches. Wetlands assessments have either taken the functional assessment approach (i.e. water quality improvement and attenuation of floods) or the ecological conditions. Both these methodological approaches can reveal the extent and nature of physical change in extent of wetland. The functional assessments approach which became popular is founded on the HGM principles (Smith *et al*., 1995).

Researchers have come to realise that traditional methods on assessing changes in wetlands used relatively complex methods to compile wetland inventories (literature reviews, map interpretation and digitising, and collation of ancillary data and analysis) often yielded incompatible and inconsistent results (Nhamo *et al*., 2017). These traditional methods were generally found to be poor and not effective when compared to remote sensing. Remote sensing is superior when it comes to monitoring wetland dynamics because it saves time while traditional methods consume time and considered too expensive. Remote sensing can detect and delineate the patio-temporal changes in wetlands almost effortlessly over defined time periods. The analysis of Landsat 8 satellite images and digital elevation models (DEM) can be used to demarcate the spatial coverage of a wetland. The moderate-resolution imaging spectroradiometer (MODIS) satellite images are useful in assessing seasonal variations in wetlands inundated areas. Nhamo *et al*. (2017) successfully determined that wetlands in the Witbank Dam catchment have reduced in spatial extent during 2000 and 2015; and an overlay of the wetland map on the land-use map of showed that 21% of the wetland area in the catchment have been cleared to give way to cultivation, mining and settlements.

It is therefore apparent that as pertaining to assessment of change in physical aspects of wetlands, remote sensing and Geographical Information Systems (GIS) techniques have become reliable tools to monitor and detect wetlands change through time (Hu *et al*., 2018; Dubeau *et al*., 2017; White *et al*., 2015; De Roeck *et al*., 2008; Guo *et al*., 2017; Nhamo *et al*., 2017). In this field, Landsat, Systeme Pour l'Observation de la Terre (SPOT), Advanced Very High Resolution Radiometer (AVHRR), Indian Remote Sensing satellite (IRS), and radar systems are the most frequently used satellite sensors for wetland detection and monitoring changes through time. Hu, *et al* (2018) successfully delineated the loss of China's urban wetland (Hangzhou Xixi Wetland) from 2000 to 2005 (about 1.81 km^2/year), 2005 to 2007 (about 0.61 km^2/year), 2007 to 2009 (about 1.26 km^2/year) and 2009 to 2013 (about 1.35 km^2/year). The study was conducted using high spatial resolution satellite imagery, manipulated using ArcGIS and Normalised Difference Vegetation Index (NDVI). This study revealed that urban wetlands reduced in extent from 2000 to 2005, followed by 2009 to 2013 and 2007 to 2009. The unchanged areas from 2000 to 2013 were about 15.4 km^2.

White *et al*. (2015) demonstrated the success of RASARSAT-2 to monitor surface water and flooded vegetation aspects of the Peace-Athabasca Delta wetlands in Canada. Changes within the wetlands were flagged by coupling the data generated with the Wishart-Chernoff Distance technique. Analysis of Synthetic Aperture Radar Imagery data was found to be an excellent technique to map and monitor changes of a wetland over specific time period. Guo *et al*. (2017) used satellite imagery to investigate the carbon sequestration and storage losses of coastal wetlands. This study found that more than 380,000 ha of coastal wetlands were being reclaimed resulting in about 20.7 TG of blue carbon being released to the atmosphere.

Other methods included bio-assessment and the use of Multimetric Indices of Biological Integrity (IBI) for wetlands using the algae/diatoms, macrophytes, macroinvertebrates, birds, amphibians or fish as indicators (Miller *et al*., 2006). For the assessments characteristics of plant communities, including species diversity, richness and evenness are the determining factors. The IBI technique involves determining wetlands stressors, evaluation of surrounding land uses, buffer characterisation to quantify the overall wetland disturbance. This data collected is then used to plot ecological dose–response curves which assists in evaluating the relationship between each attribute and the disturbance score (Miller *et al*., 2006). Others have analysed macroinvertebrates in the wetlands in assessing the disturbances in the wetlands. (Sims *et al*., 2013; Kashian and Burton, 2000). This method involved the collection of wetlands microorganisms found in water and sediments and interpreting the results by classifying these organisms depending on suitable conditions that enhance their growth.

The so called Rapid Assessments have evolved throughout the world over time and have become common among wetlands scientists (Kotzé *et al*., 2012; Marambanyika *et al*., 2017; Beuela *et al*., 2016; McInnes and Everard, 2017). These methods have an advantage of saving costs and time while being scientifically driven and defendable. The wetlands assessments from a functionality perspective based on the HGM approach have become a common method. This approach was developed to respond to the legal requirements for wetland management and assessment. The inconsistencies and lack of robustness led to growing reluctance to use these methods and a prompt shift towards rapid wetlands assessment approaches.

2.6.4 Wetlands Protection

Knowledge managers have stressed the importance of measurements and data recordings to build information for necessary interventions. Building the necessary data and information systems is a prerequisite for proper protection and management of all forms of wetlands. Once all the necessary data and information about the nature of these wetlands has been gathered and stored; continuous measurements and assessments of these systems using accepted methods form the basis of wetlands protection. These ecosystems require intensive protection from human activities. The Ramsar Convention which coordinates the protection and wise use of wetlands at the national and international levels is the only global agreement that is centred solely on wetland ecosystems (McInnes and Everard, 2017; Tatu and Anderson, 2017).

With the focus on conservation policies, wetland losses have now slowed down. These policies have tended to focus on protection of those areas designated as wetlands neglecting the supply of water to the wetland which determines the existence of wetland in the first place. The existence of intricate relationship among various users in agriculture-dominated catchments demands that wetland water management activities take into account the importance of return flows among users in the catchment. (Downard and Endter-Wada, 2013). Application of buffer zones in land-use planning has become very important in protecting wetlands ecosystems through limiting the access and use of land (McCarthy *et al*., 2018).

2.7 Wetland Management in South Africa

2.7.1 The Strategic Importance of Wetlands

South Africa is dominated by drier climate, associated with low average annual rainfall (465 mm). Wetlands are therefore very important for the country (DWS, 2018). Most wetlands in the country are considered national assets which contribute greatly in the management limited water resources of the country. A significant amount of these wetlands also have biodiversity significance and contribute in educational activities, spiritual and recreational values. (Dini and Everard, 2017). The health and livelihoods of many people in South Africa are significantly supported by wetlands. These ecosystems provide small-scale farmers with fertile soils and resources including livestock grazing, fish, water, medicines and fibre (Dini and Everard, 2017).

South African wetlands that comprise the wetlands inventory database constitute 2.4 % of the total land surface (2.9 million hectares) (Driver *et al*., 2012). This is quite small considering the amount of wetlands that still have not been mapped. It therefore means that any further deterioration of wetlands must be avoided at all cost. Studies conducted at catchment levels around the country reveal that between 35% and 60% of the wetlands along with associated benefits are severely degraded (Driver *et al*., 2012). Driver *et al.* (2012). Of the 65% threatened wetland ecosystem types, 48% are critically endangered, 12% are endangered and 5% are vulnerable. This makes wetlands the most threatened of all ecosystems assessed in the 2011 National Biodiversity Assessment (NBA).

The critically endangered ecosystem category is dominated by floodplain, with valley-bottom and valley-head seeps wetlands types coming second. Floodplain wetlands, are characterised by fertile lands and are often the ones that are drained, dammed or bulldozed for agricultural purposes. This is enffluence by their position in the land scape and become the targeted areas for cultivation. South Africa also has commitments to other initiatives, including the State of the Environment Reporting, the Convention of Biological Diversity (CBD) and the Ramsar Convention, which also require wetland assessment and monitoring data (Sandham *et al*., 2008). Many Water Use License (WUL) applications and EIAs also use or generate monitoring data on specific, often small wetlands. A total of 23 sites which constite 557,028 ha of South Africa land surface have been declare as Ramsar Sites (DWS, 2018). Higher-level wetlands assessment used in prioritizing conservation actions at a regional level is needed urgently due to the growing levels of catchment degradation occurring nationally (Kotzé, 2004).

In the South African context, wetlands are critical for sustaining the livelihoods of several communities across the country particularly in rural (Lannas and Turpie, 2009). Most wetlands are rich in wetland plants which are being used for crafts. Crafts making contributes a way of maintaining and protecting the Zulu culture in Kwazulu-Natal communities (Kotzé and Treynor, 2011). In this study, Kotzé and Treynor (2011) found that communities made crafts such as sleeping mats are made from *Cyperus latifolius*, baskets made from *Juncus kraussii*, traditional food mat and utensil holder as well as traditional beer strainer made from *Miscanthus junceus.* The production of crafts from wetland plants motivates the communities to protect the wetlands (Kotzé and Treynor, 2011). Dahlberg and Burlando (2009) also found that the Mnqobokazi community depended on resources from Mkuze wetland.

Kotzé (2011) (cited by McCartney *et al*., 2011) found that a small wetland comprising less than 1% of the catchment area found in GaMampa village supplied the Mohlapitsi River winter flows. Despite the reclamation of about 50% of its extent by agriculture since 2001, it still can provide some of much needed natural resources (reeds for making crafts and grass for livestock grazing) (Kotzé, 2005). Belle *et al*. (2018) found that the deterioration of wetlands conditions in the Free State communal areas was higher than those in protected areas and privately owned lands exposing the communities to natural disasters such as veld fires and floods. The Seekoevlei and Ingula wetlands were found to be in excellent ecological condition, offering protection to veld fires and floods risks (Belle *et al*., 2018). In the grassland catchment areas, seepage wetlands store much of the summer rainfall which is subsequently released slowly as base flow to rivers during drier seasons (Turpie *et al*., 2008).

2.7.2 Wetlands Protection

2.7.2.1 The legal framework

The Constitution of South Africa (Act 108 of 1996) state that everyone has the right (a) *to an environment that is not harmful to their health or well-being; and (b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that (i) prevent pollution and ecological degradation; (ii) promote conservation; and (iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.*

The National Environmental Management Act (NEMA) (Act No 107 of 1998), deals with the protection of all aspects of the natural environment. The protection and management of wetlands is achieved by means of various principles outlined in the Act. The EIA regulations that came into effect from 2010 stipulate all activities that must undergo the rigorous assessment. Activities that are deemed to have impacts on wetlands and other landscapes must be subjected to the EIA process. The Act gives rise to various sector legislations that deal with specific aspects of the environment administered by various sector departments. The Department of Enironmental affairs (DEA) administers this Act and other environmental management legislations. The NEMA Biodiversity Act (Act 10 of 2004) was developed specifically for biodiversity protection. Of critical importance is that this Act defines endangered and threatened ecosystems and direct all the necessary protection and management actions. The Act also decribes invasive plant species and their associated threat on indigenous plants. SANBI is a designated entity charged with management and monitoring of biodiversity conditions. The role of SANBI is to coordinate and facilitate biodiversity management activities, coordinating with other institutions such as DWS, DAFF (Department of Agriculture Forestry and Fisheries) and DEA (Driver *et al*., 2005). The National Water Act (NWA) (Act 36 of 1998) categorises wetlands as water resources and Chapter 3 of this Act, describes the range of measures to protect the water resources, which includes classification of water resources, RQOs and the Reserve. The three measures are aimed at ensuring that the water resources are protected, measures are in place to prevent water pollution, and the remedial actions are taken once pollution has occurred.

The Conservation of Agricultural Resources Act (CARA), (Act Non 43 of 1983) administered by DAFF ensures weeds control, soil protection against erosion and conserving water. Under this act, it is prohibited to drain or cultivate any wetland areas including the removal of riparian vegetation without a permit. The National Forests Act (Act No 84 of 1998) also administered by DAFF prevents the planting timber in sensitive environments.

2.7.2.2 Institutional Arrangements

The SANBI is the implementation arm of the DEA responsible for coordination of biodiversity programmes. This includes wetlands protection and management programmes. Wetlands have already been spatially delineated and classified at a national-scale by SANBI (2011). Nevertheless, not all wetlands of the country were delineated in the study done by SANBI.

Other sector departments such as DWS also play a role in biodiversity and wetlands management activities. With regards to DWS responsibilities, Catchment Management Agencies (CMAs) become critical institutions. Catchment Management Agencies will be the responsible institutions to manage water resources at catchment and water management level. These important institutions will need to cooperate with local stakeholders, consult and seek consensus on water management matters with stakeholders. The nineteen Water Management Areas (WMA) have since been reduced to nine which means that only nine WMA will have to be established (Figure 1).

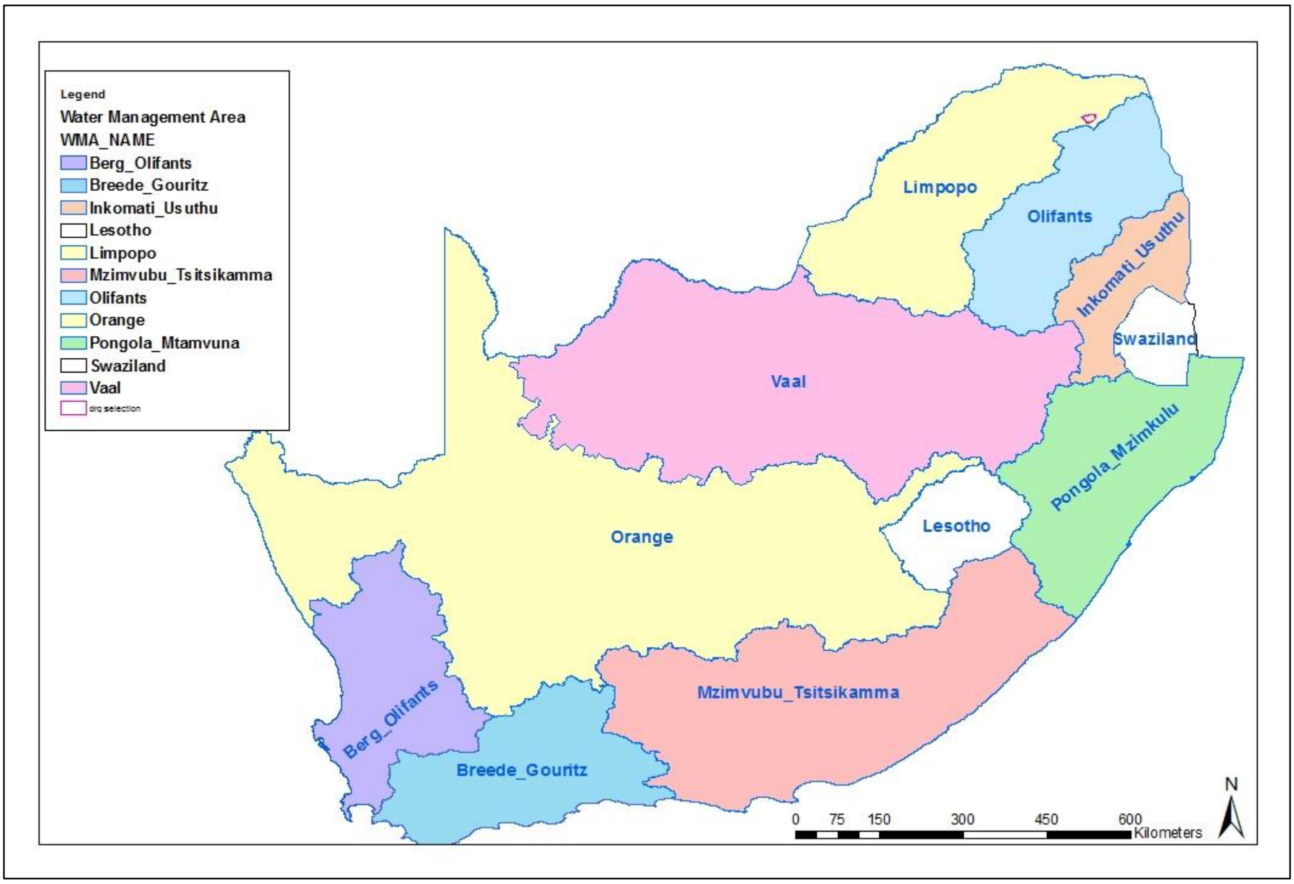

Figure 1: The nine WMAs of South Africa

2.7.3 Wetlands Management

2.7.3.1 The South African wetlands classification system

The framework for managing wetlands in South Africa started with the establishment and adoption of a wetlands classification system which serve as a basis towards the development of a wetland inventory. Macfarlane *et al*. (2008) indicated that the assessment of both wetland health as well as ecosystem services require that an individual wetlands must be divided into HGM units. According to Ollis (2013), dividing a wetland into HGM units approach attempts to combine aquatic ecosystem parameters taking into consideration how they function. This approach distinguishes the method from the more traditional approach by which the primary units of aquatic ecosystems are distinguished by their structural properties (vegetation cover, size, depth and presence of surface water). Ollis (2013) contends that a shift towards the HGM approach is consistent with local and international trends, because hydrology and geomorphology are recognised as the determining factors that influence the formation of wetlands and other aquatic ecosystems and how they function. An HGM unit is a part of or a whole wetland that exhibit uniform geomorphological and hydrological characteristics. As per Sieben *et al*. (2014) the HGM types define wetlands in terms of the structure in relation to areas of water storage together with the main inputs and outputs of water in the catchment. The most important parameters that play a role at these levels is the hydro period, which refers to the fraction of time in which a certain part of the wetland is inundated on average and in the long term.

The fourth level of the Wetlands Classification System of South Africa (SAWCS) identified seven HGM types of wetlands used in classifying wetland ecosystem according to geomorphology and hydrology, which is an important first step in characterising the habitat unit as it characterises the wetland as a whole (Dini and Cowan, 2000; Sieben *et al*., 2014; Ollis *et al*., 2013, Ollis *et al.*, 2014). The following are the seven classes:

1. **River**: A linear land form with clearly discernible bed and banks, which permanently or periodically carries a concentrated flow of water. A river is taken to include both the active channel and the riparian zone as a unit.
2. **Seeps**: This is wetland area located on gentle to steep slopes, driven by discharge of groundwater or by water percolating through the upper layers of the soil layer. Slope seepages generally feed into drainage basins or rivers.
3. **Unchannelled valley bottom wetland**: This is a wetland area on a valley floor that is connected to a drainage network, but without a major channel running through it. This is characterised by the prevalence of diffuse flow, which is at or near the surface especially after rainfall events. Water mainly enters the wetland through an upstream channel, but sometimes also from adjacent slopes.
4. **Channelled valley bottom wetland**: This occurs on the bottom of a valley with the river channel flowing through it. The source of water in these wetlands types is from adjacent valley side slopes and overtopping of the channel during floods.
5. **Floodplain**: This is a flat wetland area adjacent to a river channel in its lower reaches that is subject to periodic inundation due to flood events duringwet season. These flood events can be quite turbulent and leave many marks in the landscape, including levees and depressions where fine sediments are deposited.
6. **Flat**: These represent areas where the groundwater is near the surface, mostly on coastal plains. Their main input of water is from rainfall. The flow is imperceptible and these wetlands are basically a transition between a depression and a valley bottom wetland.
7. **Depression**: This is a closed basin where water accumulates, usually with a concave shape, but sometimes very flat, in which case it is called a pan and can be confused with a flat wetland. When the shape of the basin is concave it is usually referred to as a pool or a lake.

Since different wetland types are exposed to different risks, they may require different levels of protection. Valley bottom and floodplains are in most cases susceptible to agricultural impacts because of the availability of moisture and fertile soils. Due to the direct benefits derived from them and potential contribution to livelihoods; the importance of biodiversity of these wetland types may be overridden by livelihood values. If this situation is not managed, the wetland may become degraded leading to complete loss of biodiversity values. The contribution of valley bottom and flood plain wetlands (in maintaining wetland biodiversity and household economies) makes them unique habitats requiring an integrated approach (Pantaleo *et al*., 2011). Pantaleo *et al* (2011) asserted that valley bottom wetlands contain a wide variety of biodiversity of both flora and fauna as compared to other habitat types, yet they are the most intensively utilised habitats for livelihood and buffer against natural hazards such as droughts and floods.

2.7.3.2 The National Wetlands Inventory of South African

Protecting wetlands requires a sound scientific basis and integrated planning and decision making across the spheres of government. This is crucial because the data and information generated from wetlands inventories exercise serve as a critical prerequisite for holistic conservation, management and protection of these ecosystems (Ollis *et al*., 2015). There has been a concerted effort to develop necessary information systems on dwindling wetlands ecosystems to guide the assessment, protection and rehabilitation exercises in South Africa (Figure 2). The accurate inventorying of inland aquatic ecosystems in South Africa provides an opportunity to undertake trends analysis, and assist in planning and decision making (Nel *et al*., 2011). The inventory of South African inland aquatic ecosystems has thus far focused only on the extent and types of rivers and wetlands (i.e. the National Wetland Map).

The National Land Cover (NLC) Map of South Africa developed in the year 2000 becomes an important aspect for the wetlands inventory development for the country. This work was followed by several attempts on the Provincial and National levels which generated different land cover data layers. Notwithstanding the importance of these earlier attempts, the problem was that this was based on divisions of the original NLC water bodies and wetlands classes using visual interpretation of multi-season imagery into subclasses. This has since been developed further by various stakeholders with the adoption of different approaches trying to find ways in which freshwater biodiversity plans could form an integral part of the broader integrated water management objectives (Figure 2).

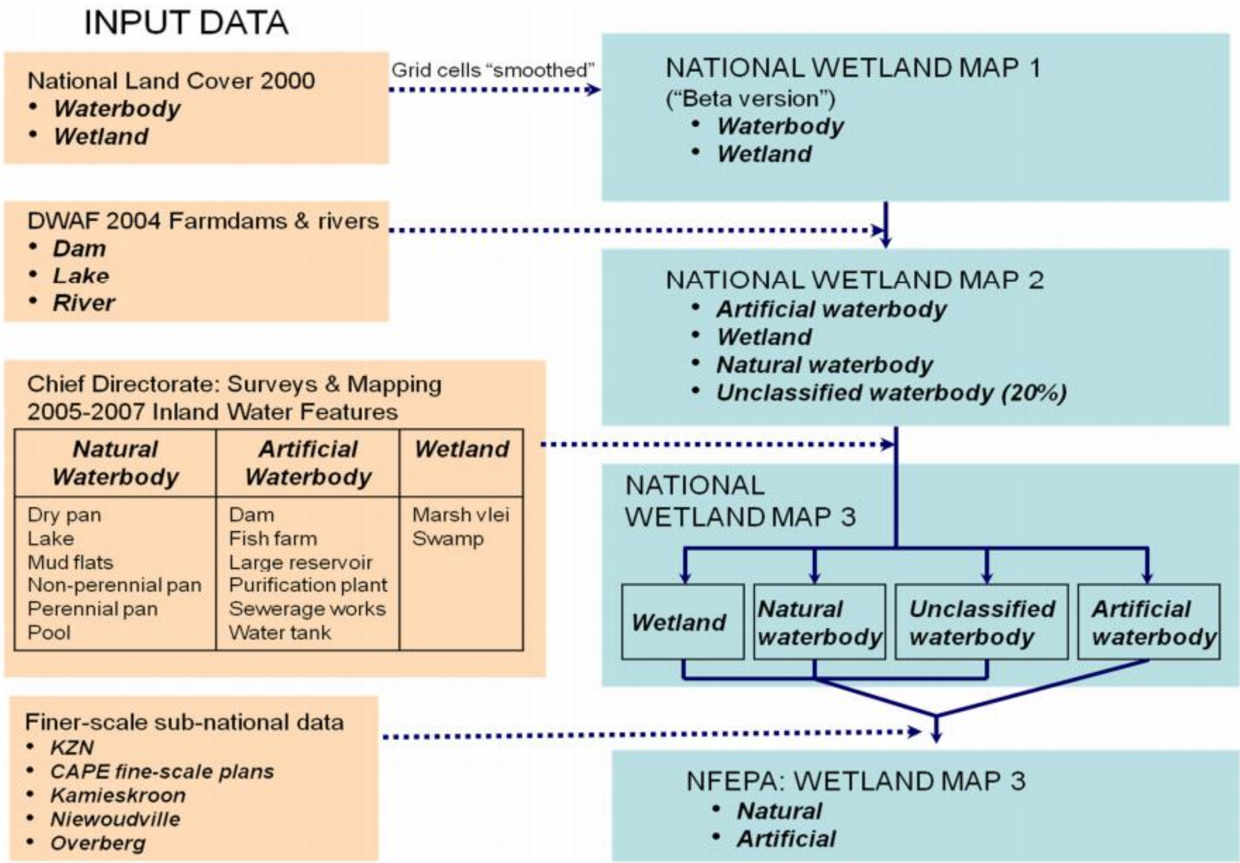

Figure 2: National Wetlands Inventory for South Africa (Job *et al*., 2018).

While the Wetland Inventory version 3 for South Africa was integrated into the NFEPA wetland layer (Nel *et al*., 2011; Wilkinson *et al*., 2016) some wetland areas in country are still inadequately mapped including the woodlands and savannah wetlands found in KwaZulu-Natal, Limpopo and Mpumalanga (NLC2000 Management Committee, 2008). Efforts have been put in place leading to the updating of data sets to generate the Wetlands Map 4. The data used to refine the Wetland Map 3 included the wetland data layers from KwaZulu-Natal and the Cape Action for People and the Environment (C.A.P.E.) fine-scale biodiversity planning domains. SANBI updates the national wetland inventory by improving the GIS layer on an ongoing basis (Nel *et al*., 2011).

The South African wetlands inventory has been established and it contains the database of all mapped wetlands and their associated data/information about their locations, classes and types. The next step is to conduct detailed assessment of those wetlands classified as critical. Wetlands can be referred as critical depending on level of deterioration due to natural and/or anthropogenic activities as well as depending on the importance of goods and services they provide or biodiversity found in those specific wetlands. In the context of South Africa, the detailed wetland assessment work arises in two ways; i.e. as part of an EIA process when there is a development proposal or when specific wetlands are identified as part of working for wetlands, working for water or related programmes.

2.7.3.3 Wetlands assessment approaches

The full job of protecting the vulnerable wetlands is unlikely to be achieved by declaring protected areas intervention alone. Wetlands are vulnerable beyond their catchments or the boundaries of protected areas. It is imperative to appreciate the approaches of integrated water management in ensuring the quantity, quality and timing of freshwater flows on which the functioning of wetlands depends on (Driver *et al*., 2012). In addition to managing damaging land use practices in the catchment, maintenance of intact buffers of natural vegetation around wetlands is a critical component of maintaining wetland function and value.

Valley bottom wetlands, particularly those in agricultural landscapes are often ignored in national and regional wetland inventories. These wetlands strongly influence catchment properties such as the water quality, hydrology and biodiversity (Merot *et al*., 2006). The wetland inventory assessment exercises are important because they enable countries to view the bigger picture of wetlands status and prioritise wetlands for rehabilitation and protection exercises.

2.7.3.3.1 Wetlands assessment as part of EIA process

To undertake an EIA for any proposed development; the proponent is required by law to appoint an independent consultant to conduct the EIA and to submit an environmental impact report (EIR) to the relevant competent authority (Sandham *et al*., 2008). Although the techniques used to assess the affected wetlands are similar, the objectives in these instances are different from national, regional or local authorities. While the assessment by an independent EIA practioner of a particular section of land is to determine the occurrence of wetlands, the ultimate goal is to ensure that potential impacts are identified, avoid or minimised during all stages of the project. The assessments by government agencies are driven by the need to determine the occurrence, state, establish trends in changes and to develop and implement measures to rectify negative impacts on wetlands and associated resources. The EIA triggered wetlands assessments are conducted by the specialist in the field but the data and information generated from these projects do not necessarily form part of the national/provincial or municipal information systems. The information from these studies in most cases remains in the produced documents submitted to authorities for decision making and is never integrated into the wetlands information systems.

2.7.3.3.2 Wetlands assessment as part of working for wetlands/working for water

In instances of wetlands identified in critical state, South Africa has seen some positive response to restoring degraded wetlands ecosystems through working for wetlands, working for water and other related programmes. In realising the key roles played by these unique ecosystems, environmental managers and other sector partners have come to realise the urgent need to protect and manage the declining wetlands ecosystems and associated resources. To try and reverse the impacts of uncontrolled land use effects on wetlands, various programmes were started by different sector players including DEA, DWS and the DAFF as well as other NGOs. Some of these programmes included highly successful Working for Water Programme, in which alien vegetation is cleared to increase runoff in rivers, have raised public awareness of wetland problems in South Africa (Sieben *et al*., 2011).

The Working for Wetlands Programme has enhanced this awareness even more and along with it came many environmental education campaigns focusing on wetlands. The partners in this programme are DWS, DEA and, SANBI, DAFF, and the Mondi Wetlands Project. In 2002 the Working for Wetlands Programme financed the restoration of 32 wetlands in different parts of the country. Most wetland restoration projects are labour-intensive and create jobs that provide skills to rural communities (Sieben *et al*., 2011). Restoration activities include the construction and installation of gabion structures to prevent control erosion, the construction of structures that divert water flow or elevate the water table, and the plugging of manmade drainage channels, and the removal of invasive plants. When it relates to environmental management functions; the work of wetlands assessment, protection and management cascades down to the local municipal levels. Local government have the responsibility in terms of the Constitution and other national legislative frameworks to protect wetlands and associated natural resources in their areas of jurisdiction. These roles are often poorly defined in local government Integrated Development Plans (IDPs). These problems are more prevalent in rural municipalities compared to urban municipalities. The Cities of Tshwane, Cape Town, Ekurhuleni and Johannesburg have these programmes and detailed biodiversity and wetlands plans in place.

2.7.3.4 The South African wetlands assessment tools

While other researchers have pushed for the use of satellite methods in wetlands assessments in South Africa (De Roeck *et al*., 2008), more focus has been directed towards physical methods and tools. This is because remote sensing or satellite methods provide more of high level results which need onsite verification and refinement. The satellite based tools and methods focussed more on physical aspects of wetlands (including soil depth, aerial extent, vegetation cover and presence of surface water) as opposed to functional analysis of the wetlands which is problematic because a thriving wetland is the one which is high in biodiversity delivering a variety of functions. The rapid wetlands assessment tools on the ground have evolved over time in South Africa particularly the functional assessment as well as goods and services tools.

2.7.3.4.1 Wetlands functionality assessment tools

➢ *Wetland-IHI*

The Wetland Index of Habitat Integrity (WETLAND-IHI) is used in the National Aquatic Ecosystem Health Monitoring Programme (NAEHMP), (DWAF, 2007). The WETLAND-IHI was developed to ensure that monitoring of water resources included channelled valley bottom and floodplain wetland types and that the collected monitoring data is integrated into the national monitoring programme. The WETLAND-IHI generates the PES score of the wetland in question. The WETLAND-IHI model is designed for the RAPID assessment of floodplain and channelled valley bottom wetland types. The model format is not vastly different from DWS's River EcoStatus models which are being used for the determination of PES in riverine environments (Kleynhans and Louw, 2007).

➢ *WET- Health*

The tool examines the wetland health using hydrology, geomorphology, and vegetation indicators (Macfarlane *et al*., 2008). It measures the deviation of a wetland characteristic from its natural reference condition to determine its health status. The tool assessed the three indicators separately. The WET-Health tool helps decision-makers to appreciate the ecosystem status of a wetland for determining the required rehabilitation intervention if any. It also helps decision makers to determine the causes of wetland degradation. WET-Health tool is also used in determining the PES of wetlands for purposes of determining an Ecological Reserve required by the NWA, and for EIAs. Two complexity levels are employed in the tool with Level 1 applicable for the assessment of the broader catchment and Level 2 focussing on detailed wetland assessment relying heavily on field assessment of indicators of degradation (Macfarlane *et al*., 2008)).

2.7.3.4.2 Wetlands goods and services tools

➢ *Wet-EcoServices tool*

After determining the PES for the wetland, it followed that the status of goods and services being rendered to the communities by the selected wetlands must be assessed. The purpose is to define the effect of PES of the wetland and nature and types of ecosystems goods and services being provided by the wetland in question. The current goods and services that individual wetlands provide are assessed, to aid in planning and decision making. This tool is designed for all wetlands type which encompasses marshes, vleis, floodplains, seeps etc. A total of 15 different ecosystem goods and services are assessed and scored in this tool (Flood attenuation, streamflow regulation, sediment trapping, phosphate trapping, nitrate removal, toxicant removal, erosion control, carbon storage, maintenance of biodiversity, water supply for human use, natural resources, cultivated foods, cultural significance, tourism and recreation and education and research) (Kotzé *et al*., 2008).

The initial step in this tool involves characterising the wetlands according to their landforms influenced by hydrologic processes (e.g. floodplain). The next step is the determination of ecosystem benefits derived from the wetland conducted either level 1 or level 2. The tool is a spreadsheet based model which integrates the 15 ecosystem services into a single value of score between 0 and 4. With scores varying from 0 (not able to perform the function) to 4 (fully functional), the tool enables wetland assessment specialist to make relative comparisons of systems based on a logical framework which measures the likelihood that a wetland is able to perform certain functions.

2.7.3.5 The recent application of WET Health, Wetland IHI and Wet-EcoServices Tools

Detailed wetlands assessment exercises have employed quite a number of tools in recent years. The three methods that have gained popularity in the recent years include Wet Health, Wet-EcoServices and Wetland IHI. Brown *et al*. (2018) successfully applied the WET-Health tool together with the Downstream Response to Imposed Flow Transformations (DRIFT) tool to derive category scores for the geomorphology, hydrology, and vegetation components of the Pongola Floodplain in their study on holistic environmental flows assessment project to ascertain the adequacy of flows being released from Jozini dam to maintain the wetlands and the flood plains along the river. The outcome of these tools recommended that the flow releases from the dam should be modified by increasing the flows to optimally support the Pongola Floodplain which contribute socially, economically and ecologically downstream of the dam.

Kotzé *et al*. (2010) applied the WET-Health tool to assess the geomorphology, vegetation and utilisation by humans, of two wetlands (Langvlei and the Ramkamp) which are situated just outside of Leliefontein in the Kamiesberg in Northern Cape. In the study, they successfully established that the Langvlei wetland condition was deteriorating with regard to hydrology and geomorphology while the environmental condition of Ramkamp was considered to be stable. In terms of the Wet-

Ecoservices, it was found that services such as biodiversity maintenance, phosphate assimilation, streamflow regulation, provision of harvestable resources, sediment trapping, erosion control, and provision of cultivated foods were being provided by Langvlei wetland. At Ramkamp wetlands the following services were being realised: nitrate assimilation streamflow regulation, harvestable resources, phosphate assimilation, erosion control, biodiversity maintenance and sediment trapping. It was established that the ecosystem service most affected by a change in the ecological state is biodiversity maintenance which highlighted that a key area of rehabilitation would be to try to shift the vegetation to a state that is less dominated by renosterbos and supports a greater abundance of grasses and sedges.

In assessing the ecosystem goods and services provided by highly valuable valley-bottom South African palmiet wetlands Rebelo *et al*. (2019) found that these wetland systems were highly endangered by agricultural development. The Wet-Ecoservices results employed in this study revealed that the palmiet wetlands provide valuable ecosystem services to society. Some of these wetlands were found to be highly degraded for short term gains. The pristine palmiet wetlands sequester between 21 and 41 $g.m^{-2}$ of carbon per year, and are highly effective in nitrogen and phosphorus uptake (efficiencies of 62–85% and 16–89%) respectively and provide about 16 times more flood attenuation compared to degraded or wetlands occupied by a different plant species (Rebelo *et al*., 2019).

CHAPTER 3 : STUDY AREA SETTING

3.1 Location of the Study Area

3.1.1 Luvuvhu River Catchment (A91)

The Dzindi River Catchment (A91E) is a sub-catchment of the bigger Luvuvhu River Catchment (A91) (Figure 3). The Luvuvhu catchment is highly developed with extensive commercial farming and forestry in the upper portions, subsistence crop farming in the middle and lower portions and substantial amount of rural settlement villages.

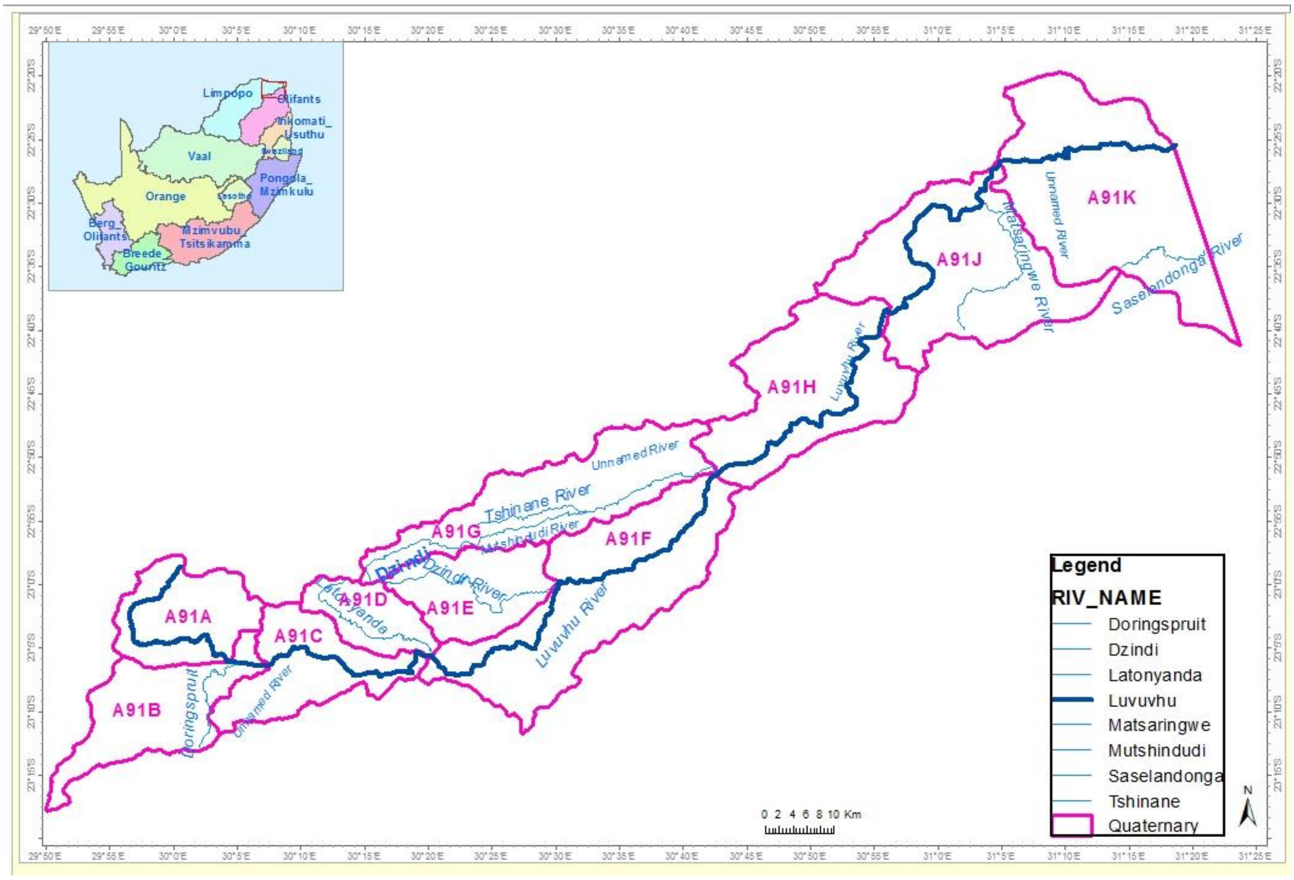

Figure 3: Luvuvhu River catchment (A91).

The Dzindi River is located within the Thulamela Local Municipality, which is one of the four local municipalities within the Vhembe District Municipality in the Northern parts of Limpopo Province.

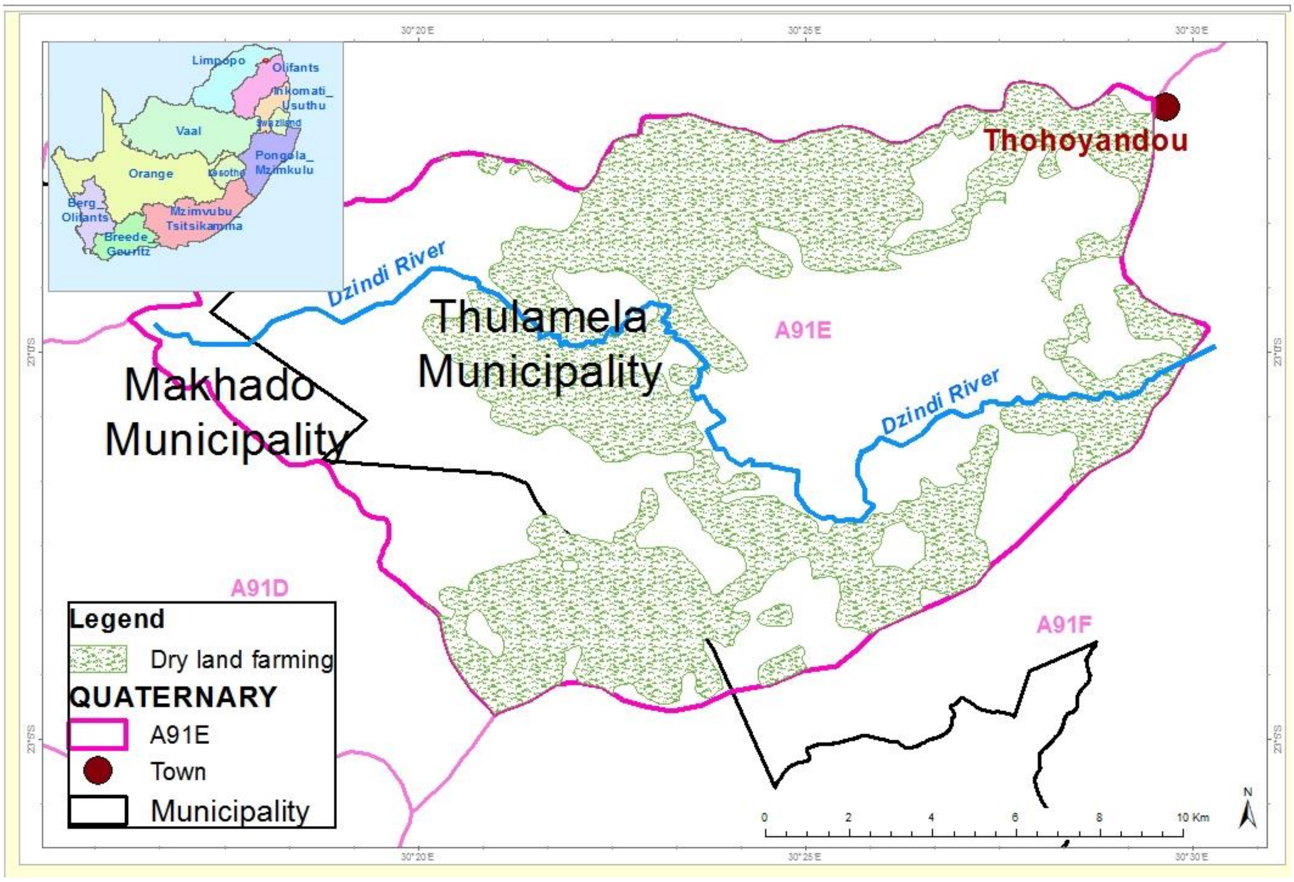

Figure 4: Dzindi River Catchment (A91E).

The Dzindi River flows through a number of villages (Mapate, Belemu, Lwamondo, Itsani, Duthuni, Shayandima, Muledane and Tshisahulu) throughout its entire length. Deforestation and animal grazing occurs along the riparian zone. The communities along the river wash their clothes and cars in the river (Edokpayi *et al*., 2014). Sediment inflows into the Dzindi River are increasing due to forestry, agriculture, brick making and informal rural settlements. The Dzindi River fish farm utilises the sewage outflow from Thohoyandou sewage works Water Research Commission (WRC, 2001). This remains a major concern since the water will eventually reach the river. Because of all this activities, terrestrial vegetation is encroaching into the riparian zone.

3.1.1.1 Climate

In general, the climatic conditions in Thulamela local municipal area comprises of warm winter and hot summer which is a good weather for the production of variety of seasonal and annual crops. The area has a sub-tropical type of climate, with 95% of rainfall during October until March (Mzezewa *et al*., 2010; Post Harvest Innovation (PHI), 2017). The mean annual precipitation ranges between 400mm in the northern and north-eastern parts and more than a 1 000mm in the south-western parts with an average of 800mm (Mzezewa *et al*., 2010) (Figure 5). The area often experiences mid-season dry spell during the year. The long-term maximum average temperatures in January ranges from 26°C in southwest and 34°C in the northeast. The long-term minimum average temperature in July ranges from 5°C in the southwest to 12°C in the northeast.

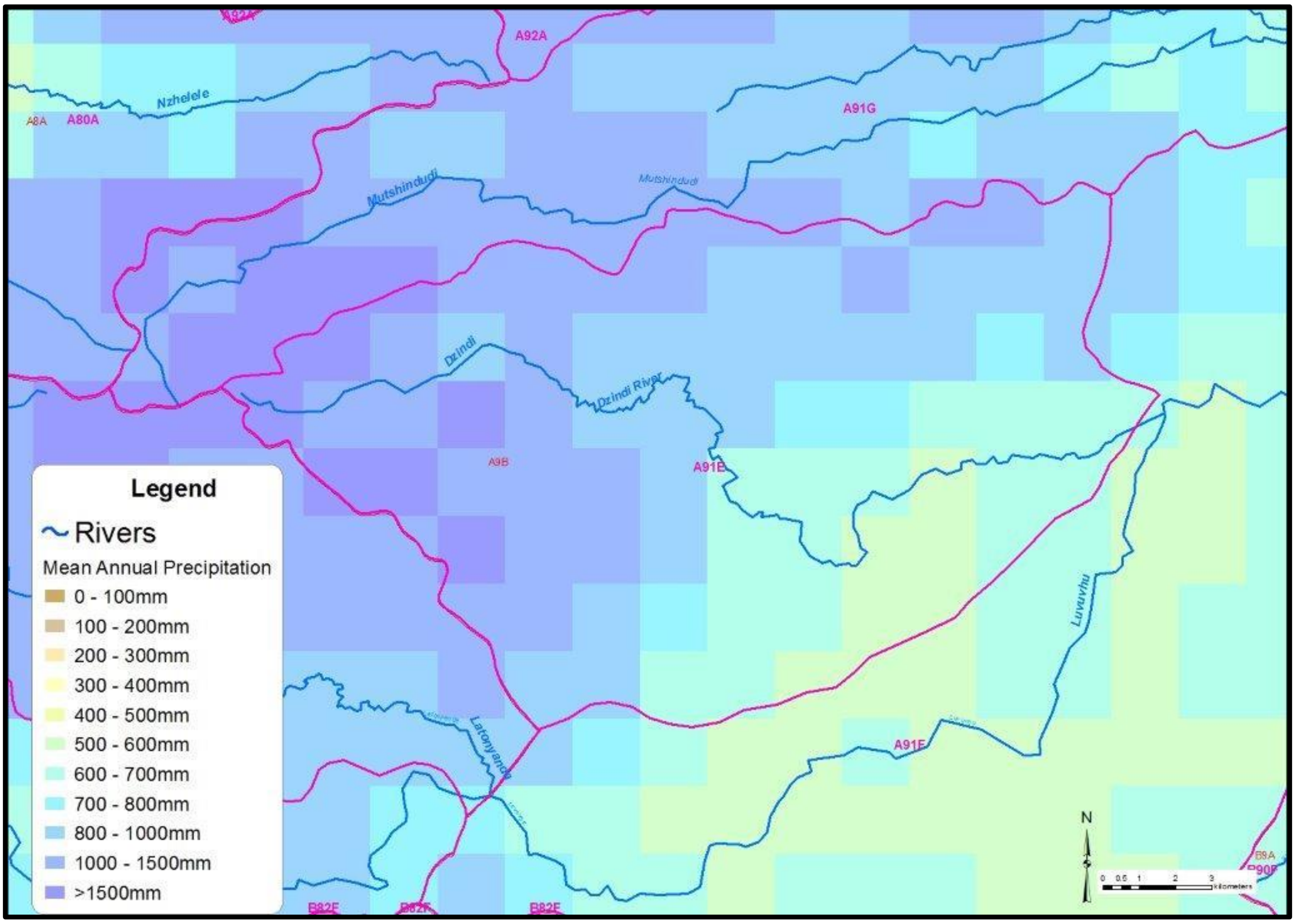

Figure 5: Rainfall distribution for Dzindi River Catchment (A91E).

3.1.1.2 Topography and Drainage

The study area is situated the Limpopo WMA, in the Lowveld of the Limpopo Province which falls within the greater Limpopo River basin. (Mzezewa *et al*., 2010). The Dzindi River is one of the major tributaries of Luvuvhu River. The Dzindi River originates in the high mountains of Soutpansberg with pine plantations. The confluence of Dzindi and Luvuvhu is locate just upstream of Nandoni Dam. The middle and lower Dzindi catchment is comprised of undulating slopes. The mountains rise to an elevation of 1400 mean above sea level at the source of the Dzindi River (Figure 6). The river flows through low lying areas where the slope is 600 mean above sea level.

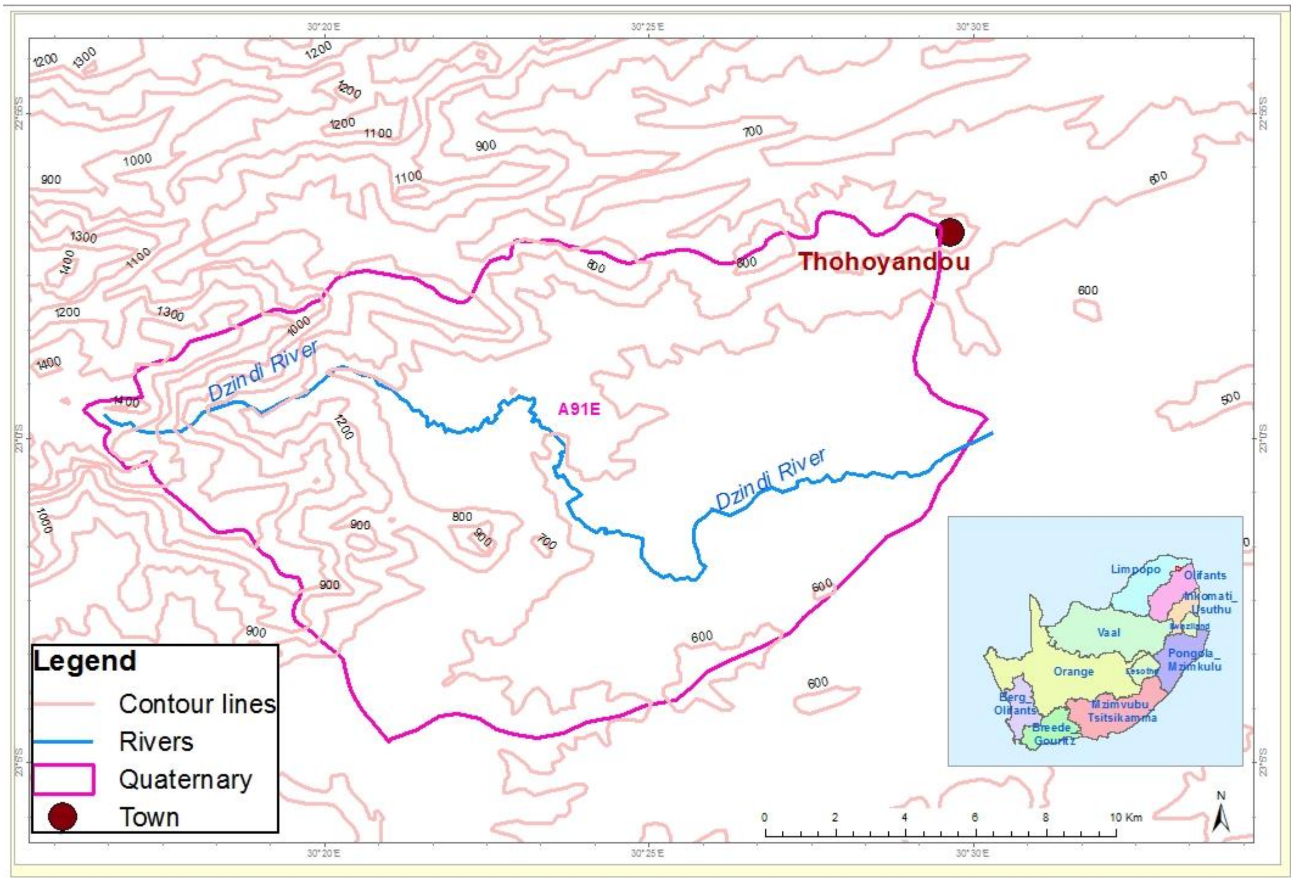

Figure 6: Topography of A91E catchment.

3.1.1.3 Land Use and Land Cover

Tshivhase Tea and Thathe Vondo pine plantations cover approximately 35% of the upper reaches of Dzindi River catchment. Subsistence farming and residential is the main land-uses of the lower Dzindi River, covering 45% of the area (WRC, 2001). The local community farm on the steep slopes along the river throughout its entire length. Maize is the main crop planted particularly during the summer season.

3.1.1.4 Geology

The geology of A91E catchment is dominated by the Soutpansberg Group which is Proterozoic in age (Raphalalani *et al*., 2019). This group represents a succession of volcano-sedimentary rocks. A total of seven formations (the Tshifhefhe, Sibasa, Funduzi, Willie's Poort, Nzhelele, Stayt and Mabiligwe) make up this group (Brandl, 1999). It is the Sibasa formation that underlies significant portions of the Dzindi River catchment. The upstream of the catchment is underlain by arenite rocks which give way to basaltic rocks towards the middle catchment (Mavunda, 2006). The underlying gneisses of the Limpopo belt are exposed in the lower Dzindi River catchment (Figure 7). Kaolin deposits exist within the Sibasa formation and it is being mined for clay brick manufacturing at Vhavenda bricks (Raphalalani *et al*., 2019).

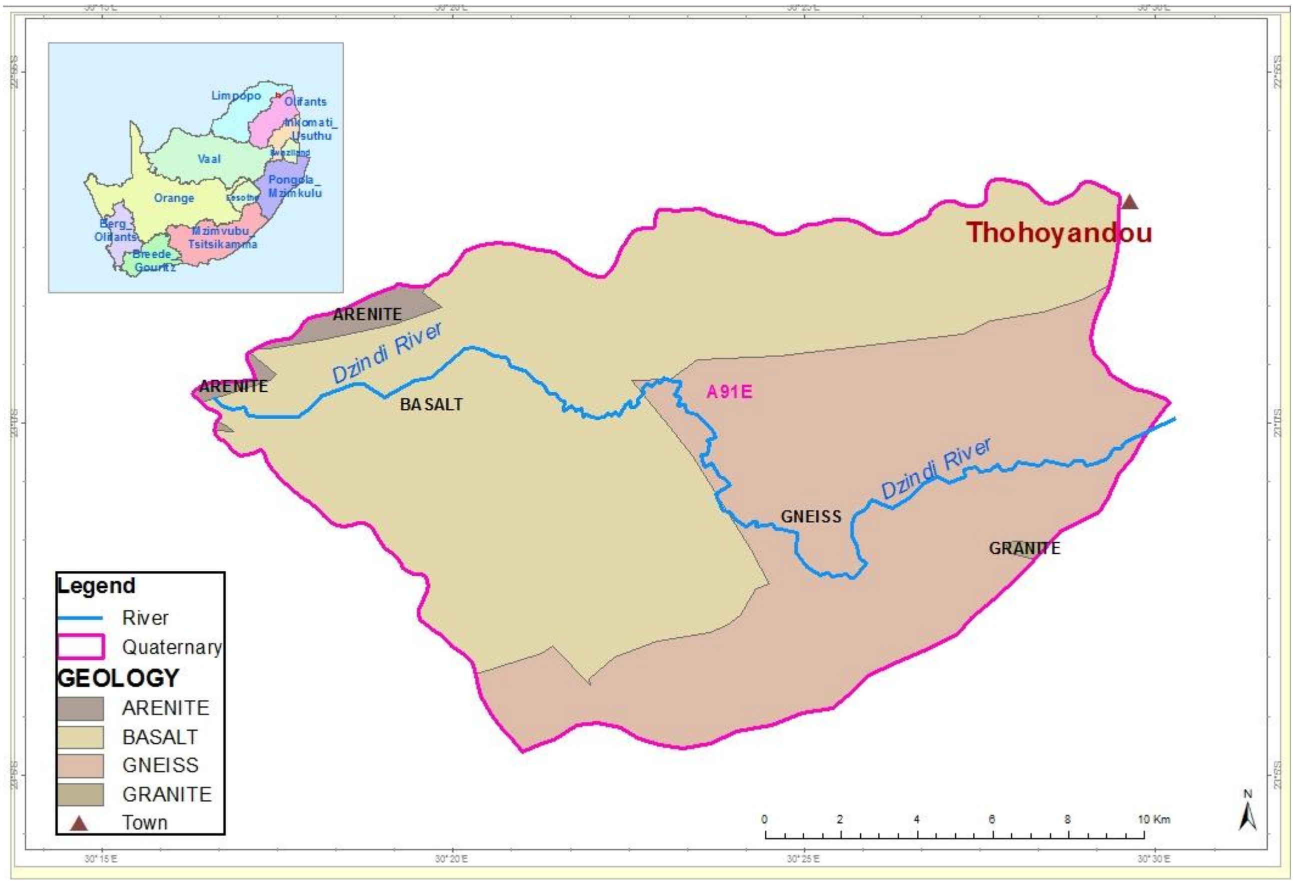

Figure 7: Geology of Dzindi River Catchment (A91E).

3.1.1.5 Soils

The Thulamela Local Municipality horticultural development plan (PHI, 2017), indicate that the upper catchment area comprising of the Soutpansberg mountains is mainly contain the soil that are resulting from weathering of quartzite and sandstones, are usually shallow, gravelly, well-drained with low nutrient and are acidic in nature. The soil type which dominates the upper catchment is termed AchHapli Acrisoils (Figure 8). An Acrisol is a Reference Soil Group of the World Reference Base for Soil Resources (WRB) (International Union of Soil Science (IUSS) Working Group WRB, 2015). It has clay-rich subsoil and is associated with humid, tropical climates. The vast area of the middle and lower Dzindi River catchment is covered by Haplic Lixisoils (Figure 9). These types of soils are comprised of subsurface build-up of low movement clays and high base saturation. These types of soils develop under intensive tropical weathering conditions and sub humid to semi-arid climate. In terms of texture, the deep weathering of basalt rocks and diabase dykes has given rise to fine textured, clayey and loam soils which are generally deep (Mostert, 2006).

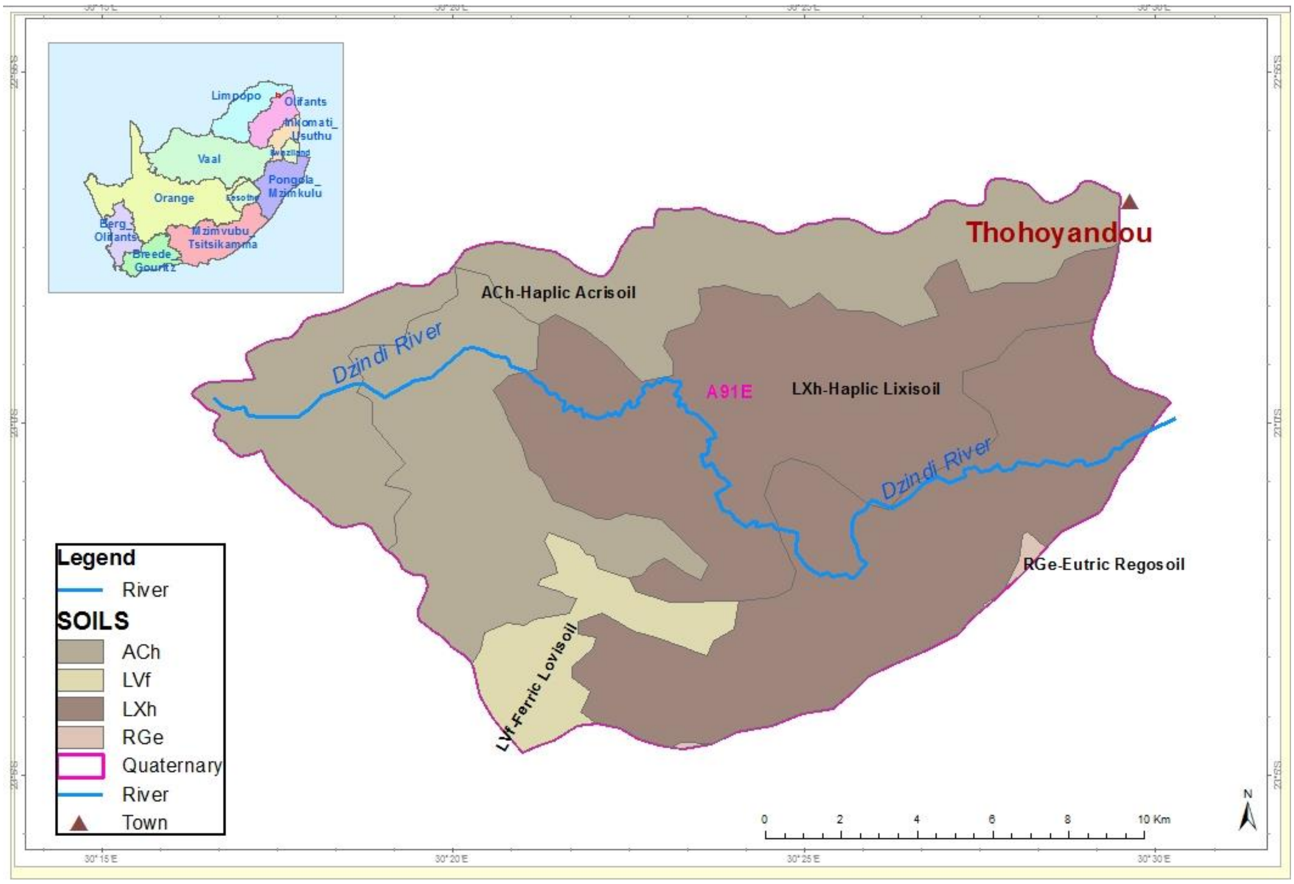

Figure 8: Soil types of A91E catchment.

3.1.1.6 Vegetation

At the biome level, Thulamela municipality falls within the Greater Savanna Biome (Mucina and Rutherford, 2006; Thulamela Local Municipality (IDP, 2018). The upper stream of the Dzindi River is dominated by the Soutpansberg mountain bushveld with small patches of northern mistbelt forest to the west. Tzaneen sour bushveld become the dominant feature in the middle of the catchment which is replaced by the granite bushveld in the lower catchment (Figure 9). Some parts of the area are significantly disturbed by human activities such as agricultural practices and are left with scattered trees and bushes. Additionally, the land is being cleared to give way to settlement for the growing population in the area.

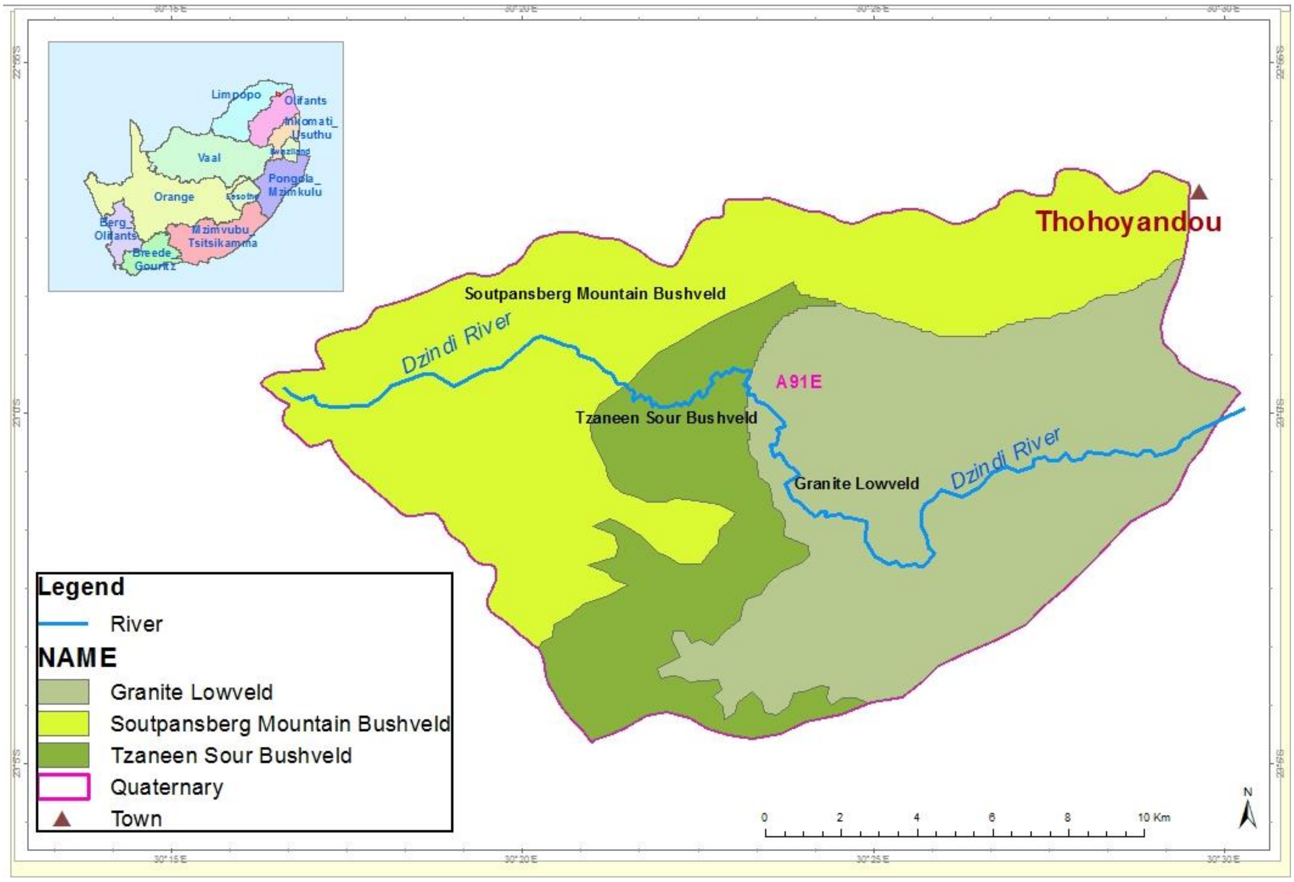

Figure 9: Vegetation of A91E catchment.

3.1.1.7 Population

Thulamela Municipality is inhabited by 618 462 people scattered around rural villages and small towns (STATS SA, 2011). This figure has since reduced due to demarcation changes which gave rise to the new municipality called LIM345. Thulamela population has decreased by 121 225 to 497 237 as confirmed by 2016 community surveys (STATSSA, 2016). The main town of Thulamela municipality is Thohoyandou. It is the main administrative capital of the former Venda homeland.

CHAPTER 4 : METHODOLOGY

4.1 Catchment Mapping and Delineation

Google Earth Pro and ArcGIS version 10.2.2 were employed to delineate the catchment and identify potential wetlands within the study area. The existing wetlands from NFEPA shapefiles obtained from SANBI were overlaid using GIS to verify the type of wetlands that exist in the area. However, the wetlands under this current study did not appear on NFEPA wetlands layers. Estimation of the area of each potential wetland was performed on GIS and five wetlands (1 ha or larger) were selected for further assessment onsite.

4.2 Data Collection and Analysis

Field visits were undertaken on 13 January 2018, 23 June 2018 and again on 11 August 2018. The data collected for each HGM unit was combined into one Wet-Health, Wet-IHI and Wet-Ecoservices score. The five selected wetlands were assessed to verify their types in terms of their HGM Unit (DWAF, 2007). As required by this technique, the boundaries (permanent, seasonal and temporal) of the each of the five wetlands were determined through delineation process onsite paying a particular focus on the occurrence of wetland plants (hydrophytes), hydromorphic soils or water logged and terrain units. The occurrence of a particular land scape or terrain unit can influence the occurrence of a wetland. The five main units of a typical landscape include the crest (hilltop), scarp (cliff), midslope (often a convex slope), footslope (often a concave slope); and a valley bottom (Figure 10) (DWAF, 2007).

The identification of zones was necessary because not all portions of the wetland are inundated for the same length of time and as such omitting other zones during the delineation exercise would misrepresent the wetland area. The three different zones normally identifiable in most wetlands include the temporary, seasonal and permanent zones (DWAF, 2007). These zones are distinguished according to the soil wetness and vegetation species indicators that change inwards to the middle of the wetland (Figure 11). The permanent zone is always saturated and is surrounded by the seasonal zone. This zone (seasonal) separates the permanent and the temporary zone. The temporary zone is there outer zone of the wetlands and is saturated for a short period in a year. Nevertheless, it is sufficient for the formation of hydromorphic soils and the growth of wetland vegetation.

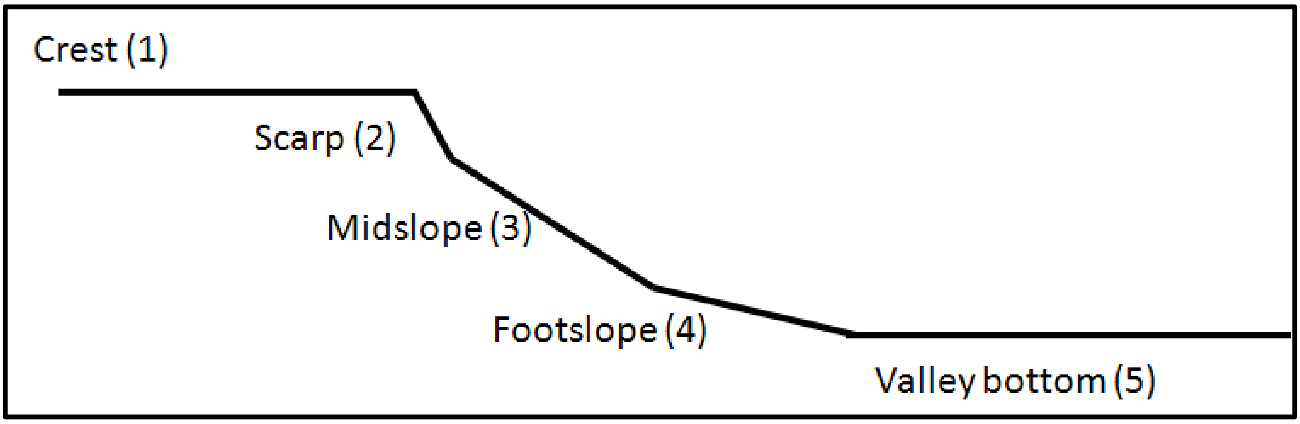

Figure 10: The five main landscape components or terrain units (DWAF, 2007).

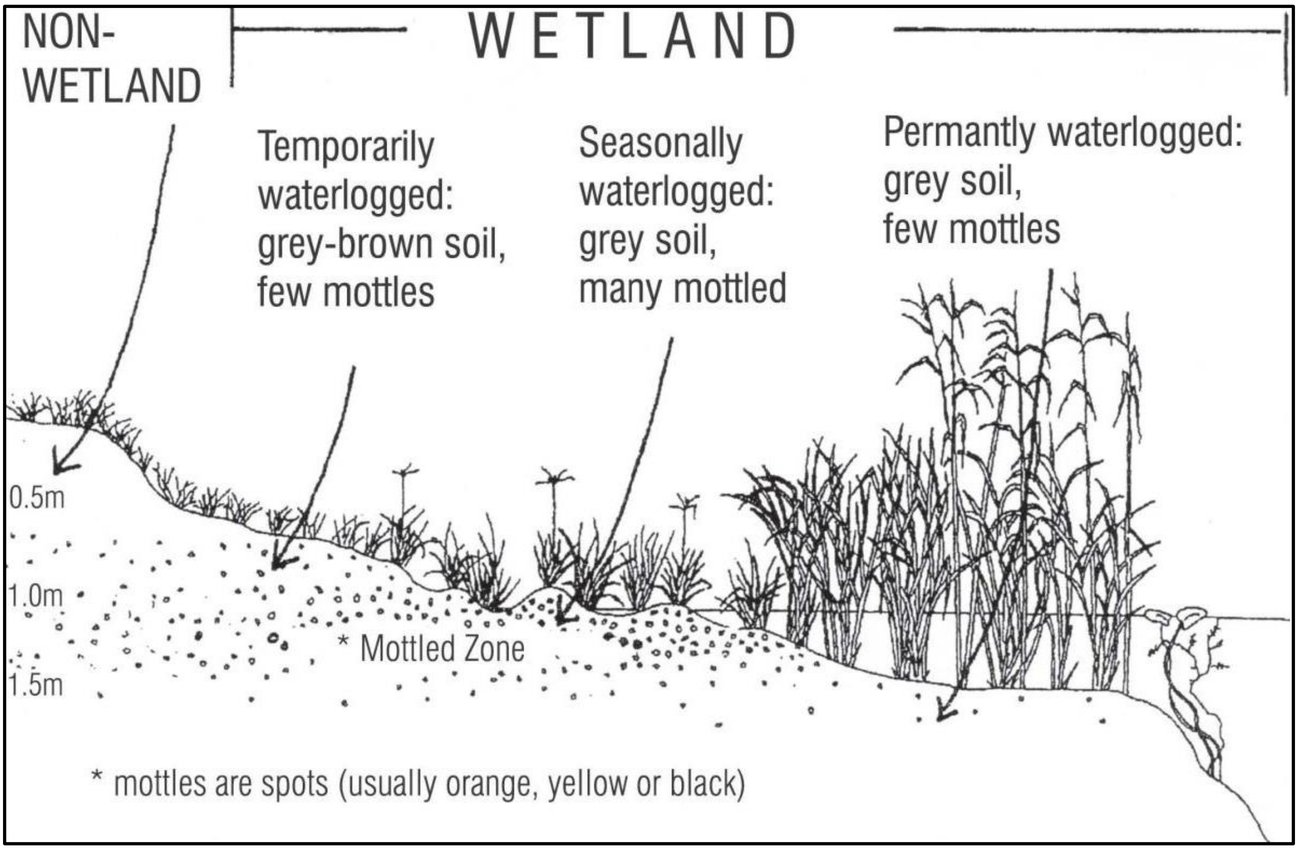

Figure 11: Wetland zones delineation (DWAF, 2007).

Soil indicators involved the determination of the presence of hydromorphic soils as well as the wetness conditions. A soil hand auger was used to auger up to 50 cm deep to analyse soil profiles. According to DWAF (2007), the hydromorphic soils in the wetlands must display signs of wetness within 50 cm of the surface soil. For the purposes of this research, the detailed soil classification was not done since it require specialist soil analysis and is time consuming. Detailed soil analysis and classification is imperative in cases of wetlands assessments in support of development projects. In this study, some baseline soil information such as the occurrence of moisture, soil mottles, occurrence of grey colour in wetland soils were considered sufficient. The soil samples at all HGM units were checked. Wetlands plant species assessment was also conducted at all wetlands sites. Current land uses in and around selected wetlands were also recorded.

During the surveys, several transect were established in order to have a representative data of the wetlands in the study area, while recording soils, vegetation, wetland zone and land uses. The wetland delineation excluded infrastructure areas (Lwamondo clinic and Dzindi water treatment plant).

4.3 Analysis Methods

Wet-Health, Wetland-IHI and Wet-EcoServices tools were used to assess all of the five identified HGM units. Each of the five wetlands selected were assessed as a single HGM. No subdivision of the wetlands was completed since they are small and do not show signs of change in the landscape. Wetland-IHI was used to determine the PES of HGM Unit 1-4 whereas WET-Health was used to determine the PES HGM unit 5. The reason for using Wet-Health determining the PES for HGM unit 5 was due to the fact that the Wetland-IHI method is not applicable on unchannelled valley bottom wetland type. The other reason was for comparison of the two methods. The PES of a wetland must be determined to gauge the level of impacts on wetlands and development of management guidelines towards a desired state. Wet-EcoServices was used to assess the benefits (ecosystem services) provided by each HGM Unit 1 to 5.

4.3.1 Wet-Health

The WET-Health model is a MS Excel-based spreadsheet model which incorporates the vegetation alteration, hydrology, and geomorphology and water quality modules to determine the PES of the HGM unit (Macfarlane *et al*., 2007). For each of the modules, scoring was performed on spatial extent, and intensity of the individual impacts within the model to generate the overall PES of a wetland (Macfarlane *et al*., 2007), while the extent and intensity are combined to determine an overall magnitude of impact. Extent, intensity and magnitude of impact are defined as follows:

Extent: The proportion of the wetland and/or its catchment affected by a given activity (expressed as a percentage). **Intensity:** The degree to which wetland characteristics have been altered within the affected area. The intensity of impact is measured on a scale of 0-10, with a score of 0 representing no impact or deviation from natural conditions, and a score of 10 representing complete transformation from natural conditions.

Magnitude: The overall impact of a particular activity or suite of activities on a component of wetland health being evaluated. This is determined by calculating an area-weighted impact score such that the intensity of impact is scaled by its extent. The magnitude of impact is expressed on a scale of 0-10 by multiplying intensity with the extent of impact. Once the scoring has been completed, the model determines the single PES score ranging from 0 (pristine) to 10 (critically impacted in all respects) for each HGM unit in the following manner:

Health = ((Hydrology score) x3 + (Geomorphology score) x2 + (Vegetation score) x2)) ÷ 7. The rationale for this is that hydrology is weighted by a factor of 3 since it is considered to have the greatest contribution to health.

4.3.2 Wetland-IHI

This is also an excel spreadsheet based model which is undertaken through seven steps to determine the PES of a particular wetland or HGM unit. Similar to Kleynhans and Louw (2007) different processes were followed to assign ecological categories A to F, where A means Natural and F means critically modified (Table 1).

Table 1: Ecological categories for EcoStatus (Kleynhans and Louw 2007)

ECOLOGICAL CATEGORY	DESCRIPTION	SCORE (% OF TOTAL)
A	**Unmodified**, in a natural state.	90 – 100
B	**Largely natural** only few alterations are evident.	80 – 89
C	**Moderately modified.** A moderate change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.	60 – 79
D	**Largely modified**. changes in habitat and biota of the wetland are more discenible	40 -59
E	**Seriously modified.** The loss of habitat and biota is extensive.	20 – 39
F	**Critically / Extremely modified**. the wetland is completely lost, impacts on biota and habitat are irreversible	0 – 19

Following the steps described in DWAF (2007), the first step involves setting up the model for the study area. This includes the site name, location (GPS co-ordinates), the 1:50 000 topographical map reference, the ecoregion the site is located in, the dominant geology of the site (if available – information can be obtained from 1:250 000 geological series maps), name of the assessor conducting the Wetland-IHI assessment and the date of the assessment. This modelling tool can only handle floodplain and channelled valley bottom wetland types (DWAF, 2007). Step 2 involves defining the reference condition of the wetland, i.e. running scenarios to check how the wetland ecosystem would look like without the catchment land use, hydrology, geomorphology and water quality alterations or impacts (DWAF, 2007).

The floodplain surface and Google earth photography are evaluated for evidence of the original channels throughout all five HGM units. The next step is to rate the land use activities which assesses the impacts on wetland vegetation. The model requires the rating of excavation within the wetland, infilling or backfilling in the wetland, alien invasive plants, vegetation clearing or loss in the scale of 1 to 5 where 1 represent least impacts and 5 is high impact. The scores of these indicators must add up to 100%.

Step four requires an assessment of Hydrological PES which involves the assessment of altered water regime conditions catchment wide and the wetland itself. This includes an assessment of the existence of dams, upstream of the wetland, any increase or decrease of base flow through liaising with DWS officials or published reports, rate any change in seasonality of flows and occurrence and duration of zero flows. The rating range is from 0 to 5 where 0 means no change while 5 means significant change. The in-wetland rating requires that the intensity and extent of the impact on connectivity - transformed channel size, increased or reduced water holding on the floodplain should be graded with scores ranging from 0 to 5.

The geomorphology rating is concerned with the sediment deposition in the wetland. Because of the characteristics of the floodplains such as reduced energy, depositional conditions, the build-up of sediments in combination with the availability of water, it creates the environments for wetland formation and persistence. At the catchment scale the geomorphology module is done by rating any change in sediment supply and transport. The water quality module is also rated on impacts of land use activities (available dams, invasive plants, forestry, riparian vegetation removal etc.). In addition, pH; salts; nutrients; water temperature; turbidity; oxygen, and toxicans are noted. Although water quality component is added in the tool, it is dealt with very superficially in the model (Macfarlane *et al*., 2008). WET-Health does not have a specific module for determining impacts that altered water quality on wetlands and their biota. It is not possible in the model to specify or input the measured water quality data. This is because it is recognised from the outset that the nature and level of solutes found in wetlands varies considerably from one wetland area to the next.

Variation over time within a given wetland area may also be considerable, particularly in areas subject to high climatic variation. This makes generalisations and standards for determining the health of a wetland from the perspective of water quality very difficult. As a result, a very coarse assessment of water quality impacts in wetlands is possible using an impacts-based approach rather than a detailed description of the biotic response to altered water quality. In this case, the same approach applied in the other modules, whereby the extent of the wetland affected by increased solute levels and the intensity of the impact on the affected area would be assessed. The magnitude of impact is based on the location of potential sources of increased solutes in relation to catchment runoff paths into the wetland and the nature of the flow through the wetland (i.e. whether channelled or diffuse). A pollution entering the wetlands at the upstream is likely to affect a much greater extent than a source entering at the downstream end of the wetland. An example of final PES scores of a hypothetical HGM unit (Table 2).

Table 2: Overall PES score on Wetland-IHI model (DWAF, 2007).

OVERALL PRESENT ECOLOGICAL STATE (PES) SCORE					
	Ranking	Weighting	Score	Confidence Rating	PES Category
DRIVING PROCESSES:		**100**	**1.2**		
Hydrology	1	100	1.5	*2.8*	**C**
Geomorphology	2	80	1.3	*2.3*	**C**
Water Quality	3	30	0.0	*2.0*	**A**
WETLAND LANDUSE ACTIVITIES		**80**	**1.4**	***2.6***	
Vegetation Alteration Score	1	100	1.4	*2.6*	**C**
OVERALL SCORE:			**1.3**		
PES %			**74.5**	***Confidence Rating***	
PES Category:			**C**	***1.2***	

4.3.3 Wet-EcoServices

Ecosystem services currently being provided by five of the wetlands HGMs were assessed using the Wet-EcoServices MS Excel spreadsheet model. Both the direct and indirect benefits were assessed as described in Table 3. The key criteria of the model are a proper classification of the HGM units. Four HGM units (1-4) were classified as channelled valley bottom while the fifth HGM was found to meet the conditions of unchannelled valley bottom. Scoring of all fifteen Wet-EcoServices based on observations recorded during the field visits were done in the model to ascertain the level of protection and rehabilitation necessary to maintain those identified services. Once all the modules are rated using the guideline for all 15 ecosystem services and characteristics, the data collected in the field for ecosystem service (example for flood attenuation in Table 4), was used to run the model in order to generate the results (Kotzé *et al*., 2008). Evidence of sediment deposition and existence of dams in the catchment and or occurrence of gullies and banks erosion are recorded for each of the five HGMs as an indicator for sediment trapping benefit, vegetation cover was recorded which helps with nutrient removal, soil erosion. Carbon storage was accounted for by recording any evidence of peat formation and thickness in the wetlands.

Evidence of existence of red data species and connectivity to other natural resources were also recorded to account for biodiversity maintenance, occurrence of alien invasive plants was also recorded. Evidence of direct collection of water from wetlands by communities, harvesting of natural resources, cultivation and crop types, cultural practices in wetlands, scenic beauty of wetland and any tourism routes or any use for research are recorded. The model weighs the ratings and the resultant scores (0 to 4) are plotted on a spider diagram within the model for ease in interpretation (Figure 12). The results determined by the model are based on average scores per relevant characteristics. All the indicators are also scored in the model for confidence levels on each of rating with the score of 4 indicating very high confidence, score of 3 being high confidence while the score of 3 indicating moderate confidence, score of 2 represent the marginal confidence and low confidence represented by a rating of 1.

Table 3: Scoring guideline used for Dzindi wetlands (Kotzé *et al*., 2008)

Ecosystem service or wetland characteristic	Method	Rationale
Catchment dimension vs HGM area coverage	The area covered by HGM unit in a catchment is obtained by diving the HGM unit size by catchment size expressed in percentage converting this to percentage. For example: 12 ha HGM unit size in a 150 ha catchment size = 12/150x100% = 8%.	The potential flood flows will be influence by the size of the wetlands in relation to its surrounding catchment.
Surface coarseness	*Method:* Classify the wetland based on vegetation cover in the following manner: *Low:* lmited vegetation cover	Rough surface of a wetland due to vegetation cover will attenuate more flood waters through resistence against the flow.
Slope of the HGM unit	Slope can be determined from the detailed ortho map at a scale of 1:10000 or in the field (expressed in percentage). An average should be taken in cases where there is variation in slope across the HGM unit.	HGM unit characterised by gentle slope will attenuate more flood waters

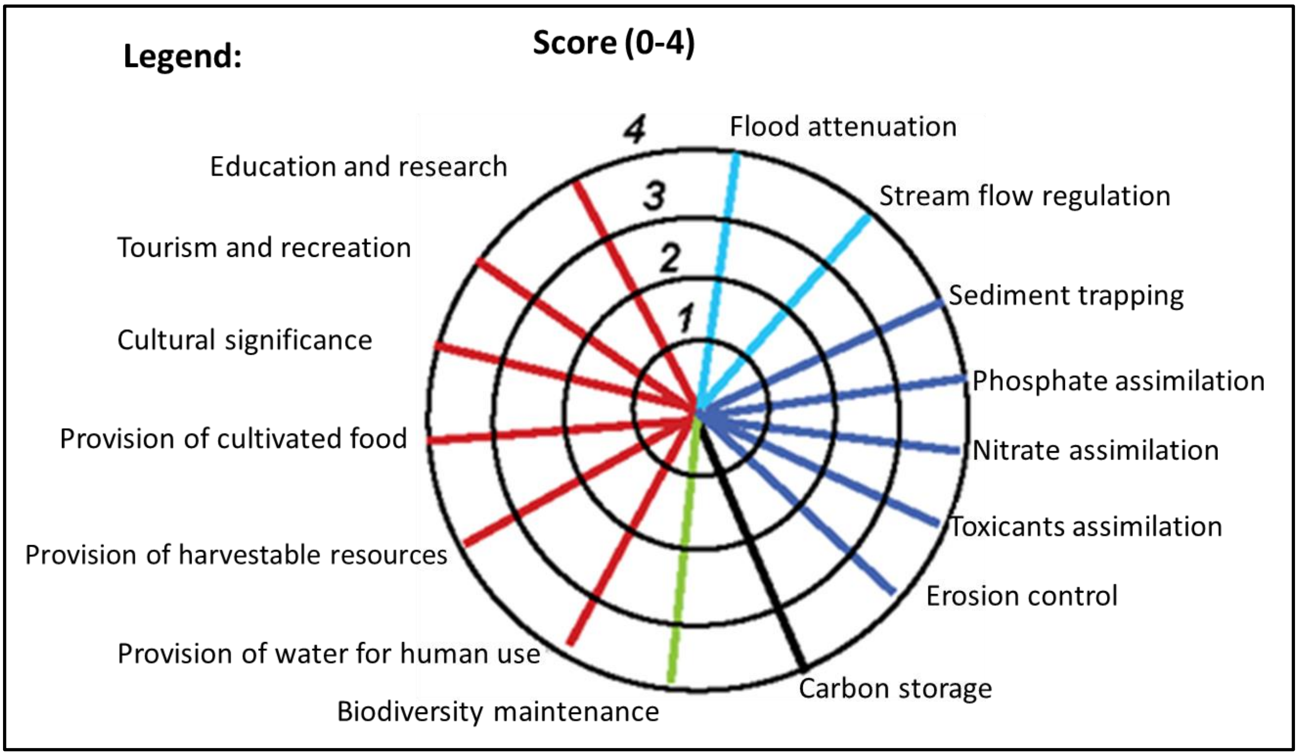

Figure 12: Spider plot of 15 ecosystem goods and services for a hypothetical wetland (Kotzé et al., 2008)

Table 4: Wet Ecoservices Ecosystem services (Kotze *et al*., 2008).

Ecosystem services supplied by wetlands	**Indirect benefits**	**Regulating and supporting benefits**	Flood attenuation		The spreading out and slowing down of floodwaters in the wetland, thereby reducing the severity of floods downstream
			Streamflow regulation		Sustaining streamflow during low flow periods
			Water quality enhancement benefits	Sediment trapping	The trapping and retention in the wetland of sediment carried by runoff waters
				Phosphate assimilation	Removal by the wetland of phosphates carried by runoff waters
				Nitrate assimilation	Removal by the wetland of nitrates carried by runoff waters
				Toxicant assimilation	Removal by the wetland of toxicants (e.g. metals, biocides and salts) carried by runoff waters
				Erosion control	Controlling of erosion at the wetland site, principally through the protection provided by vegetation.
			Carbon storage		The trapping of carbon by the wetland, principally as soil organic matter
	Direct benefits	**Biodiversity maintenance**[2]			Through the provision of habitat and maintenance of natural process by the wetland, a contribution is made to maintaining biodiversity
		Provisioning benefits	Provision of water for human use		The provision of water extracted directly from the wetland for domestic, agriculture or other purposes
			Provision of harvestable resources		The provision of natural resources from the wetland, including livestock grazing, craft plants, fish etc.
			Provision of cultivated foods		The provision of areas in the wetland favourable for the cultivation of foods
		Cultural benefits	Cultural heritage		Places of special cultural significance in the wetland, e.g. for baptisms or gathering of culturally significant plants
			Tourism and recreation		Sites of value for tourism and recreation in the wetland, often associated with scenic beauty and abundant birdlife
			Education and research		Sites of value in the wetland for education or research

4.3.4 Critical Thoughts on Wet-Health and Wet-Health

While the two methods Wet-Health and Wet-Health are slightly different in approaches; they actually perform the same analysis to determine the PES of a wetland. Not withstanding the fact that the two methods are the best available methods in South Africa for undertaking the wetland functional assessment, there are some short with respect to their application. The first shortcoming relate to the superficial nature in which the water quality module has been dealt with in the Wetland IHI model. Without using measured water quality data available for a specific river and the wetland in question, it becomes difficult to understand the real impact of human activities on the wetland. The Wet-IHI model does not include the water quality module which is a shortcoming on its own. Water quality is very important to understand the nature of impacts of anthropogenic or natural processes as well as the interaction between the wetland and the river system in channelled wetlands types.

Better explanations of the scoring systems associated with the assessment methods are needed, with additional guidance as to how to apply the scoring system to various scenarios that typically occur (e.g. rating the extent and intensity of land-use impacts where the different land-uses occur within or around a wetland). A shift in the composition of (indigenous) plant species within a wetland, which can in some cases represent a relatively significant impact, is not explicitly taken into account in the vegetation component of any of the existing assessment methods. No (or very little) explanation is given in these methods as to how an assessor should deal with the effects of wild fires, natural grazing, floods, droughts and other natural disturbances. There is a need to research on the possibility of combining the two methods into a single assessment tool or an integrated suite of assessment tools for the categorisation of wetland PES.

CHAPTER 5 : RESULTS

5.1 Wetland Identification and Classification

5.1.1 Wetland Types

A GIS layer of quaternary catchment A91E was obtained from DWS and overlaid by the NFEPA wetland layer obtained from SANBI. Significant wetlands (1 ha and more in extent) were identified. The purpose for this was to determine if any of the selected Dzindi HGMs appear on a national priority wetland layer (NFEPA). Although one of the qualifying criteria (surface area extent) is met by various wetlands identified along the Dzindi River, none of those wetlands selected were found in the NFEPA layer. Using Google Earth images, the two HGM types of were identified and delineated (Figure 13). Although there were a variety of wetlands along the Dzindi River, five significant wetlands were selected (named HGM Unit 1 to Unit 5). The wetlands identified comprise four (4) valley bottom wetlands with clearly defined channels (the Dzindi River, HGM Unit 1 to 4) as seen in Figure 14 through to 17 and one un-channelled valley bottom namely HGM Unit 5 (Figure 18). Extensive cultivation also occurs outside the wetlands, particularly around HGM unit 1, 2, 3 and 4 where communities have cultivated the opposite sides of the river which were not part of the wetlands (Figure 15 and 17). The HGM units 1 to 4 are located in Mapate Village and HGM Unit 5 is located in Lwamondo Village.

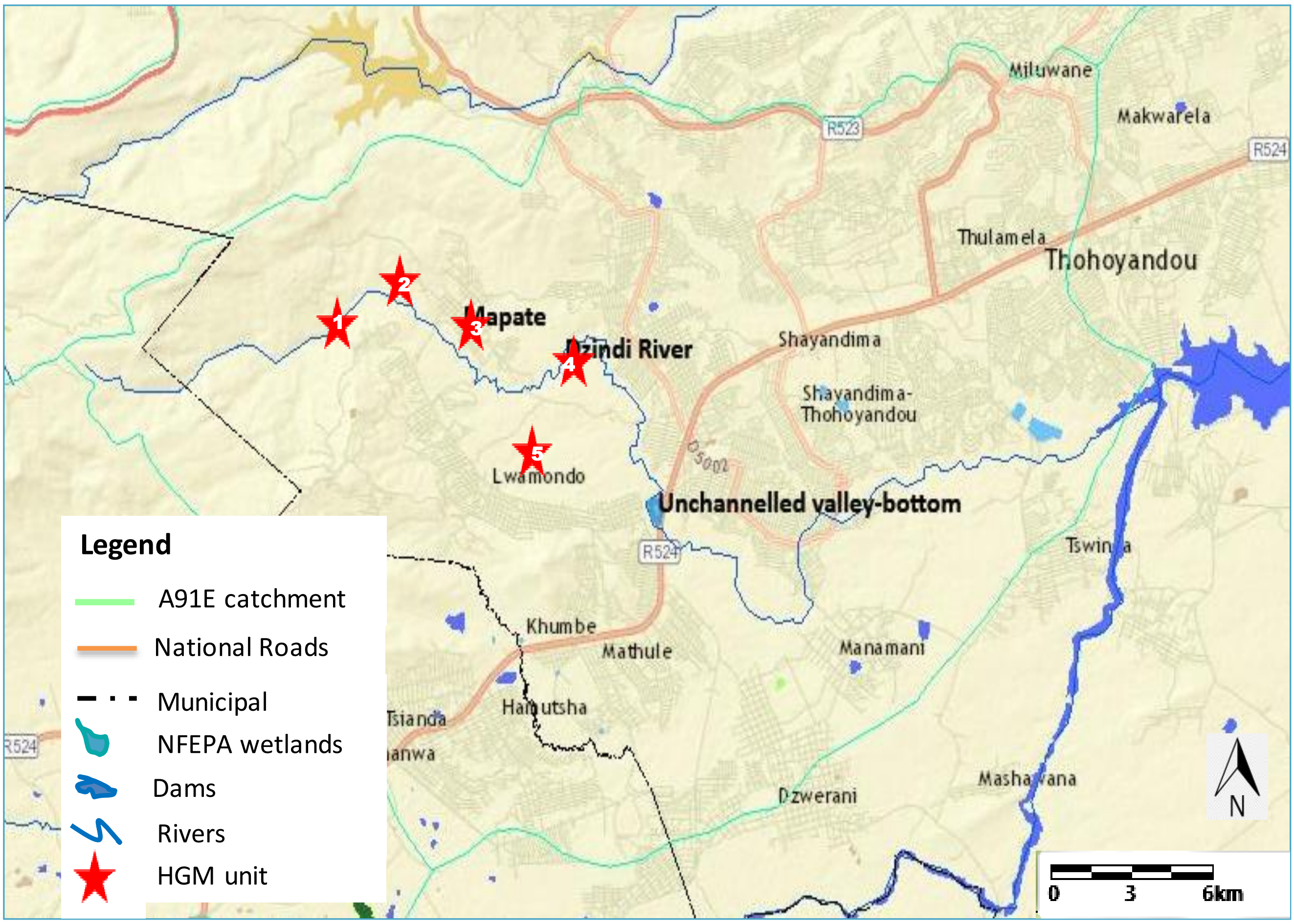

Figure 13: NFEPA wetlands layer of Dzindi River catchment (A91E).

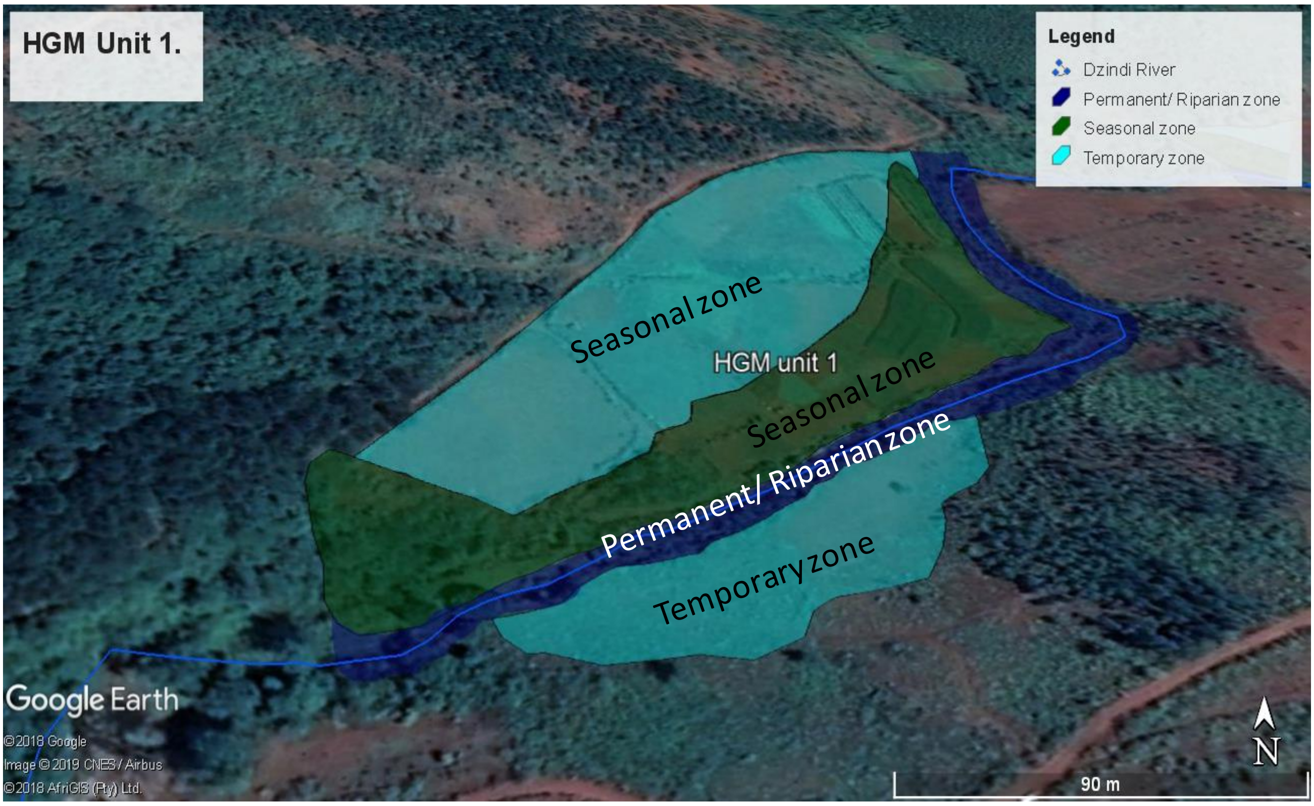

Figure 14: Location of HGM unit 1.

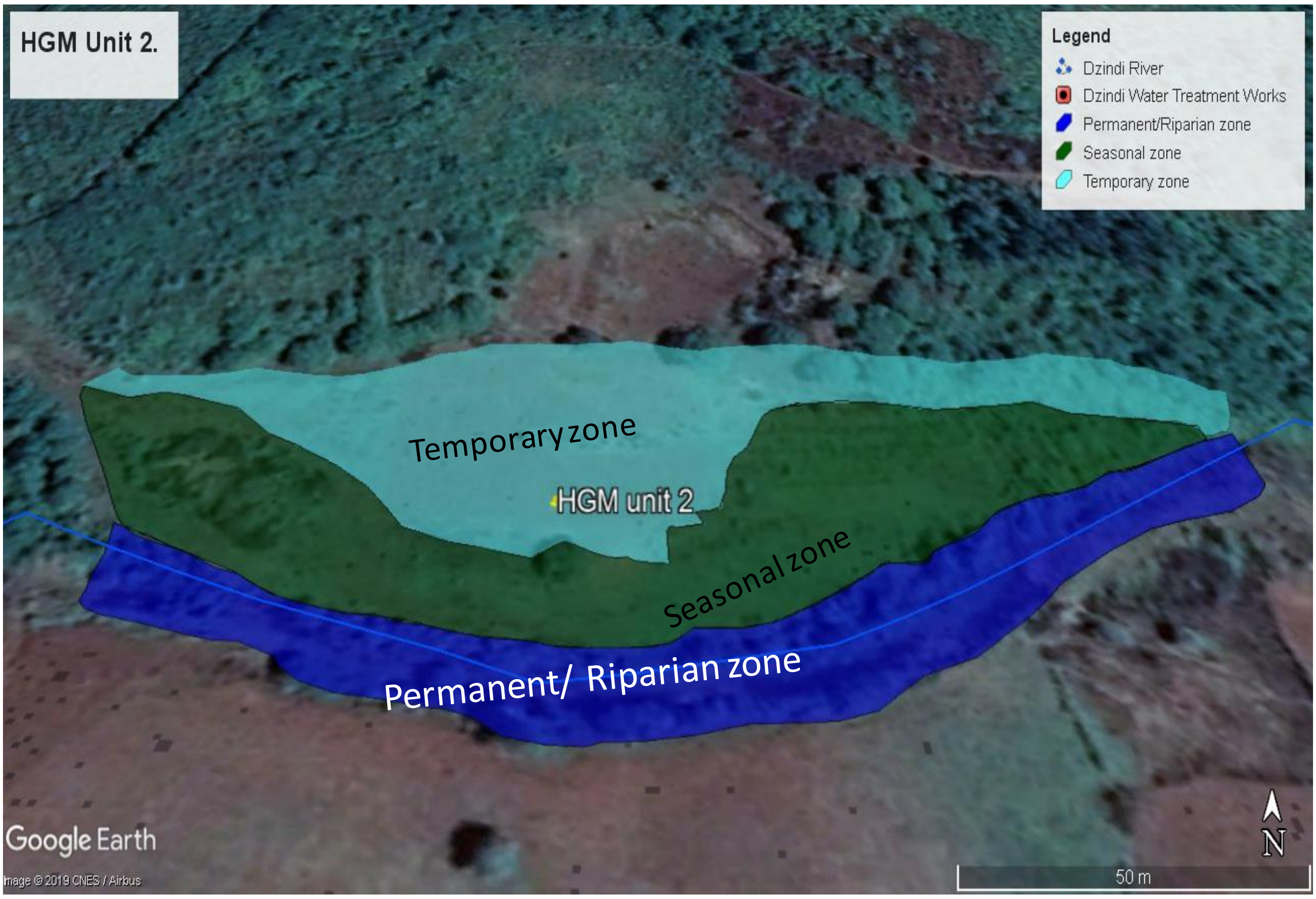

Figure 15: Location of HGM unit 2 (the other side of the river is just cultivation, not a wetland).

Figure 16: Map showing HGM unit 3 (the other side of the river beyond seasonal zone is just cultivation, not part of a wetland).

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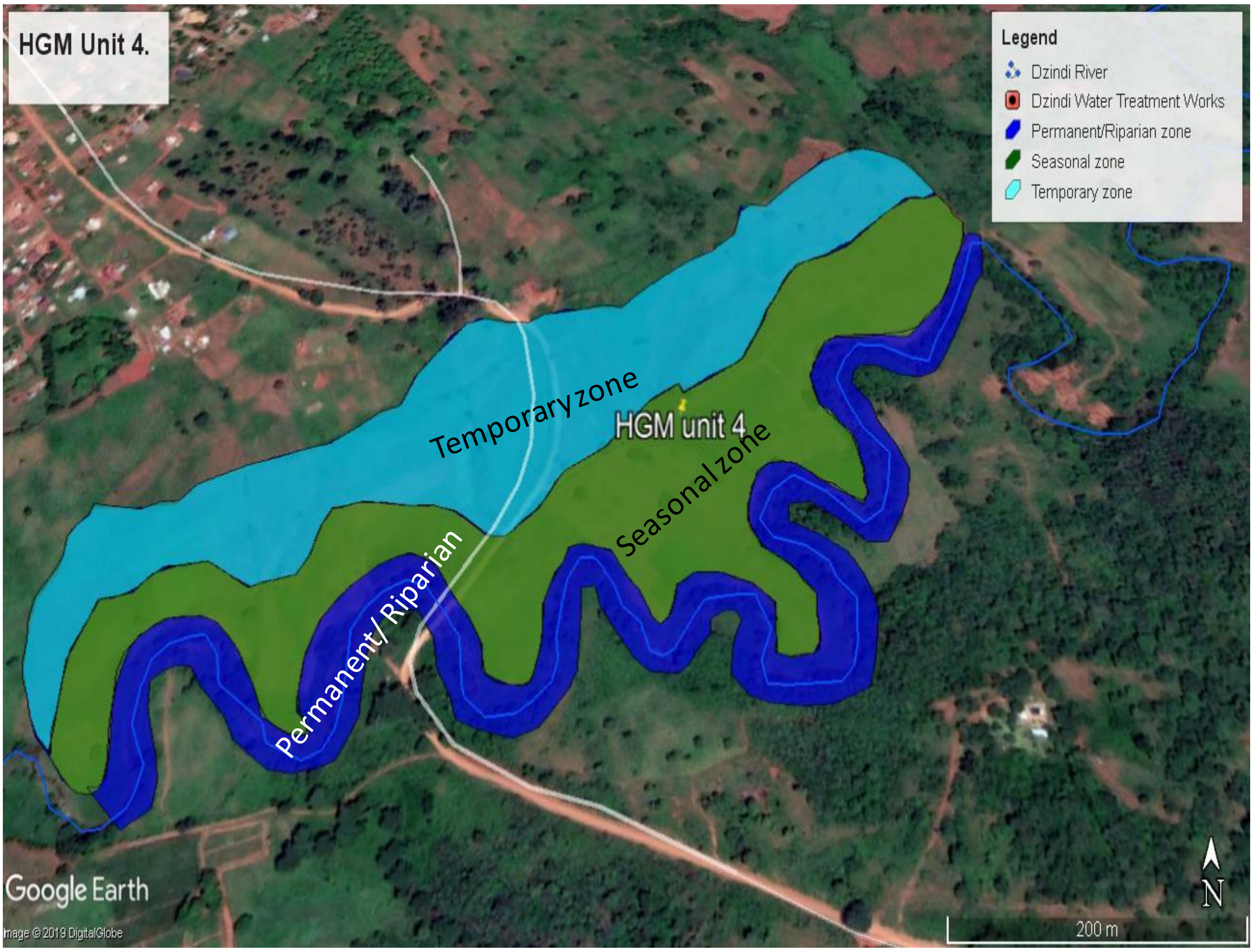


Figure 17: Map showing HGM unit 4 (the other side of the river is just cultivation, not part of a wetland).

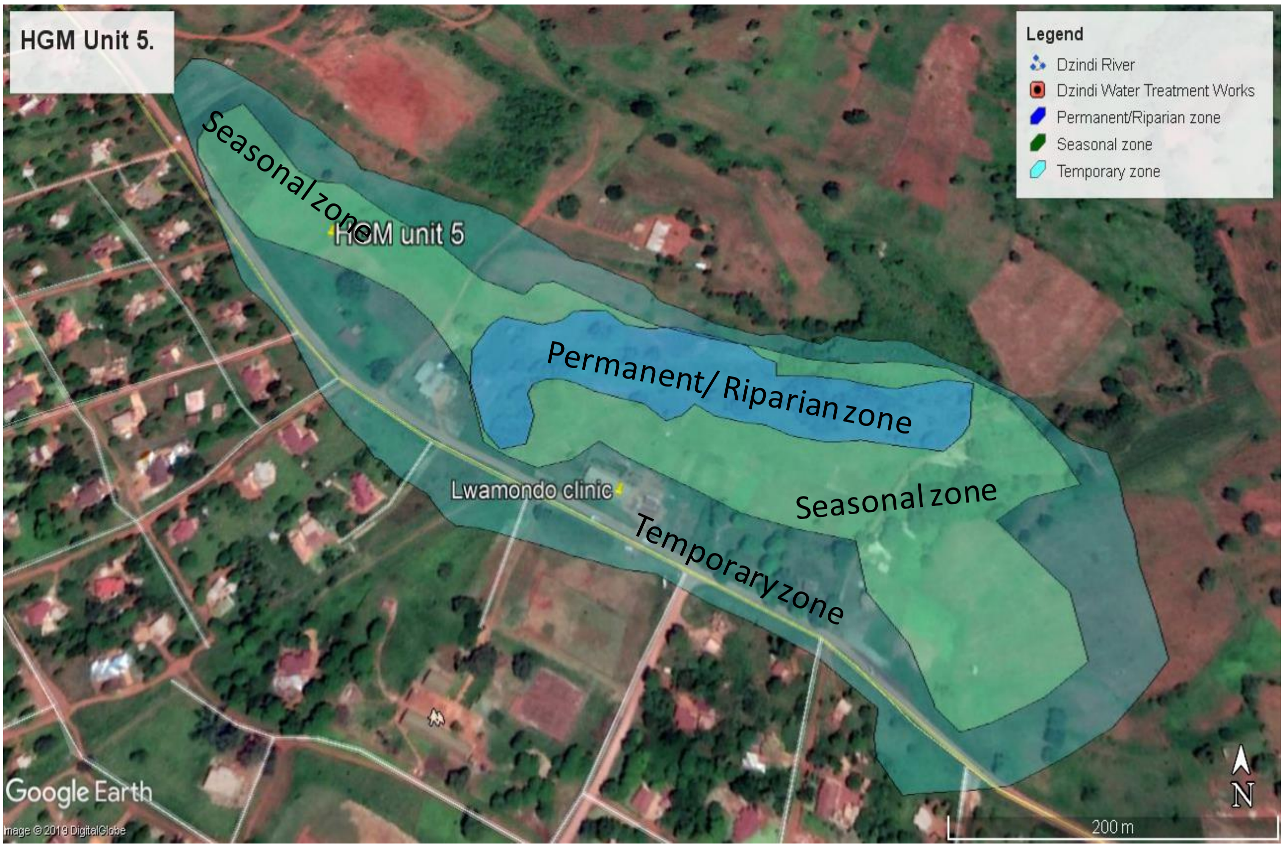


Figure 18: Map showing HGM unit 5.

5.2 Wetland Characterisation

5.2.1 Wetland Soils

All HGM units/wetlands were characterised by the same soil type which is reddish clayey-loam (Figure 19). Signs of wetness were encountered at dissimilar depths from the ground surface, particularly in the seasonal zones of all the five wetlands. Wetness was encountered at a depth of 43 cm at HGM unit 1, 30 cm at HGM unit 2, 50 cm at HGM unit 3, 38 cm at HGM unit 4 and 46 cm at HGM unit 5). Since the auguring was limited to 50 cm below surface, no moisture was encountered at this depth in all the HGM units at the temporary zone.

Figure 19: Soils assessment at HGM Unit 1.

5.2.2 Wetland Flora Biodiversity

All HGM units were dominated by grass species such as Scutch grass (*Cynodon dactylon*), particularly in temporary and seasonal zones with some herbaceous plants growing in cultivated areas (Table 5) (Figure 20). At all five HGM units, the permanent zone and the riparian zones were comprised of various water loving plants (hydrophytes) such as Common Reeds (*Phragmites australis*) (Figure 21). In HGM units1, 2, 3 and 4; the natural vegetation on both temporary and seasonal zones has been cleared leaving bare soils. The only indicator which assisted in delineating the two zones (temporary and seasonal) was the soil which was found to be wet at the depth of about 50 cm which was not the case on the temporary zone.

Table 5: List of plant species per HGM Unit.

<table>
<tr><th rowspan="2">HGM unit</th><th colspan="2">Flora species identified</th><th>Flora common to all HGM units</th></tr>
<tr><th>Common name</th><th>Scientific name</th><th>Common name/Scientific name</th></tr>
<tr><td>1</td><td>Common Reeds</td><td>Phragmites australis</td><td rowspan="7">Saligna Gum (Eucalyptus grandis)
Peanut Butter Cassia (Senna didymobotrya)
Caster-oil Plant (Ricinus communis)
Wild Celery (Apium graveolens L.)
Common thorn apple (Datura stramonium)
Tick-berry (Lantana camara)
Tall Khaki Weed (Tagetes minuta),
Rough cocklebur (Xanthium strumarium)
Silver-leaf nightshade (Solanum elaeagnifolium)
Purpletop (Verbena bonariensis)
Scutch grass (Cynodon dactylon)</td></tr>
<tr><td>2</td><td>Common Reeds</td><td>Phragmites australis</td></tr>
<tr><td>3</td><td>Herbaceous plants</td><td>-</td></tr>
<tr><td>4</td><td>Herbaceous plants</td><td>-</td></tr>
<tr><td></td><td>-</td><td>Caesalpinia decapetala</td></tr>
<tr><td rowspan="2">5</td><td>Bulrush</td><td>Typha capensis</td></tr>
<tr><td>Sedges</td><td>Carex lacustris</td></tr>
</table>

Figure 20: Vegetation at HGM units 1 – 4.

HGM unit 5 has a unique vegetation setting as compared to the other four HGM units particularly at the permanent zone. Typha also known as Bulrush (*Typha capensis*), Sedges (*Carex lacustris*) and ferns were only found at HGM unit 5 in the permanent zone (Figure 21). The temporary and seasonal zones have been cultivated.

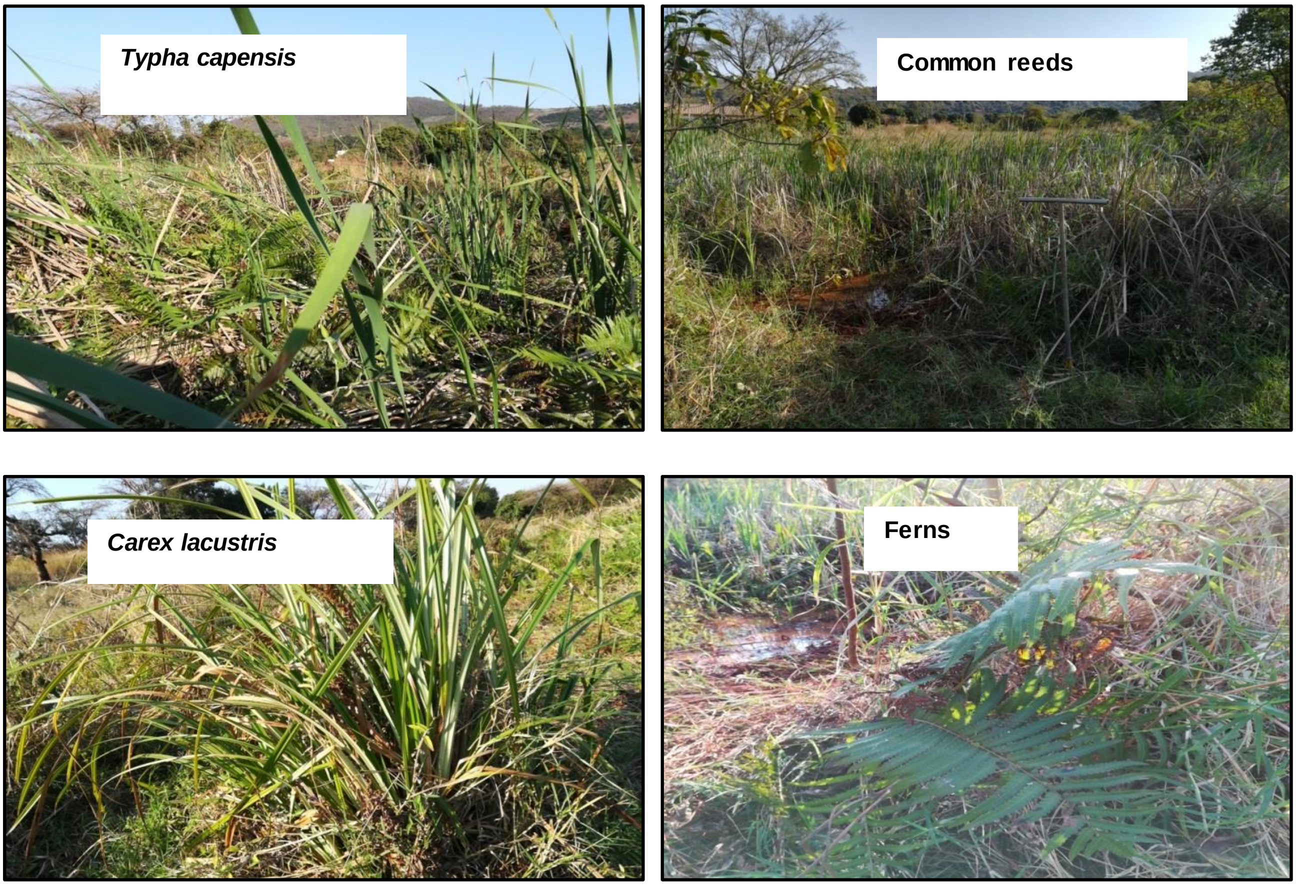


Figure 21: Some plant species found at the HGM unit 5 permanent zone

There are evidence of alien and invasive plants species in all the HGM units such as Saligna Gum (*Eucalyptus grandis*), Peanut Butter Cassia (*Senna didymobotrya*), Caster-oil Plant (*Ricinus communis*), Wild Celery (*Apium graveolens L.*), Common thorn apple *(Datura stramonium)* and tick-berry *(Lantana camara)*. Other exotic weeds such as, Tall Khaki Weed (*Tagetes minuta*), Rough cocklebur *(Xanthium strumarium),* Silver-leaf nightshade (*Solanum elaeagnifolium*) and Purpletop (*Verbena bonariensis*) also occur in disturbed areas, particularly in temporary and seasonal zones (Figure 22).

Figure 22: Some alien invasive plants at HGM units 1 – 5.

Due to unfavourable conditions for ploughing, the permanent zone of HGM unit 5 has a wide variety of wetland plant species which is also attracting birds. Evidence of birds nesting were identified at HGM unit 5 (Figure 23).

Figure 23: Flora diversity with bird nests at HGM unit 5.

5.2.3 Land Uses

5.2.3.1 HGM unit 1

This wetland occurs downstream of pine plantations and it is the first of a series of small valley bottom wetlands visible on Google Earth. The total delineated extent of the HGM unit was 6.62 hectares (ha). About 1.2 ha (18%), 2.0 ha (30%) and 3.38 ha (52%) constitute the permanent, seasonal and temporary zone respecively. The HGM unit is extensively cultivated (about 82% of temporary and seasonal zones combined) particularly during summer season when maize is grown (Figure 24). This is an indication that the HGM unit is also being used as livestock grazing area during the dry season. Cattle hoof marks were noted onsite during the dry season site visit. Few fruit orchards were also noted upstream of the HGM unit. No settlements occur within any of the wetlands assessed.

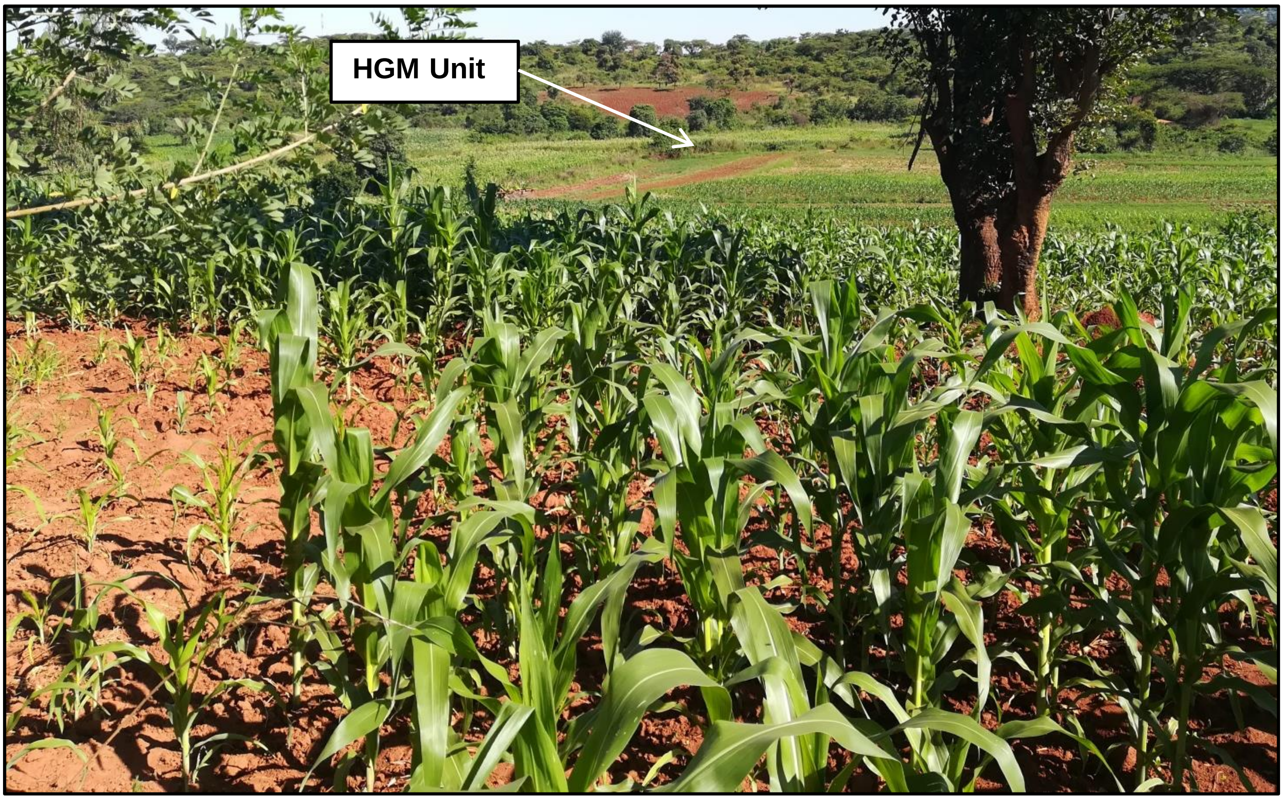


Figure 24: Maize crops on HGM Unit 1 during January 2018.

5.2.3.2 HGM unit 2

The total delineated extent of the HGM unit was 1.7 ha. About 0.43 ha (25%), 0.61 ha (37%) and 0.64 ha (38%) constitute the permanent, seasonal and temporary zones respecively. The HGM unit is extensively cultivated (about 75% of both the temporary and seasonal zones combined). Livestock grazing occur in the same 75% of the wetland during dry season. During the site visit on 13 January 2018, the two zones of the HGM unit were covered with fully grown maize crops. The HGM unit is left bare after harvesting as observed during dry season site visit (Figure 25).

Figure 25: HGM unit 2 after harvesting (Dry season).

5.2.3.3 HGM unit 3

A bridge on road D3724 which connects Mapate village and Lwamondo intercepts HGM unit 3. The bridge is being reconstructed after it was washed away by floods in 2013 (Figure 26). The total delineated extent of the HGM unit was 10.8 hectares (ha). About 1.2 ha (12%), 4.1 ha (38%) and 5.44 ha (51%) constitute the permanent, seasonal and temporary zones respecively. The HGM unit is extensively cultivated (about 52% occurring mainly on temporary and seasonal zones comined coverage area) particularly during summer season when maize is grown (Figure 27). Dzindi water purification plant is situated outside the wetland. During the field visit during a wet season (13 January 2018) it became possible to distinguish between the seasonal and temporary zones by examining how the maize crops grow in the respective zones. The maize crops on the seasonal zone did not grow well as compared the maize on the temporary zone owing to excessive wetness of seasonal zones (Figure 28).

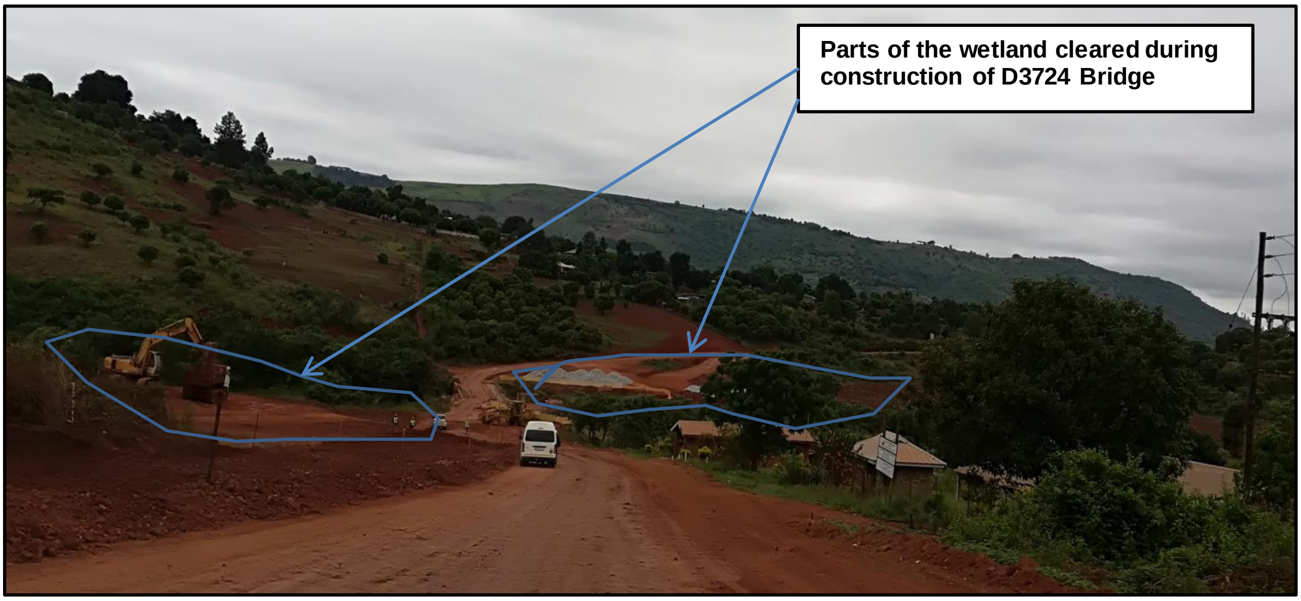


Figure 26: D3724 bridge which cuts through HGM unit 3.

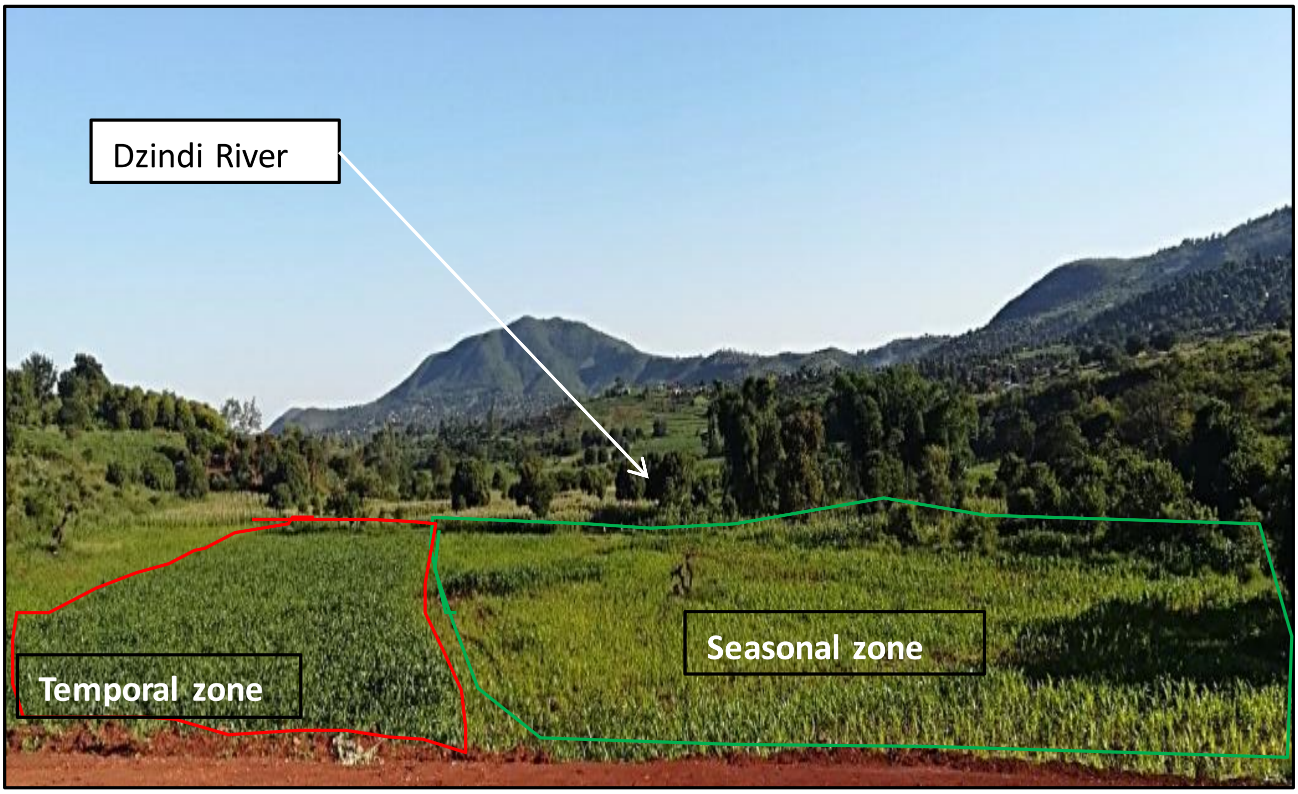


Figure 27: Some land uses at HGM unit 3.

Figure 28: HGM unit during dry season taken from the same location as Figure 28.

5.2.3.4 HGM unit 4

This HGM unit is located to the eastern border of Mapate Village along Dzindi River. The total delineated extent of the HGM unit was 21.3 ha. About 5.5 ha (26%), 7.3 ha (34%) and 8.3 ha (40%) constitute the permanent, seasonal and temporary zone respecively. The dorminant land use within the HGM unit was maize cultivation (about 82%) occurring in the temporary and seasonal zones combined) (Figure 29).

Figure 29: Maize planted during wet season at HGM unit 4.

5.2.3.5 HGM unit 5

The total delineated extent of the HGM unit was 21.4 ha. About 2.1 ha (10%), 10 ha (47%) and 9.3 ha (43%) constitute the permanent, seasonal and temporary zone respecively. The dominant land use at this HGM unit is dryland maize farming accounting for about 90% of the total wetland area (occurring in both temporary and seasonal zones (Figure 30)). Other land use included Lwamondo clinic covering 0.61 ha (2.9%), settlement consitituting for 3.51 ha (16%) and Orchards accouting for 2.3 ha (11%). Lwamondo clinic source their drinking water from the borehole that has been drilled in the wetland. During dry periods in winter, the area under maize cultivation is left bare while community livestock graze on grasses and residues left after harvesting.

Figure 30: Wet season land use at HGM unit 5.

5.3 Wetland Integrity and Functional Assessments

The PES analysis was conducted for the wetlands selected within the study area. This is necessary in establishing the basic information of the existing conditions of the wetland as part of setting a Reserve for the water resource. Wetlands-IHI was used in determining the PES component (Macfarlane *et al*., 2008). While inputting the recorded data from the site visit, this spreadsheet based model progressively generates scores for each ecosystem service plotted on the radial diagram.

WET-EcoServices is the functional technique that was used to evaluate the ecological benefits associated with the wetland habitat at all the HGM units in the study area (Kotzé *et al*., 2008). This technique analyses both the direct and indirect benefits obtained from the wetlands. The direct benefits refer to those that are derived by directly using the wetlands while indirect benefits are those services required to sustain the ecosystems functioning such as pollination of plants and nutrient cycling.

According to Kotzé *et al*., (2008), the WET-EcoServices technique serves to:

- determine the current level of functioning and highlight the importance of the wetland systems at a landscape level; and
- determine the important ecological services being provided by the wetland systems identified

5.3.1 HGM Unit 1

The results from Wetland-IHI indicate that the PES of this HGM unit was determined as C (defined as moderately modified). As can be seen in Table 6, the overall PES score is highly influenced by the hydrology module derived from the model which is categorised as C. The PES score for the hydrology module was determined by rating the water supply and distribution, flooding regime and seasonality within the wetland and the associated catchment. No flow data from a gauging weir was used. Even though the geomorphology and water quality are categorised between A and B, the overall PES remains in C category (Table 6). The PES of C indicates the change of natural habitat and biota of the wetlands, but the basic ecosystem functions of the wetland are still predominantly unchanged. The transformation of the HGM unit from reference state is due to land uses that are taking place in the area. The latter is more applicable at the permanent zone and the riparian zone of river within the HGM unit. The MS Excel sheets for each module of the model with the weighting and ratings results are included in Appendix A.

Table 6. Present Ecological State of HGM Unit 1

HGM Unit	**Hydrology**	**Geomorphology**	**Vegetation**	**Water quality**	**Overall score (PES)**
Valley bottom with channel	71.8 (C)	85.2 (B)	76.6 (C)	90.7 (A/B)	77.4 (C)

Figure 31 indicates a composite plot of both direct and indirect benefits currently being derived from the HGM unit 1. From this perspective, the highest benefits being derived from this HGM unit include cultivated foods and natural resources. This is because the HGM unit is being used for growing the maize annually during summer season and animal grazing during winter season. The cultivated food and natural resources ecosystem services scored at 3.6 (Figure 32). Tourism has the lowest score of 0.86 followed by education and research together with water supply for human use both with a score of 1.5. Other direct ecosystem services benefits including the provision of cultural significance and maintenance of biodiversity have low scores of 2 and 1.2 respectively (Figure 32). The reasons for these very low scores are because the HGM unit highly impacted, cleared of all the wetland vegetation in both the seasonal and temporary zones. As such, not much biological activities are occurring at the wetland which can support high species diversity.

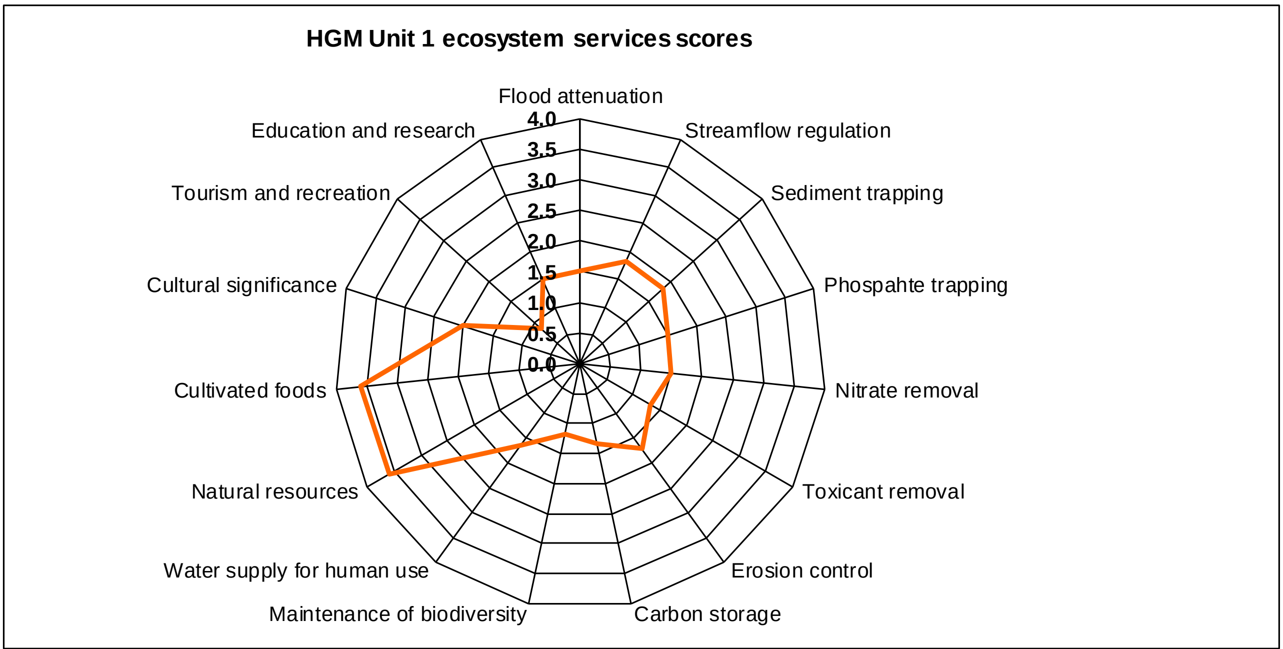


Figure 31: Overall score of the WET-Eco-Services assessment for the HGM Unit 1.

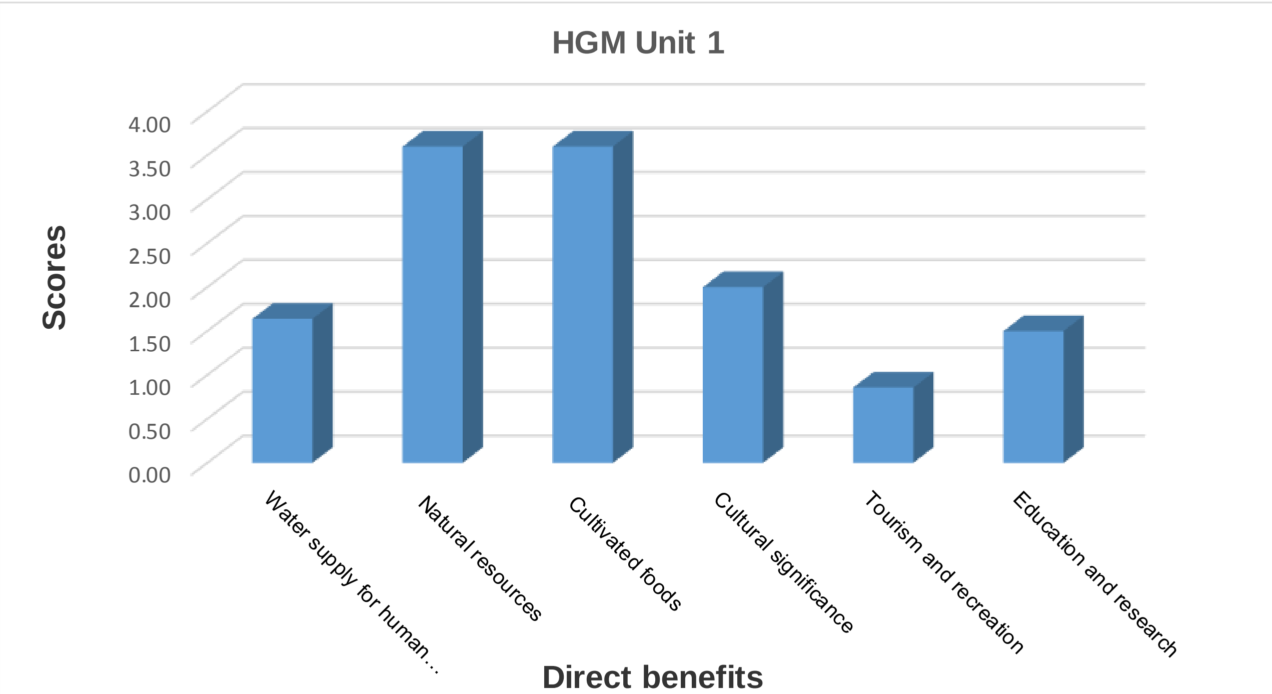


Figure 32: Direct Benefits scores for HGM Unit 1.

The highest indirect ecosystem services derived from this HGM unit include soil erosion control (1.71), sediment trapping (1.83) and streamflow regulation (1.83) (Figure 33). This valley bottom wetland occurring on Dzindi River banks is characterised by a gentle slope which influences reduction of flow velocities that supports sediments deposition and reduces soil erosion. Since the HGM unit is mostly cleared of natural vegetation, it does not come as a surprise that the maintenance of biodiversity services that it is providing is the lowest of all the ecosystem services with the score of only 1.19. Similarly, the flood attenuation, toxicant removal and carbon storage services which are also dependent on wetland functioning were scored very low (1.5, 1.33 and 1.33).

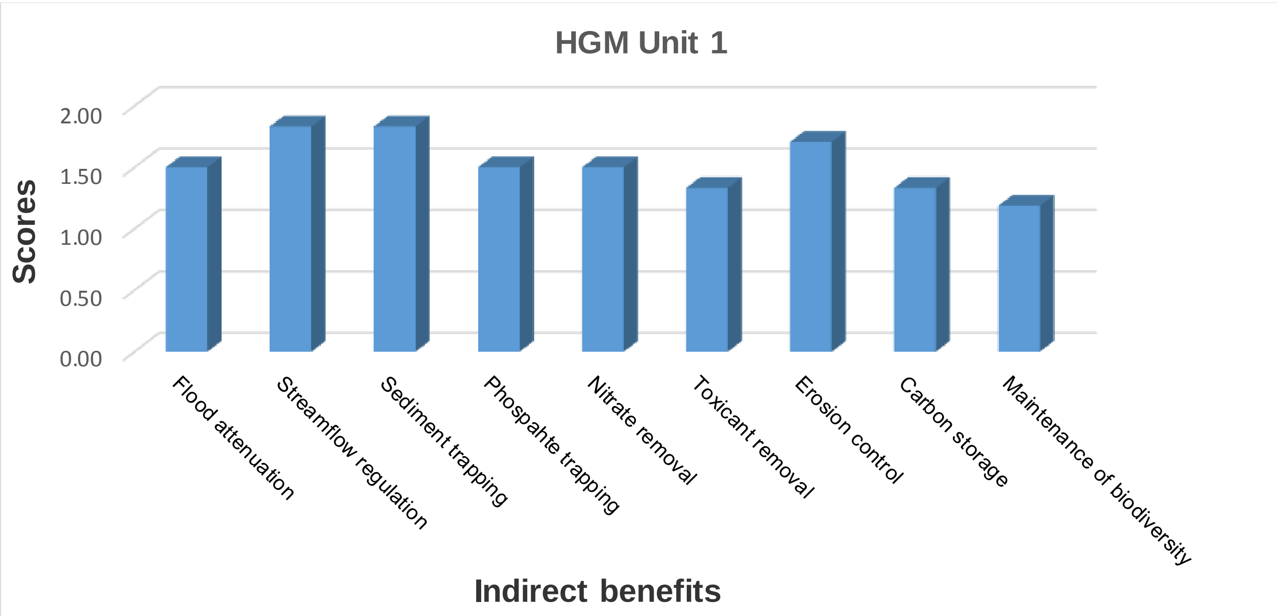


Figure 33: Indirect Benefits scores for HGM Unit 1

5.3.2 HGM Unit 2

Similar to HGM unit 1, the Wetland-IHI indicate that the PES at this wetland is determined as C (moderately modified) state (Table 7). The score of the controlling module is scored 67.4 which is categorised as C. The vegetation module is scored low at 60.8. This is an indication that the HGM unit is seriously impacted with vegetation completely removed. The score of 60.8 corresponds to category C. The overall PES score is 70.2 which is categorised as C. This PES category indicates that the HGM unit is experiencing change of natural habitat and biota. The high scores of geomorphology (85.2) and water quality are negligible owing to the high weighting factor of the hydrology module in the model. Although water quality score is high, its contribution to the overall score is very low. The weighting factor for the Hydrology is high because it is considered a controlling factor for the existence of a wetland. The MS Excel sheets for each module of the model with the weighting and ratings results are included in Appendix A.

Table 7. Present Ecological State of HGM Unit 2

HGM Unit	Hydrology	Geomorphology	Vegetation	Water quality	Overall score (PES)

Valley bottom with channel	67.4 (C)	85.2 (B)	60.8 (C)	92.3 (A)	70.2 (C)

The direct ecosystem services plot for HGM unit 2 indicates that the highest ecosystem services derived from HGM unit include cultivated foods (3.6) and natural resources (3.4) (Figure 34 and 35). The natural resource in this case is more of moist soils supporting the growth of maize crops during summer season. The water supply for human use and cultural significance scores for this HGM unit are much lower, 1.6 and 2.5 respectively. The more concerning ecosystem services which this HGM unit is providing at an extremely low scale include tourism and recreation with a score of 0.7 (Figure 35). This low score is in agreement with the score of biodiversity maintenance of 1.3 because there is very little in terms of biodiversity in the HGM unit 2 which may attract tourists to enjoy. This is an indication of the fact that the HGM unit is used solely as maize crop cultivation grounds where by the community of Mapate village targets the availability of moist soils to cushion their crops from moisture deficits in the soils during summer season.

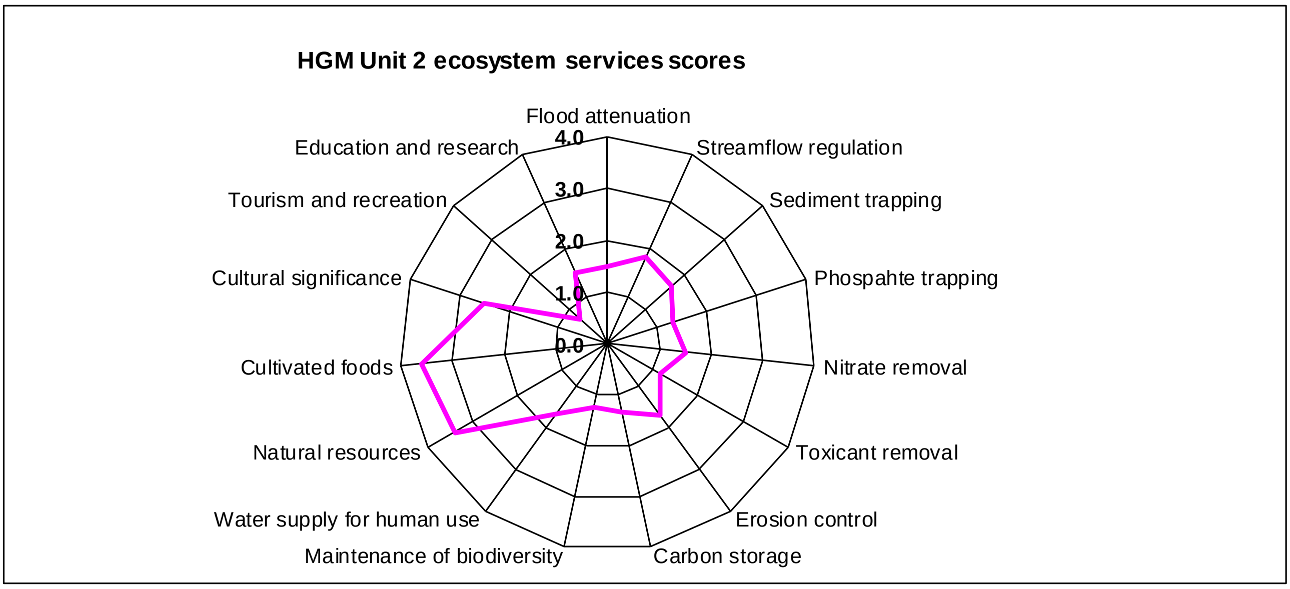


Figure 34: WET-Eco-Services plot for HGM Unit 2.

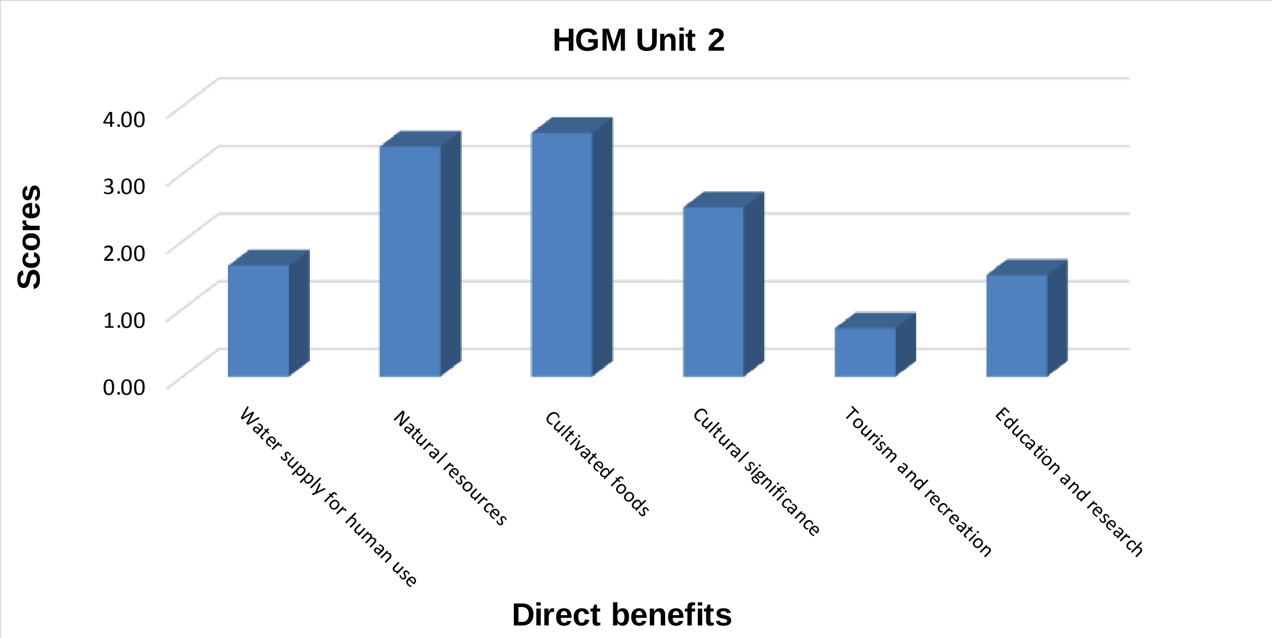


Figure 35: Direct benefits for HGM Unit 2.

The highest indirect ecosystem services provided by HGM unit 2 include streamflow regulation (1.83) and soil erosion control (1.71), floods attenuation (1.50) and sediment trapping (1.67) (Figure 36). These are more related to the physical nature of the HGM unit which is more of a flat surface or flood plains along the Dzindi River. Even through there is very little natural vegetation cover of a wetland environment on both temporary and seasonal zones, the flat nature of the surface is able to influence some sediments deposition, slows down flow velocities and reduces soil erosion in the wetland area. Other ecosystem services which require long term presence of moisture and organic matter such as phosphate removal (1.33), nitrate removal (1.5), toxicant removal (1.17), carbon storage (1.33) are much lower since the favourable conditions do not exist at the HGM unit 2 (Figure 36).

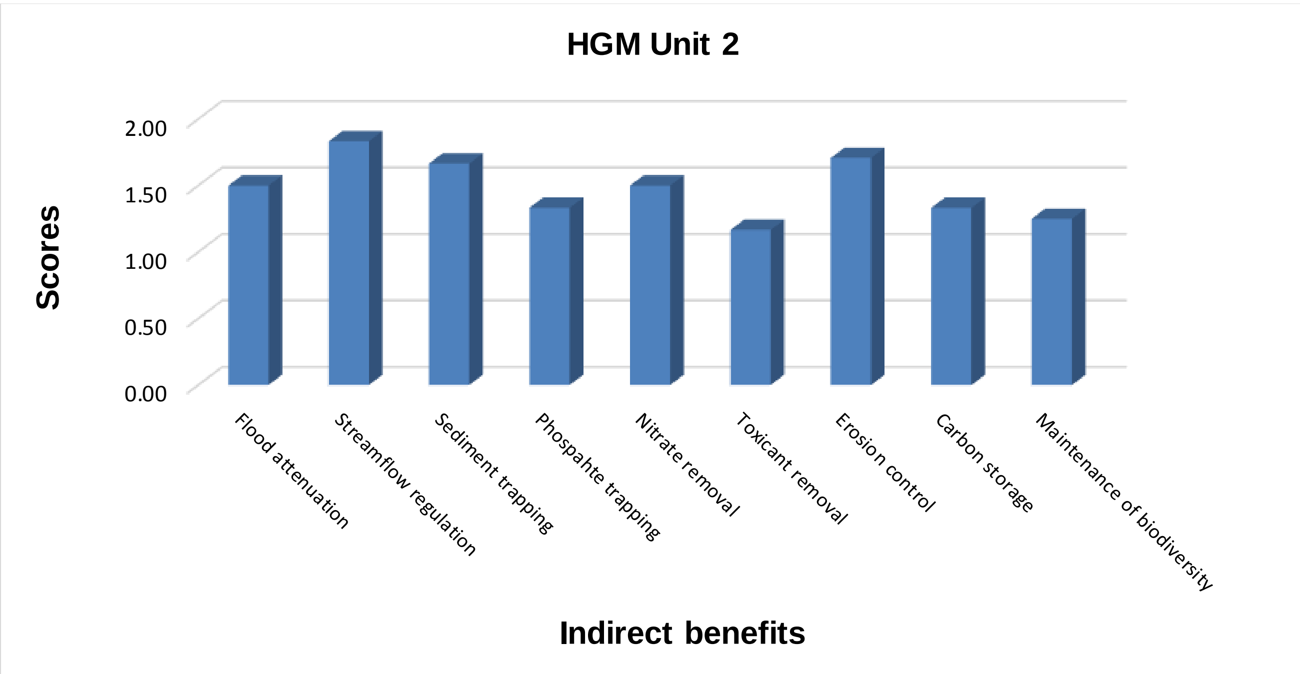


Figure 36: Indirect Benefits score for HGM Unit 2

5.3.3 HGM Unit 3

The HGM unit is highly impacted by land uses activities occurring onsite including maize crops cultivation, bridge and road construction as well as Dzindi water treatment plant. The PES of this HGM unit was determined as C, with the score of 66.1. Both the seasonal and temporary zones are cleared of natural vegetation with evidence of soils stock piles in the wetland, cleared area for storage of construction equipment (Table 8). The three components/modules were scored very low revealing the impacts onsite, hydrology (64.8), geomorphology (68.5), vegetation (61.8) and water quality (88). As in the case of HGM unit 1 and 2, the low score of Hydrology affects the overall PES score of HGM unit 3 rendering the contribution of water quality very low. These scores indicate that the natural habitat and biota at the HGM unit have been changed but the basic ecosystem functions are still predominantly unchanged. The MS Excel sheets for each module of the model with the weighting and ratings results are included in Appendix A.

Table 8: Present Ecological State of HGM Unit 3

HGM Unit	Hydrology	Geomorphology	Vegetation	Water quality	Overall score (PES)
Valley bottom with channel	64.8 (C)	68.5 (C)	61.8 (C)	88 (A/B)	66.1(C)

Like in the cases of HGM unit 1 and 2, the highest direct ecosystem services being derived from this HGM unit include cultivated foods and natural resources provision with the scores of 3.6 and 3.2 respectively (Figure 37 and 38). The education and research as well as tourism and recreation ecosystem services are scored the lowest in this category with scores of 0.6 and 1.3 respectively. There was no evidence of direct water withdrawal from the wetland and as such the score was less at 1.8 for this.

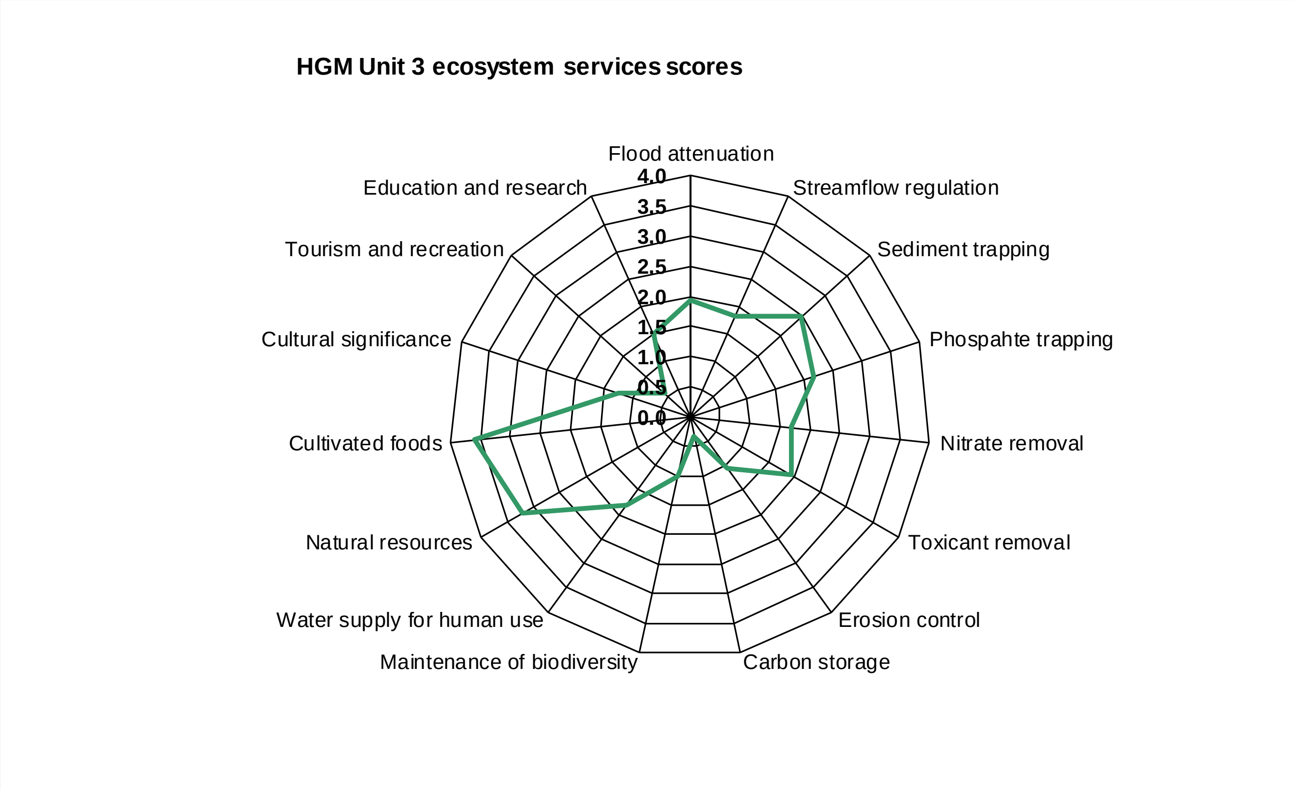


Figure 37: WET-Eco-Services for the HGM Unit 3

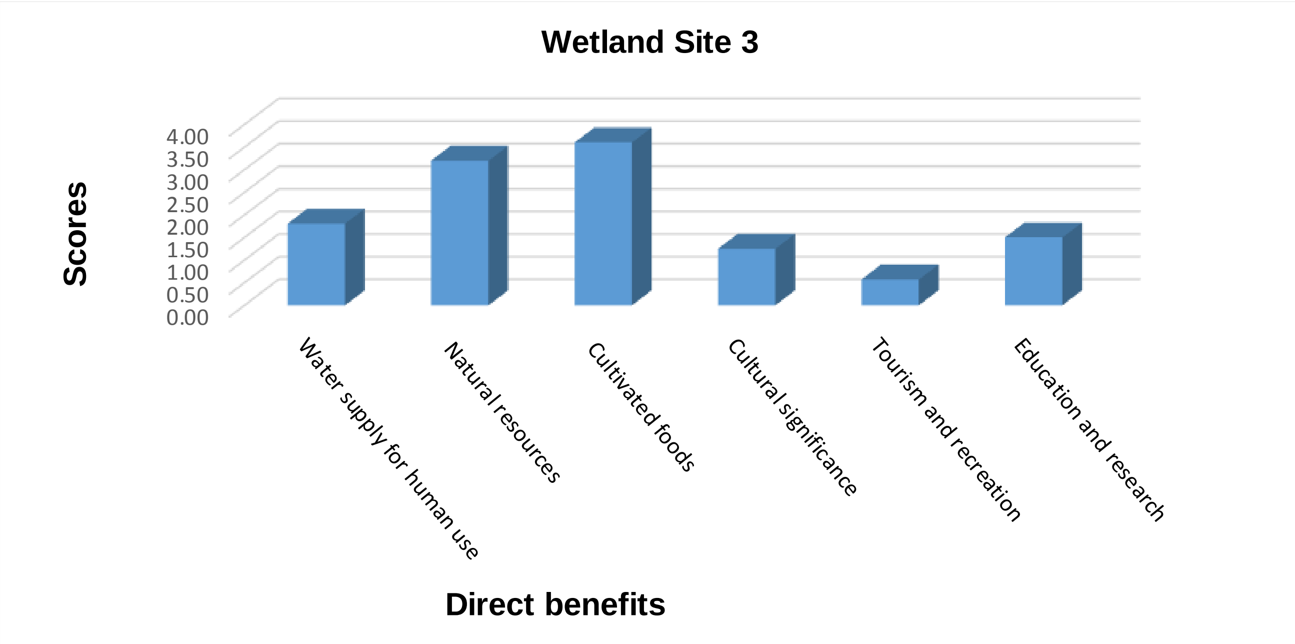


Figure 38: Direct benefits for HGM Unit 3

The physical conditions of the wetland on both the temporary and seasonal zones can still function in lowering the velocity of the water thereby enabling services such as stream flow regulation, soil erosion control, sediment deposition and floods attenuation. As a result of these services although at a limited scale, the scores were as follows: 2.49, 2.16, 1.94, 1.93 and 1.83 for sediments trapping, phosphate trapping, flood attenuation, toxicant removal and stream flow regulation respectively

(Figure 39). As reflected by these low scores, the ecosystem services that rely on proper functioning of the wetlands directly or indirectly influences function such as carbon storage, erosion control and maintenance of biodiversity which scored 0.33, 1.04 and 1.00 respectively (Figure 39).

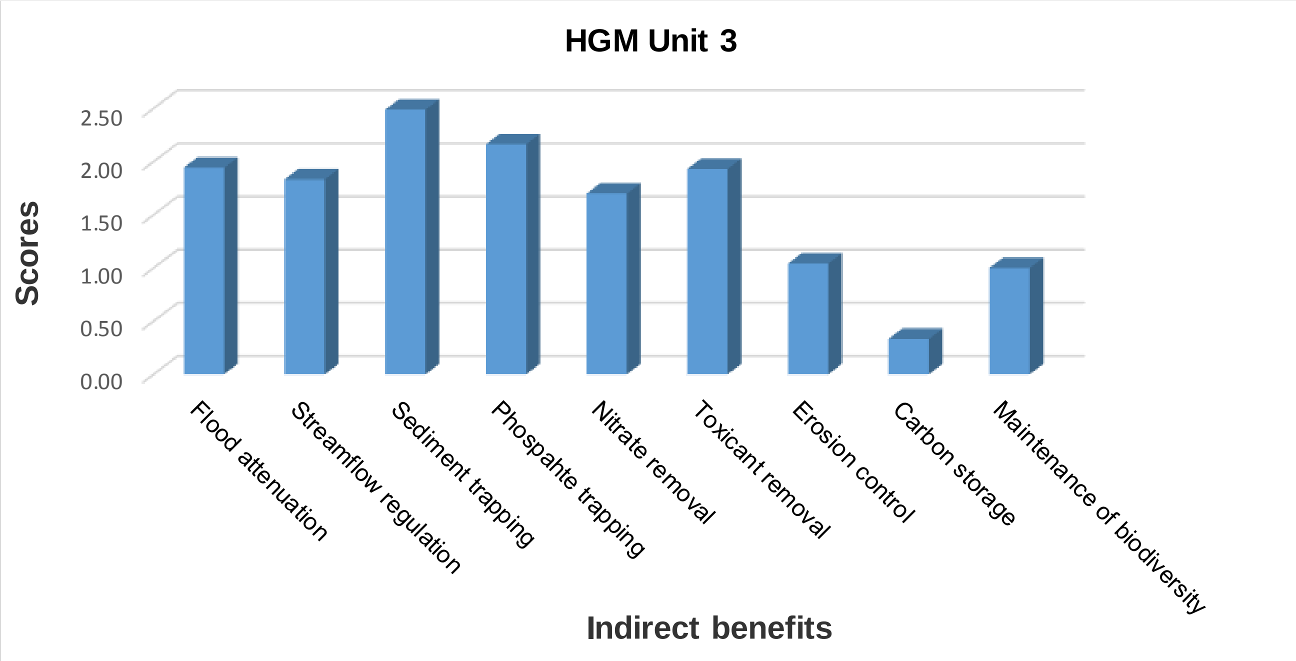


Figure 39: Indirect benefits for HGM Unit 2

5.3.4 HGM Unit 4

The PES results for HGM unit 4 is categorised as C with the score of 6.1 (Table 9). The hydrology component scored higher at 73.2 while geomorphology, vegetation and water quality scored 68.9, 63.2 and 88.3 respectively which are also categorised as C. This is an indication of a modified state which is characterised by changing natural habitat and loss of biota with limited functioning. Like other HGM units discussed in the previous sections, the impacts of a dominate land use (maize crops cultivation) is evident throughout the HGM unit. The MS Excel sheets for each module of the model with the weighting and ratings results are included in Appendix A.

Table 9. Present Ecological State of HGM Unit 4

HGM Unit	Hydrology	Geomorphology	Vegetation	Water quality	Overall score (PES)
Valley bottom with channel	73.2 (C)	68.9 (C)	63.2 (C)	88.3 (A/B)	69.1(C)

The highest direct ecosystem services being provided by the HGM unit 4 include cultivated foods with a score of 3.6 and natural resources with a score of 3.2 (Figure 40 and 41). The recreation and tourism service as well as research and education constitute the lowest ecosystem services being derived from this HGM unit with scores of 0.7 and 1.3 respectively. The HGM unit has actually been converted into a maize field which only grows herbaceous plants during winter season and this does not attract tourists. The HGM unit is also not located in any tourism route. There is no evidence of direct collection of water from the HGM unit and hence the lower score for this ecosystem service. The cultural significance ecosystem service was scored at 2.0.

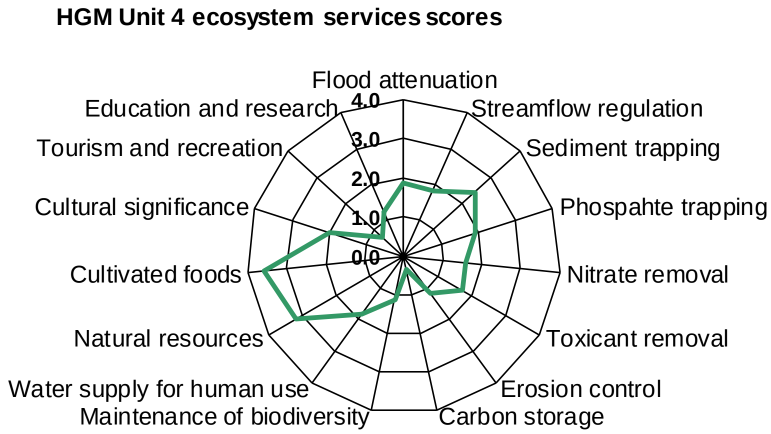


Figure 40: WET-Eco-Services assessment for the HGM Unit 4.

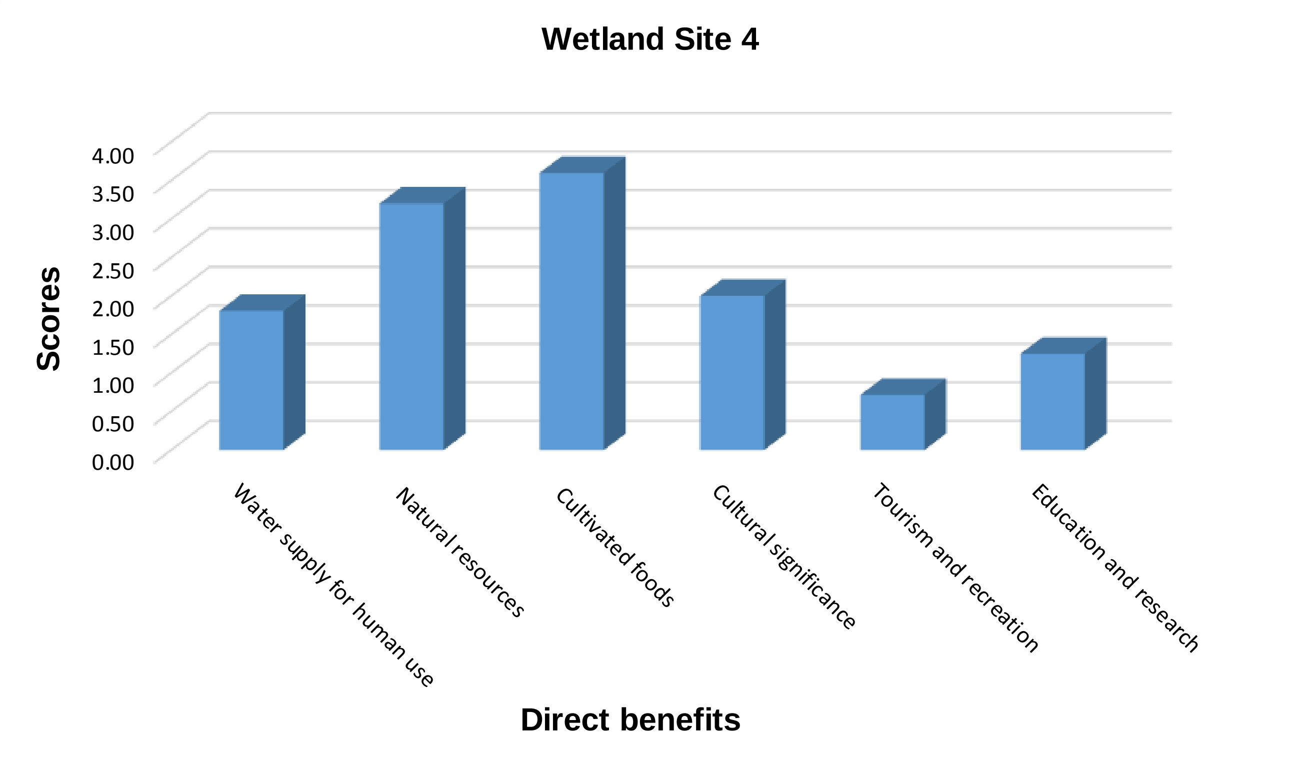


Figure 41: Direct benefits for HGM Unit 4

The HGM unit still functions with respect to sediment trapping due to its slope characteristic which is very low leading to stream flow regulation which supports sediments settlement. The conditions allow for flood water attenuation by regulating the velocity of surface flow. The scores for flood attenuation, stream flow regulation, sediment trapping, phosphate trapping, nitrate trapping and toxicant removal were 1.87, 1.83, 2.45, 1.90, 1.60 and 1.72 respectively, while the lowest ecosystem services including erosion control, carbon storage and maintenance of biodiversity scored 1.17, 0.33 and 1.13 respectively (Figure 42). Carbon storage service required a continuous deposition of organic matter under anaerobic conditions for the peat materials to form which is not occurring at HGM 4 since the area is constantly being cleared of vegetation and cultivated for maize cropping.

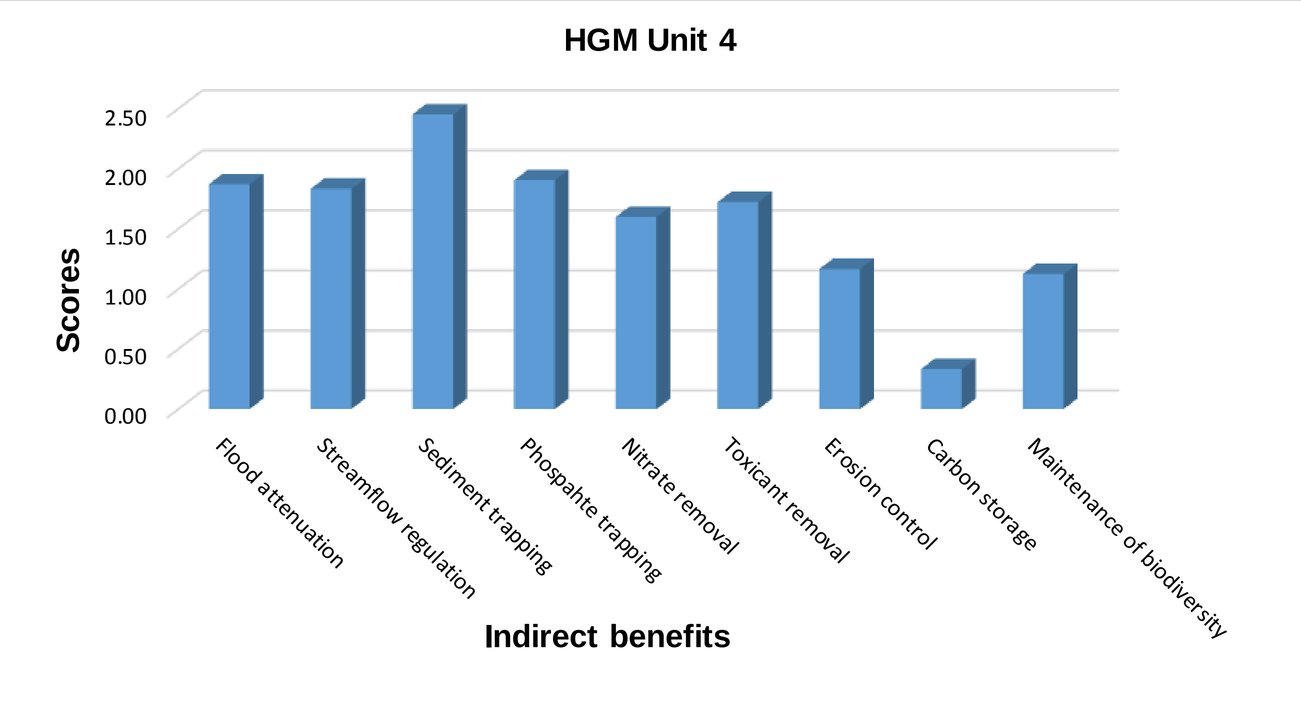


Figure 42: **Indirect benefits for HGM unit 4**

5.3.5 HGM Unit 5

As previously alluded to in Chapter 4, HGM unit 5 was assessed using Wet-Health since Wetland-IHI is not applicable in assessing unchannelled valley bottom wetland types. Although the Wet-Health is applicable on channelled valley bottom wetlands, a level 1 assessment is more of a desktop exercise which require very limited site verification which in turn affect the confidence level. A level 2 of Wet-Health was not favourable as it is time consuming and complex. The Wet-Health analysis has indicated that the PES of this HGM unit is categorised as C with the score of 3.3 from the total of 10. Although geomorphology has the highest score of 9.8, the overall PES with no increasing or decreasing trend, the influence of vegetation and hydrology is much greater resulting in the overall PES of 2.8 which is categorised as C. Of more concern is the decreasing trend of vegetation at a rate of -1 (Table 10). This result indicates that the wetland has lost the natural functioning as a result of significant change of natural biota and habitat. The MS Excel sheet of the model with the weighting and ratings results is included in Appendix B.

Table 10: Wet-Health results for HGM Unit 5.

HGM Unit	Ha	Extent (%)	Hydrology		Geomorphology		Vegetation		Present Ecological State
			Impac t Score	Change Score	Impact Score	Change Score	Impact Score	Change Score	
5	6.9	28	7.5	0	1.7	0	12.2	-1	C (2)
Area weighted impact scores*			2.1	0.0	0.5	0.0	3.4	-0.3	
PES Category			C	→	A	→	C	↓	

The direct ecosystem goods and services being derived from the HGM unit indicate that cultural significance, cultivated foods and supply of natural resources were the highest with scores of 2.8, 2.4 and 3.6 respectively (Figure 43 and 44). Tourism and recreation service was the lowest at 1.3. Water supply for human consumption as well as education and research were both scored at 1.5 each. The HGM unit is also not located in any known tourism route. Lwamondo clinic obtains its water for all the activities from the borehole drilled in the HGM unit. The clinic is also built within the wetland. There is evidence of harvesting of typha plants (sedges) in the permanent zone. The wetland is also subjected to annual maize crop planting during summer season particularly on seasonal and temporary zone.

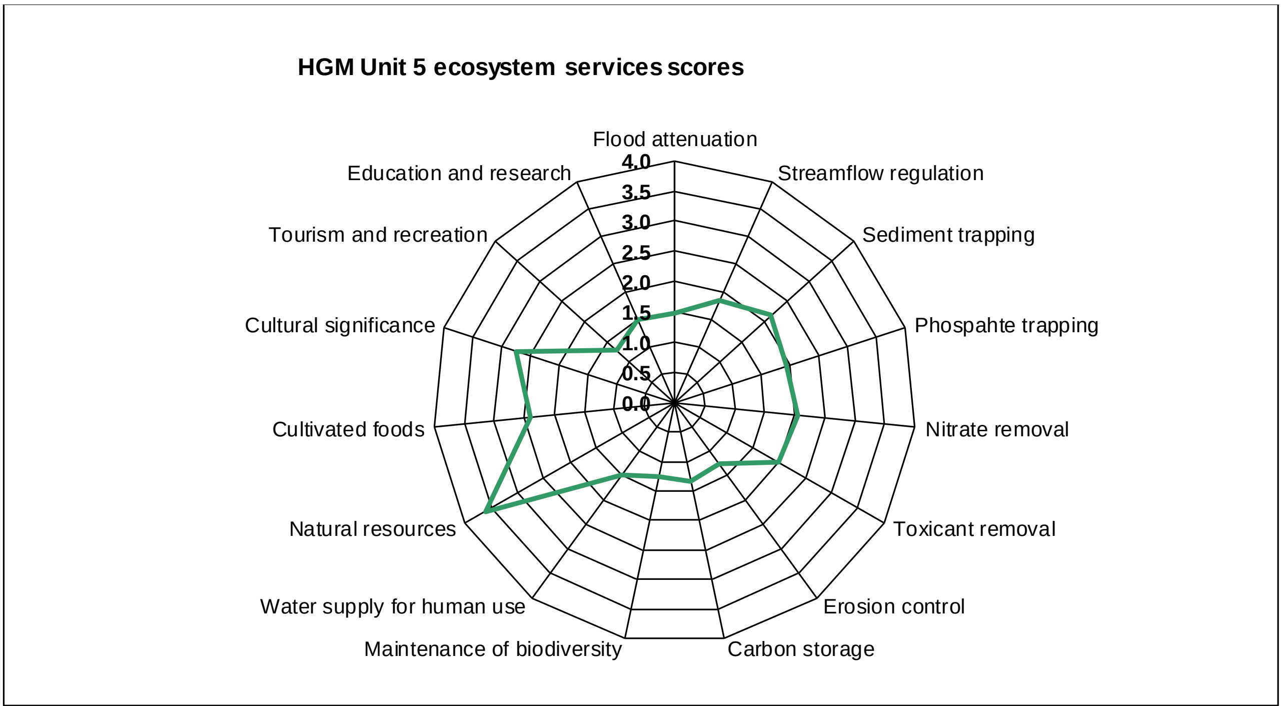


Figure 43: WET-Eco-Services assessment for the HGM unit 5.

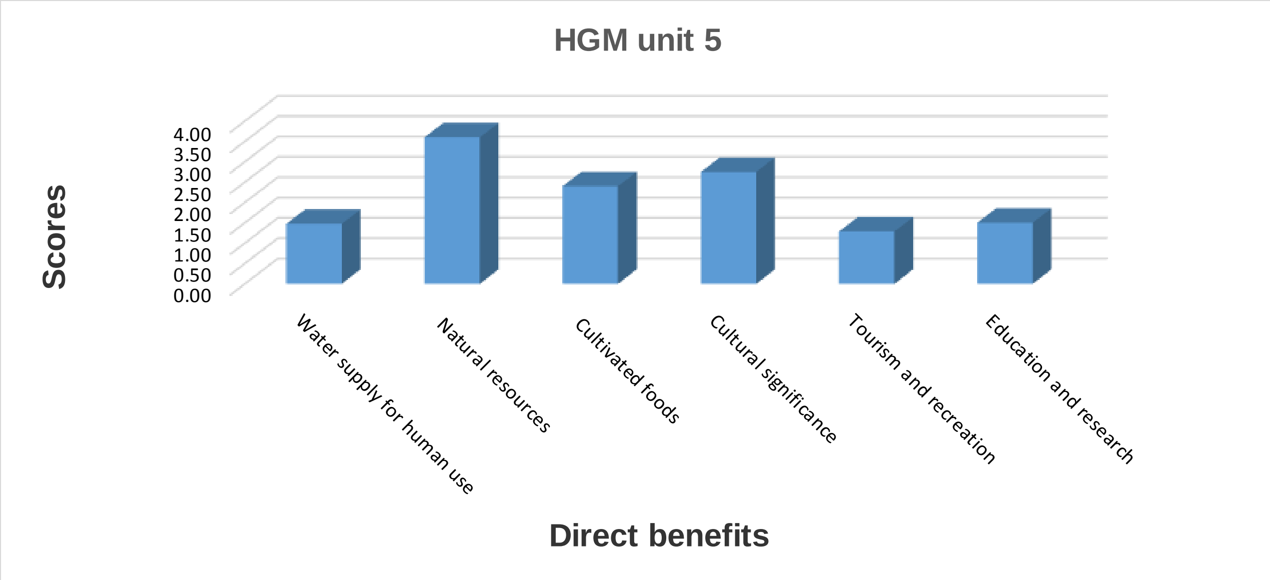


Figure 44: Direct benefits for HGM Unit 5.

The dominant indirect ecosystem services derived from this HGM unit include sediment trapping, nitrate removal, toxicant removal, phosphate trapping and streamflow regulation with scores of 2.14, 2.05, 2.00, 1.95 and 1.83 respectively. This unchannelled valley bottom type of HGM unit is unique in the sense that it supports a variety of plant species which attract birds (evidence of nesting identified) (Figure 45). This is the evidence that biodiversity maintenance is higher at this HGM although it is under pressure and hence it is experiencing negative change on the vegetation part which must be averted as soon as possible.

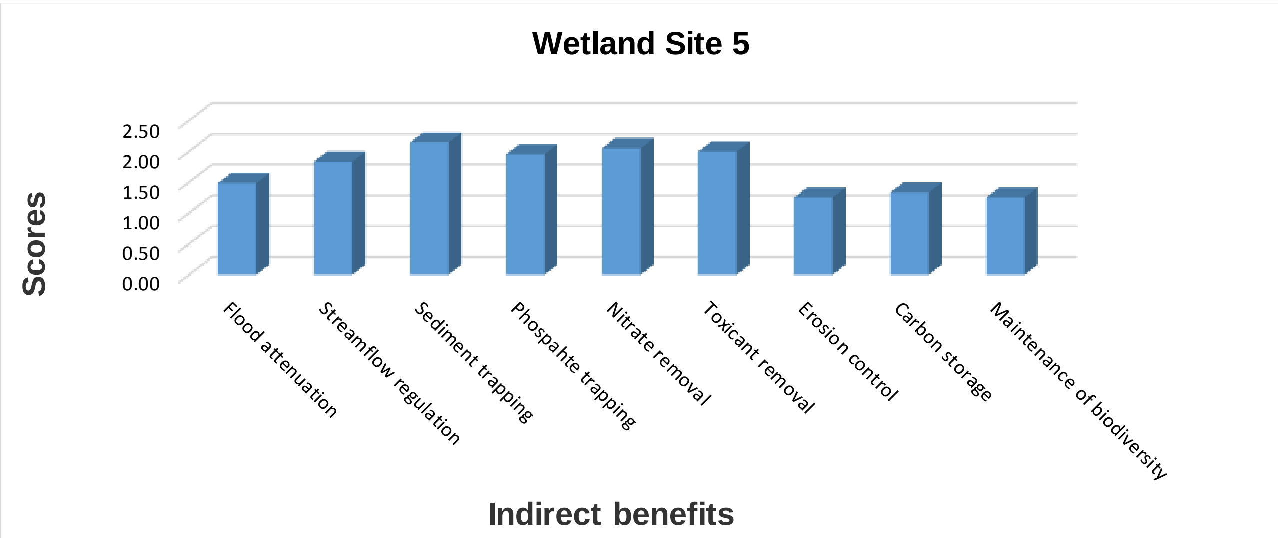


Figure 45: Indirect benefits for HGM Unit 5.

CHAPTER 6 : DISCUSSIONS

6.1 Wetland Types

Following the hydrogeomorphic approach of wetlands classification, the wetlands onsite were classified into two classes. Researchers agree that the classification system of wetlands that are guided by geomorphological and hydrological features are more vigorous and rigorous than those that rely on structural descriptors (Finlayson *et al*., 2002), since the two parameters serve as the key drivers for wetlands formation and functioning (Kotzé *et al*., 2008; Ellery *et al*., 2010). HGM Unit 1 through to 4 is classified as channelled valley bottom with the Dzindi River channel crossing through them.

In contrast with the flood plains, HGM units 1 to 4 receive their water inputs from the main river channel particularly during high flows. No evidence of groundwater seepage was noted in HGM units 1 through to 4. However, HGM unit 5 was classified as valley bottom without a distinct flowing river channel area of low relief situated on alluvial fill. Although the area has been highly disturbed by anthropogenic activities, this wetland has a clear permanent and seasonal zone. Since there is no defined river channel feeding the HGM unit, it may be assumed that the wetland is being recharged from rainfall and groundwater although the exact point of seepage could not be established onsite.

6.2 Ecological Integrity and Functioning

The PES analysis categorised all the HGM units as C which seems to be more conservative when one takes into account the impacts on the ground. Notwithstanding this, the very basic ecosystem functioning in HGM units 1 through to 4 still exists and is influenced by the gentle slope which reduces the flow velocities of water, thereby supporting the settlement of sediments and reducing soil erosion. No peat formations were identified as the HGM units are constantly under maize crop cultivation during summer seasons. The temporary and seasonal zones are completely disturbed in all the HGM units. Disturbances such as cultivation, livestock grazing, trampling of sensitive wetland area by livestock and presence of alien vegetation were accounted in determining the PES. The major drivers behind poor ecological status include deteriorating vegetation, geomorphology and hydrological conditions of the wetlands. The prevalence of alien invasive plants in all HGM units indicates that the conditions are changing and this may lead to complete disappearance of indigenous wetland plants. All four HGM units (1 – 4) are experiencing moderate change in natural habitat and loss of biota which is a matter of concern (Table 11). This is true particularly for temporary and seasonal zones of the HGM units which are completely transformed.

Table 11: Dzindi River HGM units PES

HGM Units	PES
Channelled Valley bottom (HGM unit 1)	C
Channelled Valley bottom (HGM unit 2)	C
Channelled Valley bottom (HGM unit 3)	C
Channelled Valley bottom (HGM unit 4)	C
Unchannelled Valley bottom (HGM unit 5)	C

6.3 Ecosystem Services

The Wet-EcoServices results for all HGM units indicate that the communities benefit greatly from these wetlands particularly for the growing of maize during seasons. These wetlands provide the best conditions for this purpose due to availability of fertile soils and moisture. Other direct benefits provided by these HGM units include water for human consumption, cultural significance and supply of natural resources. This is only applicable for HGM unit 5 whereby the Lwamondo clinic sources their water for all their activities at the clinic from the borehole located within this wetland. The groundwater level was not measured because the borehole is sealed with a submersible pump which switches on and off automatically at certain water levels in storage tanks. The indirect ecosystem benefits analysis however shows a different picture. Because of the imbalances brought about by maize plantations across all five HGM units, the communities are exposed to flood damage since the wetlands areas are left bear with no vegetation during winter season. Their crops are exposed to floods damage during summer season as a result of natural vegetation clearing. Soil under maize cropping is highly susceptible to water erosion (Brant *et al*., 2017). Maize crops have very shallow roots and given the fact that no conservation methods are applied, the crops are susceptible to floods damage. HGM unit 1 to 4 provide the lowest benefit for tourism (with less than 1 score) as well as biodiversity maintenance (with scores ranging between 1.0 and 1.3). Like the other four wetlands, HGM unit 5 provides the lowest tourism benefits though with a score of 1.3. HGM 5 scores are better than the other 4 indicating that although the wetland is subjected to cultivation for maize crops, some ecological functioning is still present.

The tourism and recreation services are lower in all the HGM units because there is nothing much appealing about these wetlands scenery because large portions of the wetlands have been cleared to give way to maize crops. As observed by Kotzé (2005), there is an intricate relationship between indigenous vegetation cover and the wetland health. This means that those wetlands characterised by larger vegetation removal or high invasion by alien plants have poor overall health (Kotzé, 2005). Clearing of wetland vegetation gives way to alien invasive plants which can quickly establish themselves and outcompete indigenous wetlands plants. Various alien invasive plants (*Eucalyptus grandis*, *Senna didymobotrya*, *Ricinus communis*, *Datura stramonium, Lantana camara*) *and* some exotic weeds (e.g.*Xanthium strumarium, Tagetes minuta and Solanum elaeagnifolium*) were identified at all the HGM units. All the computed PES are ranked in the category C.

6.4 Protection and Management Practices

The NFEPA maps are notoriously inaccurate in certain catchments whereby some wetlands are omitted or are mapped incorrectly. Numerous studies have shown that the FEPA maps are under representative of wetlands – especially in certain catchments. The Thulamela Municipality and Vhembe District Municipality do not have any wetland information, data or management systems in place for these wetlands. These wetlands are therefore left at the mercy of local communities to use without any form of guidance or management practices or guidelines. The suggested protection measures for these HGM unit starts with the efforts to build the knowledge base or a local inventory by the relevant authorities (Thulamela Local Municipality and Vhembe District Municipality). The management practices such as controlled use of Dzindi River wetlands can be best promoted through the traditional leaders (i.e. Village chief). Development and implementation of monitoring tool to track the changes on these systems could complement these initiatives.

CHAPTER 7 : CONCLUSION AND RECOMMENDATIONS

7.1 Conclusions

The study has successfllly managed to achieve a set of five objectives. With respect to the available Dzindi River wetlands data and protection measures, it was established that apart from the high level inaccurate NFEPA maps for the catchment, the local authorities do not have any form of data and information on Dzindi River wetlands assessed. The study also successfully established that four of the assessed wetlands were classified as channelled valley bottom type while the fifth one was classified as unchannelled valley bottom.

This study successfully applied the Wet-Health, Wetland-IHI and Wet-EcoServices tools in assessing the ecological status and functioning of five selected HGM units in the upper Dzindi catchment. The study revealed the dire situation facing the Dzindi HGM units which are in total collapse. The Dzindi River wetlands are subjected to an immense pressure as a result of unsustainable land uses along the river. Subsistence agriculture and livestock grazing within the temporary and seasonal zones has led to loss and transformation of biota and ecosystem conditions. Livestock grazing in the wetlands continuously impact on vegetation and soils. As the major source of water to these wetlands, the Dzindi River cannot be separated from these channelled valley bottom wetlands. In general, the river and its riparian zone are still in a fair state with vegetation cover and seasonal flooding delivering water into the wetlands during summers.

The tourism potential of these wetlands is currently not being realised. The underlying problem leading to this is because of vegetation that has been cleared. Bare wetlands with respect to vegetation cover are low in animal biodiversity meaning that ecological functioning is very low (Kotzé *et al*., 2008). Wetlands in this condition which is the case with all HGM units (1 to 5) cannot attract a variety of birds, arthropods, reptiles and insects species. High biodiversity determines the ecological functioning in wetlands which attract tourists and other users such as medicinal plants gatherers to the wetlands. This can provide means of growing the local economy and job creation for the local communities. While these wetlands are located in a moderately developed area, the upper catchment still presents opportunities to develop some tourism projects. The upper catchment forms part of the Thathe Vondo state forest and contains some scenic beauty and a waterfall along the Dzindi River. It may be necessary to assess the viability of this important ecosystem service against the current agricultural use to establish the need for a specific level of rehabilitation exercise. The fact that these wetlands do not appear in NFEPA wetlands layer is a serious concern. The Vhembe District Municipality and Thulamela Local Municipality also do not have any form of wetlands information system or a record of available wetlands and their conditions within their areas of jurisdiction. Although this is their constitutional obligation as, this function is not considered priority in the list of things they must deal with at the local level.

All five wetland systems (HGM unit 1-5) and the Dzindi River itself are linked to the livelihood of the communities along the Dzindi River. These wetland ecosystems and the river continue to provide natural resources and cultivation areas which is the source of income to a rural community. Their livestock graze in these wetlands during the dry season when they have not planted crops there. Maize is a staple food in the area and communities plant this crop every year in these wetlands. When wetlands are in a poor state with vegetation removed as is the case with all the wetlands assessed, the protection against threats posed by flooding diminishes as it was proven during 2010-2011 floods which damaged infrastructure in Maniini and surrounding villages along the Dzindi River (Musyoki *et al*., 2016). It was found that Maniini Village which is characterised by gentle slope had its wetlands and river banks deteriorated and in bad state giving rise to heavy flooding in December 2010 – January 2011, whereby a significant number of houses close to the flood lines were destroyed. The household survey showed that human activities such as cultivation on steep slopes (16%) and the clearing of vegetation (12%) had contributed to in floods, especially at Tshilungwi Village (Musyoki *et al*., 2016).

7.2 Recommendations

The Thulamela Municipality and Vhembe District Municipality must start to prioritise wetlands protection and management. Other municipalities, particularly metros such as Johannesburg invest a significant amount of budget to protect biodiversity and associated landscapes in their areas of jurisdiction (CoJ, 2018; City of Tshwane, 2018; City of Cape Town, 2018). The City of Johannesburg has developed what is known as a Bioregional Plan. In pursuit of protection of wetlands and open spaces of the city, the plan specifies the two categories of Biodiversity Priority Areas including Areas supporting certain types of ecosystems and Critical Biodiversity Areas (CBAs). These areas essentially constitute wetlands and aquatic ecosystems. According to this plan, CBAs should be protected to achieve certain targets with respect to species biodiversity, ecosystems and ecological conditions (CoJ, 2018). The Vhembe District Municipality and Thulamela Local Municipality can learn from this process and start working on the systems and policies towards managing and protecting their wetlands systems. Wetland management and protection must form part of the Integrated Development Planning (IDP) processes particularly under the protection of natural resources and economic development components. This must start right from the status quo analysis of the whole municipal area with respect of the existing level of development, priority issues and problems and their causes, followed by the formulation of strategies on how to address the existing problems including identification of specific projects. Specific projects must be developed on wetlands rehabilitation and management and must be included along with other projects when collating the document into an IDP. The required budgets for establishing and maintaining wetlands information systems, monitoring of these systems and promotion of economic activities on wetlands ecotourism must be prioritised at Vhembe District Municipality, Thulamela Local Municipality and traditional leadership levels.

Education and awareness should be rolled out by national government (DWS and DEA) together with SANBI to Vhembe District and Thulamela Municipality so that they can appreciate their roles with respect the catchment management and water resources management. The municipalities will then roll out the education and awareness to surrounding communities so that they can utilise the wetlands sustainably. It is necessary to establish the dedicated natural resources management units in the Thulamela local municipality to coordinate environmental protection activities and linking with the national government departments.

All the HGM units/wetlands assessed show evidence of alien plants invasive plants which are becoming a serious concern. The DEA through their Natural Resource Management programme should commission an intensive alien invasive plants control which is being rolled out in other parts of the country. Alien plants are impacting Dzindi River wetlands negatively, and this may get worse if not controlled as a matter of urgency. The advantage of this programme is that it coupled with wetland rehabilitation and brings about job creation while eradicating alien plants, restoring wetlands functioning and reduces poverty and at the same time making communities aware of unwanted alien plants and their devastating effects to water resources and wetlands.

Other key aspects that can improve this study include the detailed analysis of soils of these HGM units to determine the extent of excessive cultivation and tiling by communities. The detailed analysis which in most cases are time consuming include trenching to expose the soil profile, sampling and samples collection for laboratory analysis of reduction or oxidation. This would assist to determine the rehabilitation measures of these HGM units if any. A simple rehabilitation and management (Table 11 and 12) as well as the monitoring plan (Table 12) are proposed to assist in managing and maintaining HGM units 1 – 5 to curb the current problems.

7.2.1 Rehabilitation activities for HGM units 1 – 5.

To counter the impacts identified in this study and restore ecosystem functioning, the five HGM units need to be rehabilitated. The purpose of rehabilitation is to bring the wetlands closer to its original natural conditions. Healthy wetlands are characterised by high biodiversity which promote complex interaction among and between biota in the wetland ecosystem. These enable the wetlands to generate desired ecosystem services and goods to support the surrounding communities. Table 12 provides the suggested rehabilitation plan which defines initiatives that are urgently needed in each of the five HGM units.

Table 12: Rehabilitation activities for HGM units 1 – 5.

HGM unit	Rehabilitation activity	Who is responsible
HGM units 1 – 4	Filling of excavated area during bridge construction with soils from other areas	Limpopo Road Agency
	Planting of indigenous wetland plants	DEA working for water/ Local communities
	Stabilisation of areas showing evidence of soil erosion with gabions	DEA working for water, DWS and Thulamela/ Vhembe District municipality
	Filling in of gullies with soils from other areas	DEA working for water, DWS and Thulamela/ Vhembe District municipality
	Fencing off of the sensitive areas to keep grazers off the wetlands	DEA working for water, DWS and Thulamela/ Vhembe District municipality
	Building a bund around the wetland to avoid excessive sediments input	DEA working for water, DWS and Thulamela/ Vhembe District municipality
	Avoid cultivation within a 10 m buffer from the edge of temporary zone	Local community and traditional leadership?
	Training of community on conservation agriculture practices	DAFF, Thulamela/Vhembe Municipality
HGM unit 5	All of the above and the following:	
	Manage groundwater abstraction	Department of Health (Lwamondo clinic) and DWS

7.2.2 Management activities

Table 12 provide the suggested management plans which define management activities to be taken into consideration to avoid wetlands deteriorating further and also to support rehabilitation initiatives for all the five HGM units. The management activities must be guided by field data collected and the results from Wet-Health and Wetland IHI models which must be run biannually (Table 13).

Table 13: Management activities

HGM Unit	Management activity	Who is responsible
1 - 5	Avoid draining or channelising the natural drainage area	Local community and traditional leadership
	Manage or control harvesting of natural resources from the wetlands	Local community and traditional leadership
	Education of communities about the importance of wetlands	DEA, Thulamela/Vhembe Municipality
	Collect field data and run the Wet-Health and Wetland IHI models	DWS

7.2.3 Dzindi River Wetlands Monitoring Plan

Onsite monitoring of wetlands after rehabilitation is necessary. Wetland practitioners together with the traditional leadership will have to visit the wetlands and conduct assessments on a specific time frame as specified in Table 14. Specific data about the wetland will be recorded to track any form of recovery in each of the wetlands identified (Table 14). Interventions to address any specific issue identified during monitoring are implemented progressively.

Table 14: Monitoring programme for HGM units 1 – 5.

Monitoring activity	Monitoring period
Hydrology (flow distribution during dry and wet season in temporary, permanent and seasonal zones).	Seasonal
Soil and sediment build up (organic matter content, development of soil mottles, soil colour), baseline to be established through first field assessment.	Yearly
Vegetation (species composition, relative abundance) and removal of alien invasive plants.	Yearly in summer and Monthly for invasive plants.
Water quality (sources of pollution upstream of the wetland).	Quarterly
Monitor groundwater quality and levels at HGM unit 5.	Quarterly
Collect field data and run the Wet-Health and Wetland IHI models .	Yearly

A host of socioeconomic studies could improve the understanding and management of Dzindi River wetlands. This will assist government departments and other donor funding agencies to come on board and assist in this regard. The studies may include the following:

- The state of subsistence agriculturein the area
- Tourism activities
- Economic activities of the area
- Different social structures that exist within communities
- Institutional dynamics in the area
- Education status of the the communities and availability of schools and libraries
- Road networks, public transport
- Telecommunication networks

REFERENCES

Adekola, O. & Mitchell, G. (2011). The Niger Delta wetlands: threats to ecosystem services, their importance to dependent communities and possible management measures. Int. J. Biodivers. Journal of Science of Ecosystem Service Management 7, pp. 50 – 68.

Allan, J.D. (2004). Landscapes and riverscapes: the influence of land use on stream ecosystems. Annu Rev Ecol System 35, pp. 257 – 284.

Amis, M.A., Rouget, M., Balmford, A., Thuiller, W., Kleynhans, C.J., Day, J. and Nel, J. (2007). Predicting freshwater habitat integrity using land-use surrogates. Water SA 33, pp. 215–222.

An, S., Li, H., Guan, B., Zhou, C., Wang, Z., Deng, Z., Zhi, Y., Liu, Y., Xu, C., Fang, S., Jiang, J. and Li, H. (2007). China's Natural Wetlands: Past Problems, Current Status, and Future Challenges, AMBIO, Journal of the Human Environment 36, No. 4, pp. 335 – 342.

Behna, K., Beckera, M., Burghof, S., Möselera, B.M., Willy, D.K. and Alvareza, M. (2018). Using vegetation attributes to rapidly assess degradation of East African Wetlands, Journal of Ecological Indicators 89, pp. 250 – 259.

Belle, J.A., Collins, N. and Jordaan, A. (2018). 'Managing wetlands for disaster risk reduction: A case study of the eastern Free State, South Africa', Jàmbá: Journal of Disaster Risk Studies 10, No. 1, pp. 1 – 10.

Beuela, S, Alvarez, M., Amler, E., Behn, K., Kotzé, D., Kreye, C., Leemhuis, C., Wagner, K., Willy, D.K., Ziegler, S. and Becker, M. (2016). A rapid assessment of anthropogenic disturbances in East African wetlands. Ecological Indicators 67, pp. 684 – 692.

Brandl, G. (1999). Soutpansberg Group. Catalogue of South African Lithostratigraphic Units. SA Committee for Stratigraphy, Council Geoscience, Pretoria, South Africa, pp. 6-39 – 6-4.1

Brant, V., Kroulík, M., Pivec, J., Zábranský P., Hakl, J., Holec J., Kvíz, Z. and Procházka, L. (2017). Splash Erosion in Maize Crops under Conservation Management in Combination with Shallow Strip-tillage before Sowing. Soil & Water Res., 12, 2, pp. 106–116.

Brinson, M.M. (1993). A hydrogeomorphic classification for wetlands. Technical Report WRP-DE-4, US Army Engineer Waterways Experiment Station, Vicksburg, USA.

Brown, C., Joubert, A., Tlou, T., Birkhead, A., Marneweck, G., Paxton, B. and Singh, A. (2018). The Pongola Floodplain, South Africa – Part 2: Holistic environmental flows assessment. Water SA 44, 4, pp. 746 – 759.

City of Cape Town. (2018). Integrated Development with proposed amendments (2018/19). Cape Town, South Africa.

City of Johannesburg. (2018). 2017/18 Integrated Development Plan (IDP): Review. Johannesburg, South Africa.

City of Tshwane. (2018). 2018/19 Draft review of the 2017/21 Integrated Development Plan, Version 3: Draft , Pretoria, South Africa.

Conservation of Agricultural Resources Act (Act No. 43 of 1983), Gazette 8673, 27 April 1983. Pretoria, South Africa.

Constitution of the Republic of South Africa (Act 108 of 1996), South Africa, Pretoria.

Cowardin, L.M., Carter, V., Golet, F.C. and LaRoe, E.T. (1979). Classification of Wetlands and Deepwater Habitats of the United States. U.S. Department of the Interior Fish and Wildlife Service Office of Biological Services Washington, D.C.

Dada, R., Kotzé, D.C., Ellery, W.N., and Uys, M. (2007). WET-Road Map. A guide to the Wetland Management series. Wetland Management Series. Water Research Commission Report TT 321/07, Pretoria, South Africa.

Dahlberg, A. C. and Burlando, C. (2009). Addressing trade-offs: experiences from conservation and development initiatives in the Mkuze wetlands, South Africa. Ecology and Society 14, No. 2, pp. 1 – 12.

Daryadel, E. and Talaei, F. (2014). Analytical Study on Threats to Wetland Ecosystems and their Solutions in the Framework of the Ramsar Convention, International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering 8, No. 7, pp. 2100 – 2110.

Davidson, N. C., & Finlayson, C. M. (2007). Earth observation for wetland inventory, assessment and monitoring. Aquatic Conservation, 17 No. 3, pp. 219 – 229.

Davidson, N.C. (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. Mar. Freshwater Res. 65, No. 10, pp. 934 – 941.

Department of Water Affairs and Forestry. (1999). Resource Directed Measures for Protection of Water Resources. Volume 4: Wetland Ecosystems Version 1.0, Pretoria, South Africa.

Department of Water Affairs and Forestry. (2007). Manual for the assessment of a wetland index of habitat integrity for South African floodplain and channelled valley bottom wetland types. Edited by Rountree, M., Todd, C.P., Kleynhans, C.J., Batchelor, A.L., Louw, M.D., Kotzé, D., Walters, D., Schroeder, S., Illgner, P., Uys, M. and Marneweck, G.C. Report Number. N/0000/00/WEI/0407. Resources Quality Services, Pretoria, South Africa.

Department of Water Affairs (2013). National Water Resource Strategy, second edition., Pretoria, South Africa.

Department of Water and Sanitation. (2018). The National Water Master Plan, Volume 1: Call for Action. Pretoria, South Africa.

De Roeck, E.R., Verhoest, E.C., Miya, M.H., Lievens, H., Batelaan, O., Thomas, A. and Brendonck, L. (2008). Remote Sensing and Wetland Ecology: a South African Case Study. Sensors 8, pp. 3542 – 3556.

Dinar A. and Encarna, E. (2016). The role of groundwater-dependent ecosystems in groundwater management. Natural resource modelling 29, No. 1, pp. 98 – 130.

Dini, J.A. and Cowan, G.I. (2000). Proposed classification system for the South African National Wetland Inventory. Wetlands Conservation Program, Department of Environmental Affairs and Tourism, Pretoria, South Africa.

Dini, J. and Everard, M. (2017). 'National Wetland Policy: South Africa'. In Finlayson, C.M., Milton, G.R., Prentice, R.C. and Davidson, R.C. (Ed.), The Wetland Book I: Structure and Function, Management, and Methods (pp. 691 – 698). Springer Science+Business Media B.V, Netherlands.

Dixon, M.J.R., Lohb, J., Davidson, N.C., Beltrame, C., Freeman, R. and Walpole M. (2016). Tracking global change in ecosystem area: The Wetland Extent Trends index. Journal of Biological Conservation 193, pp. 27 – 35.

Downard, R. and Endter-Wada, J. (2013). Keeping wetlands wet in the western United States: Adaptation to drought in agriculture-dominated human-natural systems. Journal of Environmental Management 131. pp. 394 – 406.

Driver, A., Maze, K., Rouget, M., Lombard, A.T, Nel, J., Turpie, J.K., Cowling, R.M., Desmet, P, Goodaaan, R, Harris, J., Jonas, Z., Reyers, B., Sink, K. and Strauss, T. (2005). National Spatial Biodiversity Assessment 2004: priorities for biodiversity conservation in South Africa. Strelitzia 17. South African National Biodiversity Institute, Pretoria.

Driver, A., Sink, K.J., Nel, J.L., Holness, S., Van Niekerk, L., Daniels, F., Jonas, Z., Majiedt, P.A., Harris, L. and Maze, K. (2012). National Biodiversity Assessment 2011: an assessment of South Africa's biodiversity and ecosystems. Synthesis Report. South African National Biodiversity Institute and Department of Environmental Affairs, Pretoria.

Dubeau, P, King, D.J. Unbushe, D.G. and Rebelo, L. (2017). Mapping the Dabus Wetlands, Ethiopia, Using Random Forest Classification of Landsat, PALSAR and Topographic Data. Remote Sens 9, No. 1056, pp. 1 – 23.

Eamus, D and Froend, R. (2006). Groundwater-dependent ecosystems: the where, what and why of GDEs. Australian Journal of Botany 54, pp. 91 – 96.

Edokpayi, J.N., Odiyo, J.O. and Olasoji, S.O. (2014). Assessment of Heavy Metal contamination of Dzindi River, in Limpopo Province, South Africa. International Journal of Natural Sciences Research 2, No. 10, pp. 185 – 194.

Ellery, W., Grenfell, S., Grenfell, M., Jaganath, C., Malan, H. and Kotzé, D. (2010). A method for assessing cumulative impacts on wetland functions at the catchment or landscape scale, Water Research Commission, Report No. TT 437/09, South Africa.

Ewart-Smith, J.L., Ollis, D.J., Day, J.A. and Malan, H.L. (2006). National Wetland Inventory: Development of Wetland Classification System for South Africa, Water Research Commission and South African National Biodiversity Institute (SANBI), Report No. KV 174/06.Finlayson, C.M. & van der Valk, A.G. (1995). Wetland classification and inventory: A summary. Vegetation 118, pp. 185 - 192.

Finlayson, CM and van der Valk, AG 1995, Classification and Inventory of the World's Wetlands. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Finlayson C.M. and Rea, N. (1999). Reasons for the loss and degradation of Australian wetlands. Wetlands Ecology and Management 7, pp. 1 – 11.

Finlayson C.M., Begg, G.W., Howes, J., Davies, J., Tagi, K. and Lowry, J. (2002). A manual for an inventory of Asian wetlands: Version 1.0. Ramsar Wetlands International Global Series 10, Kuala Lumpur, Malaysia.

Finlayson, M., Bellio, M.G. and Lowry, J.B. (2005). A conceptual basis for the wise use of wetlands in northern Australia – linking information needs, integrated analyses, drivers of change and human well-being. Marine and Freshwater Research 56, pp. 269 – 277.

Fu, B., Pollino, C.A., Cuddy, S.M. and Andrews, F. (2015). Assessing climate change impacts on wetlands in a flow regulated catchment: A case study in the Macquarie Marshes, Australia. Journal of Environmental Management 157, pp. 127 – 138.

Grundling, A.T., van den Berg, E.C. and Price, J.S. (2013). Assessing the distribution of wetlands over wet and dry periods and land-use change on the Maputaland Coastal Plain, north-eastern KwaZulu-Natal, South Africa. South African Journal of Geomatics 2, No. 2, pp. 120 – 139.

Guidugli-Cook, M., Richter, S.C., Scott, B.J. and Brown, D.R. (2017). Lang and McCarty remote sensing data for regional wetland mapping in the united states: trends and future prospects. *Wetlands: Ecology, Conservation and Restoration*, R.E. Russo (ed.), Nova Science Publishers, Inc. New York. pp. 74–112.

Gumbo, J.R., Ratshilumela, A.D., and Nethengwe, N.S. (2016) Impact on Water Quality of Nandoni Water Reservoir Downstream of Municipal Sewage Plants in Vhembe District, South Africa. Sustainability 8, No. 597, pp. 1 – 16.

Guo, M., Li, J., Sheng, C., Xu, J. and Wu, L. (2017). A Review of Wetland Remote Sensing. Sensors 17, No. 777, pp. 1 – 36.

Houlahan, J.E., Keddy, P.A., Makkay, K. & Findlay C.S. (2006). The effects of adjacent land use on wetland species richness and community composition. Wetlands 26, No. 1, pp. 79 – 96.

Hu, T., Liu, J., Zheng, G., Li, Y. and Xie, B. (2018). Quantitative assessment of urban wetland dynamics using high spatial resolution satellite imagery between 2000 and 2013. Scientific Reports 8, No. 7409, pp. 1 – 10.

International Water Management Institute (IWMI). (2014). Wetlands and people. Colombo, Sri Lanka.

IUSS Working Group WRB. (2015). World Reference Base for Soil Resources 2014 update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.

Jeppesen, E., Søndergaard, M. and Liu, Z. (2017). Lake Restoration and Management in a Climate Change Perspective: An Introduction. Water 9, No, 2, pp. 122.

Job, N., Mbona, N., Dayaram, A. and Kotze, D. (2018). Guidelines for mapping wetlands in South Africa. SANBI Biodiversity Series 28, South African National Biodiversity Institute, Pretoria, South Africa.

Jogo, W. and Hassan, R. (2010). Balancing the use of wetlands for economic well-being and ecological security: The case of the Limpopo wetland in southern Africa. Journal of Ecological Economics 69, pp. 1569 – 1579.

Jones, M.G.W. (2002). Developing a classification system for Western Cape wetlands. Master's dissertation, University of Cape Town, South Africa

Junk, W.J., An., S, Finlayson, C. M., Gopal B, Kveˇt J Mitchell, S.A., Mitsch, W.J. and Robarts, R. D. (2012). Current state of knowledge regarding the world's wetlands and their future under global climate change: a synthesis. Journal of Aquatic Science 75, pp. 151 – 167.

Kashian, D.R. and Burton, T.M. (2000). A Comparison of Macroinvertebrates of Two Great Lakes Coastal Wetlands: Testing Potential Metrics for an Index of Ecological Integrity. Journal of Great Lakes Research 26, No. 4, pp. 460 – 481.

Kimmel, K., Kull, A., Salm. J.O. and Mander Ü. (2010). The status, conservation and sustainable use of Estonian wetlands. Journal of Wetland, Ecology and Management. 18, pp. 375 – 395.

Kleynhans, C.J. and Louw, M.D. (2007). Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. Report No. TT 329/08, Pretoria, South Africa.

Kotzé, D.C. (2004). An assessment of freshwater wetlands for the 2004 KwaZulu-Natal State of the Environment Report. KwaZulu-Natal State of the Environment Report, Pietermaritzburg, South Africa.

Kotzé, D.C. (2005). An ecological assessment of the health of the Mohlapetsi wetland, Limpopo Province. Centre for Environment, Agriculture and Development, University of KwaZulu-Natal, South Africa.

Kotzé, D.C., Marneweck, G.C., Batchelor, A.L., Lindley, D.S. and Collins, N.B. (2008). Wet-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands, Water Research Commission, Report No. TT 339/09, Pretoria, South Africa.

Kotzé, D., Malan, H., Ellery, W., Samuels, I. and Saul, L. (2010). Assessment of the environmental condition, ecosystem service provision and sustainability of use of two wetlands in the Kamiesberg uplands. Water Research Commission, Report No. TT 439/09, Pretoria, South Africa.

Kotzé, D.C. and Treynor, C.H. (2011). Wetland Plant Species Used for Craft Production in Kwazulu–Natal, South Africa: Ethno-botanical Knowledge and Environmental Sustainability, Journal of Economic Botany, 65, No. 3, pp. 271 – 282.

Kotzé, D.C., Ellery, W.N., Macfarlane, D.M. and Jewitt, G.P.W. (2012). A rapid assessment method for coupling anthropogenic stressors and wetland ecological condition. Ecological Indicators 13, pp. 284 – 293.

Lankford, B., Pringle, C., Dickens, C., Lewis, F., Mander, M., Chhotray, V., Goulden, M., Nxele, Z. and Quayle, L. (2011). Hydrological modelling of water allocation, ecosystem services and poverty alleviation in the Pongola floodplain, South Africa, Journal of Environmental Planning and Management, 54, No. 9, pp. 1237 – 1260.

Lannas, K.S.M. and Turpie, J.K. (2009). Valuing the Provisioning Services of Wetlands: Contrasting a Rural Wetland in Lesotho with a Peri-Urban Wetland in South Africa. Ecology and Society 14, No. 2, pp. 1 – 19.

Lou, Y., Pan, Y., Gao, C., Jiang, M., Lu, X. and Xu, Y.J. (2016). Response of Plant Height, Species Richness and Aboveground Biomass to Flooding Gradient along Vegetation Zones in Floodplain Wetlands, Northeast China. PLoS ONE 11, No. 4, pp. 1 – 16.

Macfarlane, D.M., Kotze D.C., Ellery, W.N., Walters, D., Koopman, V., Goodman, P. and Goge, C. (2007). WET-Health: A technique for rapidly assessing wetland health. Water Research Commission Report No. TT 340/08, Pretoria, South Africa.

Macfarlane, D.M., Kotze, D.C., Ellery, W.N., Walters, D. Koopman, V., Goodman, P. and Goge, C. (2008). WET-Health: A technique for rapidly assessing wetland health. Water Research Commission Report No. TT 340/09, Pretoria, South Africa.

Macfarlane, D.M. and Bredin, I.P. (2017). Buffer Zone Guidelines for Rivers, Wetlands and Estuaries, Part 1: Technical Manual, Water Research Commission WRC Report No. TT 715/1/17, Pretoria, South Africa.

Malekmohammadi, B. and Jahanishakib, F. (2017). Vulnerability assessment of wetland landscape ecosystem services using driver-pressure-state-impact-response (DPSIR) model. Journal of Ecological Indicators 82, pp. 293 – 303.

Mantel, S.K., Hughes, D.A. and Muller, N.W.J. (2010). Ecological impacts of small dams on South African rivers: part 1 Drivers of change–water quantity and quality. Water SA 36 No. 3, pp. 351 – 360.

Marambanyika, T., Beckedahl, H., Ngetar, N.S. and Dube, T. (2017). Assessing the environmental sustainability of cultivation systems in wetlands using the WET-health framework in Zimbabwe. Phys. Geogr. 38, pp. 62 – 82.

Matenga, L. (2019). Placing Climate Change in Wetland Conservation and Urban Agriculture Contestations in Harare, Zimbabwe. In Cobbinah, P. B. and Addaney, M. (eds.). The Geography of Climate Change Adaptation in Urban Africa. University of the Witwatersrand, South Africa.

Mavunda, T.I. (2006). Potability of Spring Water at Mapate Village. (Unpublished Honours Dissertation), University of Venda, Thohoyandou, South Africa.

Merot, P., Hubert-Moy, L., Gascuel-Odoux, C., Clement, B., Durand, P., Baudry, J. & Thenail, C. (2006). Environmental assessment: A Method for Improving the Management of Controversial Wetland, Environmental Management Vol. 37, No. 2: 258–270.

McCarthy, T.S., Tooth, S., Jacobs, Z., Rowberry, M.D., Thompson, M., Brandt, D., Hancox, P.J., Marren, P.H., Woodborne, S. and Ellery, W.N. (2011). The origin and development of the Nile River floodplain wetland: trunk-tributary river interactions in a dryland setting. South African Geographical Journal 93, pp. 172 – 190.

McCarthy M.J, Radabaugh K.R, Moyer R.P. and Muller-Karger F.E. (2018). Enabling efficient, large-scale high-spatial resolution wetland mapping using satellites, Science Direct Remote Sensing of Environment 208, pp. 189 – 201.

McCartney, M., Rebelo, L.M., Senaratna Sellamuttu, S. and de Silva, S. (2010). Wetlands and agriculture and poverty reduction. IWMI Research Report 137, Colombo, Sri Lanka.

McCartney, M., Morardet, S., Rebelo, L., Finlayson, C.M. and Masiyandima, M. (2011). Kotze's study of wetland hydrology and ecosystem service provision: GaMampa wetland, South Africa, Hydrological Sciences Journal 56, No. 8, pp. 1452 – 1466.

McInnes, R.J. (2014). The Ramsar Convention and SWS–delivering wetland conservation at a global level. Wetland Science in Practice. 31, No. 4, pp. 12 – 16.

McInnes, R.J. and Everard, M. (2017). Rapid Assessment of Wetland Ecosystem Services (RAWES): An example from Colombo, Sri Lanka, Journal of Ecosystem Services 25, pp. 89 – 105.

Millennium Ecosystem Assessment, (2005). Ecosystems and human well-being: wetlands and water. World Resources Institute, Washington, DC.

Miller, S.J., Wardrop, D.H., Mahaney, W.M. and Brooks, R.P. (2006). A plant-based index of biological integrity (IBI) for headwater wetlands in central Pennsylvania. Ecological Indicators 6, No. 2, pp. 290 – 312.

Min, J.-H., Perkins D.B. and Jawitz, J.W. (2010). Wetland-Groundwater Interactions in Subtropical Depressional Wetlands. Wetlands 30, pp. 997 – 1006.

Mostert THC. (2006). Vegetation ecology of the Soutpansberg and Blouberg Area in the Limpopo Province. Unpublished PhD report, University of Pretoria, Pretoria, South Africa.

Mucina, L., and Rutherford, M.C. (Eds.), 2006. The Vegetation of South Africa, Lesotho and Swaziland. Strelitzia, 19. South African National Biodiversity Institute, Pretoria, South Africa.

Münch, Z. and Conrad, J. (2007). Remote sensing and GIS based determination of groundwater dependent ecosystems in the Western Cape, South Africa. Hydrogeology Journal 15, 19 – 28.

Musyoki, A., Thifhufhelwi, R. and Murungweni, F.M. (2016). The impact of and responses to flooding in Thulamela Municipality, Limpopo Province, South Africa, Jàmbá: Journal of Disaster Risk Studies 8, No. 2, pp. 1 - 10.

Mzezewa, J., Misi, T. and van Rensburg, L. D. (2010). Characterisation of rainfall at a semi-arid ecotope in the Limpopo Province (South Africa) and its implications for sustainable crop production. Water SA 36 No. 1, pp. 165 – 172.

Rivers-Moore, N.A. and Cowden, C. (2012). Lindenmayer, Hobbs and Montague-Drake's checklist for ecological management of landscapes for conservation. Ecol. Lett. 11, pp. 78 – 91.

South Africa. (1998). National Forests Act 84 of 1998. Gazette 19408, 30 October 1998, Pretoria, South Africa.

South Africa. (1998). National Environmental Management Act 107 of 1998. Gazette 19519, 27 November 1998, Pretoria, South Africa.

South Africa. (2004). National Environmental Management: Biodiversity Act 10 of 2004. Gazette 26436, 7 June 2004, Pretoria, South Africa.

South Africa. (1998). National Water Act 36 of 1998. Gazette 19182, 26 August 1998, Pretoria, South Africa.

Nasongo, S.A.A., Zaal, F., Dietz, T. and Okeyo-Owuor, J.B. (2015). Institutional pluralism, access and use of wetlands resource in the Nyando Papyrus wetlands, Kenya. Journal of Ecology and the Natural Environment 7, No. 3, pp. 56 – 71.

Nel, J.L., Murray, K.M., Maherry, A.M., Petersen, C.P., Roux, D.J., Driver, A., Hill, L., van Deventer, H., Funke, N., Swartz, E.R., Smith-Adao, L.B., Mbona, N., Downsborough, L. and Nienaber, S. (2011). Technical Report for the National Freshwater Ecosystem Priority Areas project, Water Research Commission Report No. 1801/2/11. Pretoria, South Africa.

Nel, J.L. and Driver, A. (2012). National Biodiversity Assessment 2011: Technical Report, Volume 2, Freshwater Component, Report Number CSIR/ECO/IR/2012/0022/A, Council for Scientific and Industrial Research, Stellenbosch, South Africa.

Nhamo, L., Magidi, J. and Dickens, C. (2017). Determining wetland spatial extent and seasonal variations of the inundated area using multispectral remote sensing. Water SA 43 (4).

NLC2000 Management Committee. (2008). South African National Land-Cover 2000 Database Project, Raster Map, Pretoria, CSIR Environmental / Agricultural Research Council Institute for Soil, Climate and Water, Pretoria, South Africa.

Ollis, D.J. (2013). A common language for describing inland aquatic ecosystems in South Africa. The Water Wheel July/August, Water Research Commission, Pretoria, South Africa.

Ollis, D., Snaddon, K., Job, N. and Mbona, N. (2013). Classification system for wetlands and other aquatic ecosystems in South Africa. User Manual: Inland Systems. SANBI Biodiversity series 22, Pretoria, South Africa.

Ollis, D.J. and Malan, H.L. (2014). Development of Decision-support Tools for Assessment of Wetland Present Ecological Status (PES), Volume 1: Review of available methods for the assessment of the ecological condition of wetlands in South Africa. Water Research Commission Report No. TT 608/14, Pretoria, South Africa.

Ollis, D.J., Day, J.A., Malan, H.L., Ewart-Smith, J.L. and Job, N.M. (2014). Development of Decision-Support Tools for Assessment of Wetland Present Ecological Status (PES):

Development of a decision-support framework for wetland assessment in South Africa and a decision-support protocol for the rapid assessment of wetland ecological condition, Volume 2. Water Research Commission Report No. TT 609/14, Pretoria, South Africa.

Ollis, D.J., Ewart-Smith, J.L., Day, J.A., Job, N.M., Macfarlane, D.M., Snaddon, C.D., Sieben, E.J.J., Dini, J.A. and Mbona, N. (2015). The development of a classification system for inland aquatic ecosystems in South Africa. Water SA 41, No. 5, pp. 727 – 745.

Palmer, M.A., Liermann, C.A.R., Nilsson, C., Florke, M., Alcamo, J., Lake, P.S. and Bond, N. (2008). Climate change and the world's river basins: Anticipating management options. Journal of Ecology and Environment 6, pp. 81 – 89.

Palmer, M.A., Liermann, C.A.R., Nilsson, C., Florke, M., Alcamo, J., Lake, P.S. & Bond, N. (2008). Climate change and the world's river basins: Anticipating management options. Front. Journal of Ecology and Environment. 6: 81-89.

Pantaleo, K.T., Munishi, N.N., Nshare, W.J.S. Moe, S.R., Shirima, D.D. and Kilungu, H.H. (2011). Valley Bottom Wetlands Can Serve for Both Biodiversity Conservation and Local Livelihoods Improvements. In Grillo, O and Venora, G. (Eds.), Ecosystems Biodiversity (pp. 219 – 232. InTech, Shanghai, China.

Post-Harvest Innovation (PHI) programme. (2017). Horticultural development plan for the Thulamela Local Municipality, Appendix E: Environmental Analysis. Optimal Agricultural Business Systems, Cape Town, South Africa.

Ramsar Convention (2012). Report of the Secretary General on the implementation of the Convention at the global level. Ramsar COP11 DOC. 7. Bucharest, Romania.

Ramsar Fact Sheet (2014). http://www.ramsar.org/sites/default/files/ramsar_factsheets_1-4, accessed on 26 May 2018.

Raphalalani, A., Ekosse, G., Odiyo, J., Ogola, J. and Bukalo, N. (2019). Trace Element and Stable Isotope Geochemistry of Lwamondo and Zebediela Kaolins, Limpopo Province, South Africa: Implication for Paleo-environmental Reconstruction. Minerals 9, No. 93, pp. 1 – 19.

Rebelo, L.-M., Finlayson, C.M. and Nagabhatla, N. (2009). Remote sensing and GIS for wetland inventory, mapping and change analysis. Journal of Environmental Management 90, pp. 2144 – 2153.

Rebelo, L.M., McCartney, M.P. and Finlayson, C.M. (2010). Wetlands of Sub-Saharan Africa: distribution and contribution of agriculture to livelihoods. Journal of Wetlands Ecological Management 18, pp. 557 – 572.

Rebelo, A.J., Morris, C., Meirea, P. and Esler, K.J. (2019). Ecosystem services provided by South African palmiet wetlands: A case for investment in strategic water source areas. Ecological Indicators 101, pp. 71–80.

Riddell, E.S., Everson, C., Clulow, A. and Mengistu, M. (2013). The hydrological characterisation and water budget of a South African rehabilitated headwater wetland system, Water SA 39, No.1, pp. 57 – 66.

Roberts, D. (2008). Thinking globally, acting locally – institutionalizing climate change at the local government level in Durban, South Africa. Environment and urbanisation, 20, No. 2, pp. 521 – 537.

SANBI (South African National Biodiversity Institute). (2011). National wetland inventory. SANBI Freshwater Programme. http://bgis.sanbi.org/nwi/map.asp accessed on 26 May 2018.

Sandham, L.A., Moloto, M.J. and Retief, F.P. (2008). The quality of environmental impact reports for projects with the potential of affecting wetlands in South Africa. Journal of Water SA 34 No. 2, pp. 155 – 162.

Serran, J.N. and Creed, I.F. (2016). New mapping techniques to estimate the preferential loss of small wetlands on prairie landscapes. Hydrol. Process. 30, pp. 396 – 409.

Sieben, E. J. J., Ellery, W.N., Kotze D.C. and Rountree M. (2011). Hierarchical spatial organization and prioritization of wetlands: A conceptual model for wetland rehabilitation in South Africa. Wetlands Ecology and Management 19, No. 3, pp. 209 – 222.

Sieben, E.J.J., Mtshali, H. and Janks, M. (2014). National wetland vegetation database: Classification and analysis of wetland vegetation types for conservation planning and monitoring. Water Research Commission Report No. 1980/1/14, Pretoria, South Africa.

Sieben, E.J.J., Collins, N.B., Kotze, D.C., Mofutsanyana, S.S. and Janks, M. (2017). Temperate grassy wetlands of South Africa: Description, classification and explanatory environmental factors. South African Journal of Botany 113, pp. 68 - 76.

Sims, A., Zhang, Y., Gajaraj, S., Brown, P.B. and Hua, Z. (2013). Toward the development of microbial indicators for wetland assessment. Water Research 47, pp. 1711 – 1725.

Smith, R.D, Ammann A., Bartoldas, C. and Brinson, M.M. (1995). An approach for assessing wetlands functions using hydrogeomorphic classification, reference wetlands and functional indices. Wetlands Research Program technical report, US Army Corps of Engineers.

STATS SA. (2011). Census 2011. Statistics South Africa, Pretoria, South Africa.

STATS SA (2016). The 2016 Community Surveys. Statistics South Africa, Pretoria, South Africa.

Tatu K.S. and Anderson J.T. (2017). An Introduction to Wetland Science and South Asian Wetlands. In: Prusty B., Chandra R., Azeez P. (eds.) Wetland Science. Springer, New Delhi, pp. 3 – 30.

Thulamela Local Municipality. (2018). Final Integrated Development Plan (IDP) for financial year 2018/2019. Thohoyandou, Limpopo Province.

Tiner, R.W. (2003). Geographically isolated wetlands of the United States, Wetlands 23 pp. 494 – 516.

Turpie, J.K., O’Connor, T., Mills, A. and Robertson, H. (2007). The ecological and economic consequences of changing land use in the southern Drakensberg grasslands. South Afr. S. Afr. J. Econ. Manag. Sci. 10, pp. 423–441.

Turpie, J.K., Marais, C. and Blignaut, J.N. (2008). The working for water programme: Evolution of a payments for ecosystem services mechanism that addresses both poverty and ecosystem service delivery in South Africa. Journal of Ecological Economics 65, pp. 788 – 798.

van Deventer, H., Smith-Adao, L., Petersen, C., Mbona, N., Skowno, A. and Nel, J.L. (2018). Review of available data for a South African Inventory of Inland Aquatic Ecosystems (SAIIAE). Water SA 44 No. 2, pp. 184 – 199.

Warburton, M.L., Schulze, R.E. and Graham Jewitt, P.W. (2012). Hydrological impacts of land use change in three diverse South African catchments, Journal of Hydrology 414–415, pp. 118 – 135.

Weitjers, M.J., Janse, J.H., Alkemade, R.and Verhoeven, J.T.A. (2009). Quantifying the effect of catchment and use and water nutrient concentrations on freshwater river and stream biodiversity. Aquatic Conservation: Marine Freshwater Ecosystem 19, pp. 104 – 112.

White, L., Brisco, B., Dabboor, M., Schmitt, A. and Pratt, A. (2015). A Collection of SAR Methodologies for Monitoring Wetlands. Remote Sens. 7, pp. 7615 – 7645.

Wilkinson, M., Mulders, J., Mitchell, S., Malia, D. and Danga, L. (2016). The Design of a National Wetland Monitoring Programme Implementation Manual Volume 2, Water Research Commission Report No. 2269/2/16, Pretoria, South Africa, South Africa.

WRC. (2001). State of Rivers Report: Letaba and Luvuvhu river systems. Water Research Commission Report No. TT 165/01, Water Research Commission, Pretoria, South Africa.

Zedler, J.B. and Kercher, S. (2005). Wetland Resources: Status, Trends, Ecosystem Services, and Restorability. Annu. Rev. Environ. Resources. 30, pp. 39 – 74.

Zhanga, B., Shia, Y., Liuc, J., Xu, J. and Xie, G. (2017). Economic values and dominant providers of key ecosystem services of wetlands in Beijing, China, Journal of Ecological Indicators 77, pp. 48 – 58.

APPENDICES: WET-HEALTH AND WETLAND-IHI DATA

Appendix B: Wetland- IHI – HGM Units 1 – 4 data

HGM Unit 1 data.

Site name:	Dzindi River_Downstream Pine Plantations
Location (GPS co-ordinates):	22 59'53.60"S 30 22'08.69"E
1:50 000 topo map reference:	
EcoRegion:	Savannah
Geology (if available):	basaltic rock
Recorder:	
Date:	09/08/2018

To use this model: fill in the shaded cells as follows:

LIGHT YELLOW CELLS*: these formula are fixed and can not be altered by the user*

BLUE CELLS *show recommended values for this component, but these can be altered by experts or when confidence for the new value is high.*

WHITE CELLS: *Date inputs, or notes and comments, are required in here.*

Notes and/or Sketch of the site

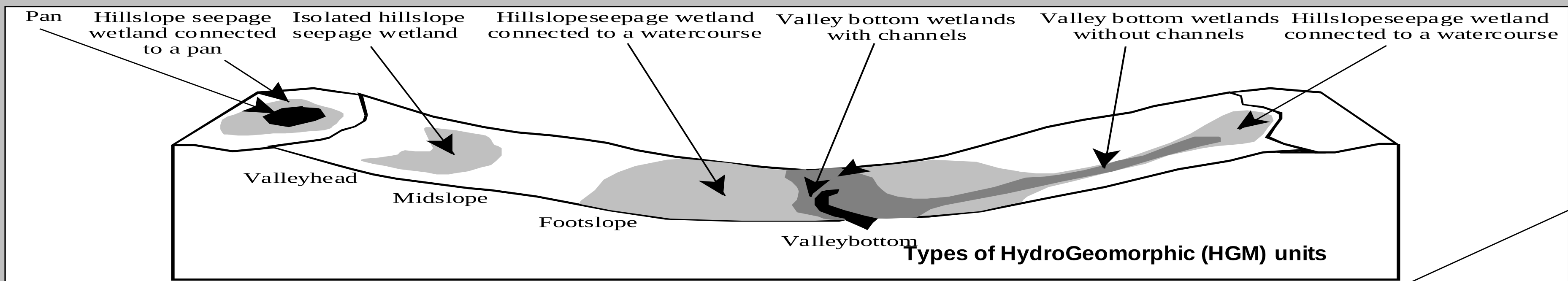
WETLAND CLASSIFICATION				
Level I	**Level II**			**Level III**
System	**EcoRegion**	**Dominant Geology**	**Landscape Position/ Setting**	**HydroGeomorphic Unit**
INLAND	Savannah	basaltic rock	Valley Bottom	River
				Lake
				Unchannelled Valley Bottom
				Channelled Valley Bottom
				Meandering Floodplain
			Slopes	Seepage (isolated)
				Seepage (connected)
			Crest	Seepage (connected)
				Pan

This model (WETLAND-IHI) is designed for the RAPID assessment of floodplain and channeled valley bottom wetland types, for the purposes of determining the PES.

PES (Present Ecological State) is an indication of the current ecological state of the wetland, relative to its Reference (natural) State - i.e. the deviation from the historic/pre-development condition of the wetland.

Type of wetland system:	**Channelled Valley Bottom**
Confidence in the assessment (1-5)	**3**

This current model is only designed for floodplains and channeled valley bottoms.



Types of HydroGeomorphic (HGM) units

VEGETATION ALTERATION - the impacts of landuse activities *within* the wetland on the vegetation of the wetland

Estimate the impact **RATING** (0-5) and aerial **EXTENT** (0-100 %) of the various landuse activities on the wetland system

Landuse Activities on the wetland	Ranking	Weighting	Rating (0-5)	Extent (0-100%)	Impact Score	Weighted Impact Score	*Confidence Rating (1-5)*	*Notes (describe the details of impacts here)*
Mining/Excavation	1	***100***	0	0	0	0	**3**	
Infilling/Backfilling	2	***70***	1	10	0.1	0.07	**2**	
Vegetation Clearing/Loss/Alteration	3	***60***	3	50	1.5	0.9	**3**	
Weeds or Invasive plants	4	***50***	2	30	0.6	0.3	**3**	
Percentage in Reference State	6	0	0	10	0	0	**2**	
VEGETATION ALTERATION SCORE				100		**1.27**	***Confidence:***	
					PES %:	**74.6**	***2.8***	
					PES Category:	**C**		

Total Extent must always be 100%!!! If there is a site with two types of impact in the same location; score according to the larger impact weighting.

Reference State: this is what the site would have looked like without the landuse activities and without the on-site and catchment hydrology, geomorphology and water quality alterations/impacts which have occurred.

Description of the Reference State:

HYDROLOGY

	Ranking	Weighting	Weighted Rating	Confidence Rating (1-5)
Catchment	1	100	1.5	3.0
Within-wetland Effects	2	60	1.3	2.9
TOTAL HYDROLOGY PES		160	1.4	Confidence:
		PES %:	71.8	3.0
		PES Category:	C	

If the weighted value of the "within-wetland effects" exceeds 3.5, then a threshold value is exceeded and this affects the overall PES score. This is to ensure that where wetlands are highly degraded due to on-site impacts, the resultant scores are not masked by good catchment conditions

Catchment Effects	Ranking	Weighting (0-100%)	Rating	Confidence Rating (1-5)	Impact Score	Weighted Impact Score	Notes
Changes in flood peaks/frequencies	1	100	1.0	3	1	0.4	
Changes in base flows	2	60	-2.0	3	1.2	0.5	
Changes in seasonality	2	60	2.0	3	1.2	0.5	
Zero flows	3	10	0.0	3	0	0.0	
Sub-total		230		3.0		1.5	

Within-wetland Effects	Rating	Extent (0-100%)	Impact Score	Confidence Rating (1-5)	Notes
Connectivity - altered channel size/competency	2.0	40	0.8	3	
Increased water retention on the floodplain	0.0	0	0	3	
Decreased water retention on the floodplain	1.0	50	0.5	3	
Reference State conditions	0.0	10	0	2	
Sub-total		100	1.3	2.9	

Total Extent must always be 100%!!! If there is a site with two types of impact in the same location; score according to the larger impact rating.

Assessing Catchment Effects

Changes in flood peaks	
INCREASE? Is there catchment hardening (urbanisation) in the catchment?	no change
DECREASE? Are there many small dams, or a very large dam, upstream of the wetland?	none
Changes in base flow	
INCREASE: are there any interbasin transfers, or releases of elevated flows to cater for irrigation?	no change
DECREASE: is there extensive abstraction for irrigation, or extensively afforested areas, upstream of the wetland?	small decrease

GEOMORPHOLOGY

Importance of catchment vs on-site effects	Ranking	Weighting (0-100%)	Weighted Score	*Confidence Rating (1-5)*
Catchment	1	***100***	0.0	*3.0*
Within-wetland Effects	2	80	1.7	*3.0*
TOTAL GOMORPHOLOGY PES		180	**0.7**	***Confidence:***
		PES %:	**85.2**	***3.0***
		PES Category:	**B**	

If the weighted value of the "within-wetland effects" exceeds 3.5, then a threshold value is exceeded and this affects the overall PES score. This is to ensure that where wetlands are highly degraded due to on-site impacts, the resultant scores are not masked by good catchment conditions

Catchment effects	Ranking	Weighting (0-100%)	Rating	*Confidence Rating (1-5)*	Impact Score	***Notes***
Change in **SEDIMENT BUDGET** (calculate below)	1	100	**0.0**	**3**	0.0	
					0.0	

Within-wetland Effects	Ranking	Weighting (0-100%)	Rating (0-5)	*Confidence Rating (1-5)*	Impact Score	Weighted Impact Score
Erosional features	1	***100***	2.0	**3**	2	1.3
Depositional features	2	***50***	1.0	**3**	0.5	0.3
Sub-total		150		3.0		***1.7***

SEDIMENT BUDGET

If you don't know the answer, leave the cell blank

Increases in sediment supply	***Change?***	**Increase in sediment transport capacity**	***Change?***
Can you see evidence of extensive active erosion in the catchment?	small increase	Have flood peaks increased due to catchment hardening?	no change
Is there active bank erosion of the channel in the wetland?	no change	Has an interbasin transfer scheme increased the erosive capacity of the flow?	no change
Are there many dirt roads in the catchment, and/or are the hillslopes under cultivation?	few	Have releases from upstream dams *increased* the erosive capacity of the flow? (e.g. sustained high flow releases below very large dams)	no change
Have any upstream dams or weirs been breached, causing an increase in sediment supply?	no change	Has the capacity of the channel been increased by, for example, levee construction along the channel edges, or channel deepening/widening and/or straightening?	small increase
Has the vegetation cover of the catchment decreased for any reason?	moderate decrease		
Decreases in sediment supply		**Decrease in sediment transport capacity**	
Is sediment being trapped by dams or weirs upstream of the wetland?	no change	Has the frequency and/or size of floods been reduced by an upstream dam?	no change
If there are upstream dams, are there any major tributary confluences between the dam and the wetland system that could introduce replace some sediment?	none	Has there been a decrease in flow due to diversions from the upstream channel?	small decrease
Are there weirs or causeways or other obstructions across the channel, upstream of the wetland, which would trpa sediment?	few		
Has there been sediment mining in any areas?	none		
Has there been an increase in the catchment vegetation cover?	small increase		
Given the above, to what extent do you think the sediment supply to the wetland has changed? (-10 to +10)	1	**Given the above, to what extent do you think the transport capacity in the wetland has changed? (-10 to +10)**	-2
Adjusted sediment supply index	**0.3**	**Adjusted transport capacity index**	**-0.7**
Use the table below to assess the change in sediment budget (0-5) :			**0**

Notes

		CONSIDER THE IMPACT OF THESE ACTIVITIES ON WATER QUALITY:																		
		Modified flow conditions	Inundation: Weirs	Inundation: Dams	Effluent: Urban areas	Effluent: Cultivation (agricultural activities; return flows)	Effluent: Industries	Effluent: Mining	Instream plants (macrophytes) & algae (incl. blue-green)	Forestry	Roads & crossings	Invasive riparian vegetation	Riparian vegetation removal	Bed disturbance: Bull dozing, sand mining, etc.	Bank disturbance: vegetation removal, artificial covering.	Solid waste disposal (rubbish disposal)	AVERAGE	MEDIAN	MODE	RATING (use avg, median or mode)
Water Quality Components	pH	X	X	X						0.5	X		X	X	X	X	0.5	0.5	#N/A	0.5
	Salts					0.5			X	X	X	X	X	X	X	X	0.5	0.5	#N/A	0.5
	Nutrients					1.0				X	X	X		X	X	X	1.0	1.0	#N/A	1.0
	Water Temp.					X				X	X			X	X	X	#DIV/0!	#NUM!	#N/A	
	Turbidity					1.5				0.5	0.5	0.5				X	0.8	0.5	0.5	0.5
	Oxygen									X	X	X	X	X	X		#DIV/0!	#NUM!	#N/A	
	Toxics	X	X	X						X		X	X	X	X		#DIV/0!	#NUM!	#N/A	

		RATING	Weighting	Confidence (1-5)
Water Quality	pH	0.5	100	2
	Salts	0.5	70	2
	Nutrients	1.0	50	2
	Water Temp.	0.0	10	2
	Turbidity	0.5	10	3
	Oxygen	0.0	10	2
	Toxics	0.0	50	2

Water Quality: overall scores			
Rating:	0.5	*Confidence:*	*2.0*
Percentage:	90.7		
PES Category:	A/B		

Notes

HGM Unit 2 data

Site name:	HGM Unit 2_ Confluence Dzindi and Lupanganamadzi
Location (GPS co-ordinates):	22 58'57.16"S 30 20'14.79"E
1:50 000 topo map reference:	
EcoRegion:	Savannah
Geology (if available):	basaltic rock
Recorder:	T.I Neswiswi
Date:	09/08/2018

To use this model: fill in the shaded cells as follows:
***LIGHT YELLOW CELLS** : these formula are fixed and can not be altered by the user*
***BLUE CELLS** show recommended values for this component, but these can be altered by experts or when confidence for the new value is high.*
***WHITE CELLS:** Date inputs, or notes and comments, are required in here.*

Notes and/or Sketch of the site

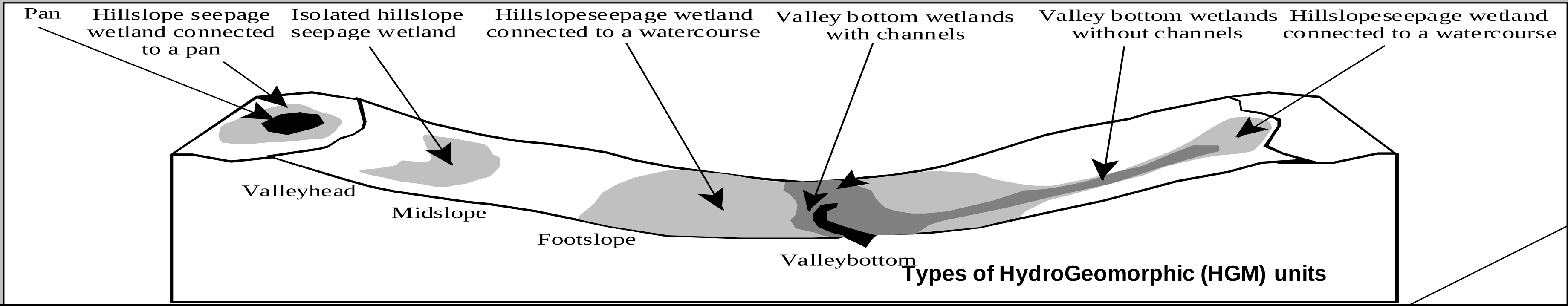
WETLAND CLASSIFICATION				
Level I	Level II			Level III
System	EcoRegion	Dominant Geology	Landscape Position/ Setting	HydroGeomorphic Unit
INLAND	Savannah	basaltic rock	Valley Bottom	River
				Lake
				Unchannelled Valley Bottom
				Channelled Valley Bottom
				Meandering Floodplain
			Slopes	Seepage (isolated)
				Seepage (connected)
			Crest	Seepage (connected)
				Pan

This model (WETLAND-IHI) is designed for the RAPID assessment of floodplain and channeled valley bottom wetland types, for the purposes of determining the PES.

PES (Present Ecological State) is an indication of the current ecological state of the wetland, relative to its Reference (natural) State - i.e. the deviation from the historic/pre-development condition of the wetland.

Type of wetland system:	**Channelled Valley Bottom**
Confidence in the assessment (1-5)	**3**

This current model is only designed for floodplains and channeled valley bottoms.



Types of HydroGeomorphic (HGM) units

VEGETATION ALTERATION - the impacts of landuse activities *within* the wetland on the vegetation of the wetland

Estimate the impact **RATING** (0-5) and aerial **EXTENT** (0-100 %) of the various landuse activities on the wetland system

Landuse Activities on the wetland	Ranking	Weighting	Rating (0-5)	Extent (0-100%)	Impact Score	Weighted Impact Score	*Confidence Rating (1-5)*	***Notes (describe the details of impacts here)***
Mining/Excavation	1	***100***	0	0	0	0	**3**	
Infilling/Backfilling	2	***70***	1	10	0.1	0.07	**2**	
Vegetation Clearing/Loss/Alteration	3	***60***	4	60	2.4	1.44	**3**	
Weeds or Invasive plants	4	***50***	3	30	0.9	0.45	**3**	
Percentage in Reference State	6	0	0	0	0	0		
VEGETATION ALTERATION SCORE				100		**1.96**	***Confidence:***	
					PES %:	**60.8**	***2.9***	
					PES Category:	**C/D**		

Total Extent must always be 100%!!! If there is a site with two types of impact in the same location; score according to the larger impact weighting.

Reference State: this is what the site would have looked like without the landuse activities and without the on-site and catchment hydrology, geomorphology and water quality alterations/impacts which have occurred.

Description of the Reference State:

HYDROLOGY				
	Ranking	Weighting	Weighted Rating	*Confidence Rating (1-5)*
Catchment	1	100	1.7	*3.0*
Within-wetland Effects	2	70	1.6	*2.8*
TOTAL HYDROLOGY PES		170	**1.6**	***Confidence:***
		PES %:	**67.4**	***2.9***
		PES Category:	**C**	

If the weighted value of the "within-wetland effects" exceeds 3.5, then a threshold value is exceeded and this affects the overall PES score. This is to ensure that where wetlands are highly degraded due to on-site impacts, the resultant scores are not masked by good catchment conditions

Catchment Effects	Ranking	Weighting (0-100%)	Rating	*Confidence Rating (1-5)*	Impact Score	Weighted Impact Score	*Notes*
Changes in flood peaks/frequencies	1	***100***	2.0	**3**	2	0.9	
Changes in base flows	2	***60***	1.0	**3**	0.6	0.3	
Changes in seasonality	2	***60***	2.0	**3**	1.2	0.5	
Zero flows	3	10	0.0	**2**	0	0.0	
Sub-total		230		***3.0***		***1.7***	

Within-wetland Effects	Rating	Extent (0-100%)	Impact Score	*Confidence Rating (1-5)*	*Notes*
Connectivity - altered channel size/competency	2.0	30	0.6	**3**	
Increased water retention on the floodplain	0.0	0	0	**3**	
Decreased water retention on the floodplain	2.0	50	1	**3**	
Reference State conditions	0.0	20	0	**2**	
Sub-total		100	**1.6**	***2.8***	

Total Extent must always be 100%!!! If there is a site with two types of impact in the same location; score according to the larger impact rating.

Assessing Catchment Effects

Changes in flood peaks	
INCREASE? Is there catchment hardening (urbanisation) in the catchment?	no change
DECREASE? Are there many small dams, or a very large dam, upstream of the wetland?	none
Changes in base flow	
INCREASE: are there any interbasin transfers, or releases of elevated flows to cater for irrigation?	no change
DECREASE: is there extensive abstraction for irrigation, or extensively afforested areas, upstream of the wetland?	no change

GEOMORPHOLOGY

Importance of catchment vs on-site effects	Ranking	Weighting (0-100%)	Weighted Score	*Confidence Rating (1-5)*
Catchment	1	***100***	0.0	*2.0*
Within-wetland Effects	2	80	1.7	*2.7*
TOTAL GOMORPHOLOGY PES		180	**0.7**	***Confidence:***
		PES %:	**85.2**	***2.3***
		PES Category:	**B**	

If the weighted value of the "within-wetland effects" exceeds 3.5, then a threshold value is exceeded and this affects the overall PES score. This is to ensure that where wetlands are highly degraded due to on-site impacts, the resultant scores are not masked by good catchment conditions

Catchment effects	Ranking	Weighting (0-100%)	Rating	*Confidence Rating (1-5)*	Impact Score	***Notes***
Change in **SEDIMENT BUDGET** (calculate below)	1	100	**0.0**	**2**	0.0	
					0.0	

Within-wetland Effects	Ranking	Weighting (0-100%)	Rating (0-5)	*Confidence Rating (1-5)*	Impact Score	Weighted Impact Score
Erosional features	1	***100***	2.0	**3**	2	1.3
Depositional features	2	***50***	1.0	**2**	0.5	0.3
Sub-total		150		2.7		***1.7***

SEDIMENT BUDGET

If you don't know the answer, leave the cell blank

Increases in sediment supply	***Change?***	**Increase in sediment transport capacity**	***Change?***
Can you see evidence of extensive active erosion in the catchment?	small increase	Have flood peaks increased due to catchment hardening?	no change
Is there active bank erosion of the channel in the wetland?	no change	Has an interbasin transfer scheme increased the erosive capacity of the flow?	no change
Are there many dirt roads in the catchment, and/or are the hillslopes under cultivation?	few	Have releases from upstream dams *increased* the erosive capacity of the flow? (e.g. sustained high flow releases below very large dams)	no change
Have any upstream dams or weirs been breached, causing an increase in sediment supply?	no change	Has the capacity of the channel been increased by, for example, levee construction along the channel edges, or channel deepening/widening and/or straightening?	no change
Has the vegetation cover of the catchment decreased for any reason?	moderate decrease		
Decreases in sediment supply		**Decrease in sediment transport capacity**	
Is sediment being trapped by dams or weirs upstream of the wetland?	no change	Has the frequency and/or size of floods been reduced by an upstream dam?	no change
If there are upstream dams, are there any major tributary confluences between the dam and the wetland system that could introduce replace some sediment?	none	Has there been a decrease in flow due to diversions from the upstream channel?	small decrease
Are there weirs or causeways or other obstructions across the channel, upstream of the wetland, which would trpa sediment?	few		
Has there been sediment mining in any areas?	none		
Has there been an increase in the catchment vegetation cover?	no change		
Given the above, to what extent do you think the sediment supply to the wetland has changed? (-10 to +10)	2	**Given the above, to what extent do you think the transport capacity in the wetland has changed? (-10 to +10)**	-1
Adjusted sediment supply index	0.7	**Adjusted transport capacity index**	-0.3

Use the table below to assess the change in sediment budget (0-5) : **0**

Notes

Water Quality Components	CONSIDER THE IMPACT OF THESE ACTIVITIES ON WATER QUALITY: Modified flow conditions	Inundation: Weirs	Inundation: Dams	Effluent: Urban areas	Effluent: Cultivation (agricultura activities; return flows)	Effluent: Industries	Effluent: Mining	Instream plants (macrophytes) & algae (incl. blue-green)	Forestry	Roads & crossings	Invasive riparian vegetation	Riparian vegetation removal	Bed disturbance: Bull dozing, sand mining, etc.	Bank disturbance: vegetation removal, artificial covering.	Solid waste disposal (rubbish disposal)	AVERAGE	MEDIAN	MODE	RATING (use avg, median or mode)
pH	X	X	X		0.5					X	0.5	X	X	X	X	0.5	0.5	0.5	0.5
Salts								X	X	X	X	X	X	X	X	#DIV/0!	#NUM!	#N/A	
Nutrients					1.0				X	X	X		X	X	X	1.0	1.0	#N/A	0.5
Water Temp.					X				X	X			X	X	X	#DIV/0!	#NUM!	#N/A	
Turbidity					0.5					0.5					X	0.5	0.5	0.5	1.0
Oxygen		0.5							X	X	X	X	X	X		0.5	0.5	#N/A	0.5
Toxics	X	X	X		0.5				X		X	X	X	X		0.5	0.5	#N/A	0.5

Water Quality	RATING	Weighting	Confidence (1-5)
pH	0.5	100	2
Salts	0.0	70	2
Nutrients	0.5	50	3
Water Temp.	0.0	10	2
Turbidity	1.0	10	3
Oxygen	0.5	10	2
Toxics	0.5	50	2

Water Quality: overall scores

Rating:	**0.4**	***Confidence:***	***2.2***
Percentage:	**92.3**		
PES Category:	**A**		

Notes

HGM Unit 3 data

Site name:	HGM Unit 3_ Below Mapate bridge
Location (GPS co-ordinates):	22 59'25.81"S 30 21'11.12"E
1:50 000 topo map reference:	
EcoRegion:	Savannah
Geology (if available):	basaltic rock
Recorder:	TI Neswiswi
Date:	09/08/2018

To use this model: fill in the shaded cells as follows:

LIGHT YELLOW CELLS *: these formula are fixed and can not be altered by the user*

BLUE CELLS *show recommended values for this component, but these can be altered by experts or when confidence for the new value is high.*

WHITE CELLS: *Date inputs, or notes and comments, are required in here.*

Notes and/or Sketch of the site

WETLAND CLASSIFICATION

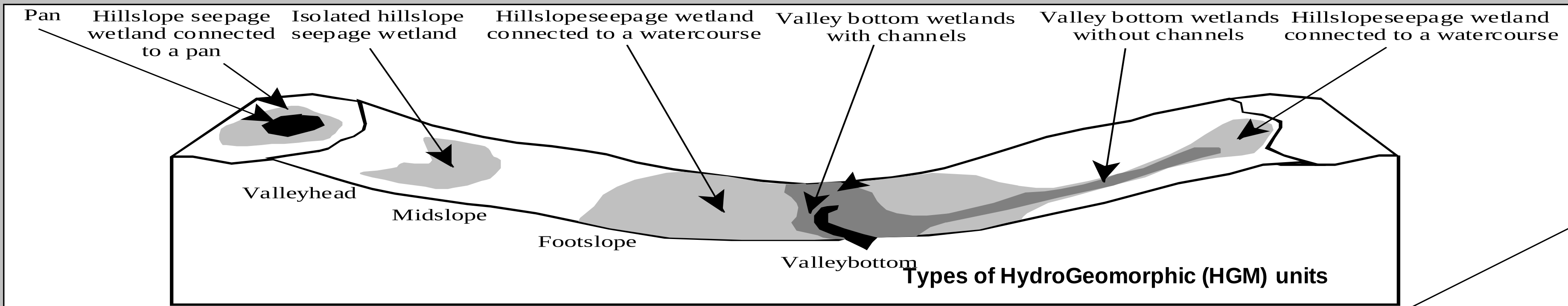
Level I	Level II			Level III
System	EcoRegion	Dominant Geology	Landscape Position/ Setting	HydroGeomorphic Unit
INLAND	Savannah	basaltic rock	Valley Bottom	River
				Lake
				Unchannelled Valley Bottom
				Channelled Valley Bottom
				Meandering Floodplain
			Slopes	Seepage (isolated)
				Seepage (connected)
			Crest	Seepage (connected)
				Pan

This model (WETLAND-IHI) is designed for the RAPID assessment of floodplain and channeled valley bottom wetland types, for the purposes of determining the PES.

PES (Present Ecological State) is an indication of the current ecological state of the wetland, relative to its Reference (natural) State - i.e. the deviation from the historic/pre-development condition of the wetland.

Type of wetland system:	**Channelled Valley Bottom**
Confidence in the assessment (1-5)	**3**

This current model is only designed for floodplains and channeled valley bottoms.



Types of HydroGeomorphic (HGM) units

VEGETATION ALTERATION - the impacts of landuse activities *within* the wetland on the vegetation of the wetland

Estimate the impact **RATING** (0-5) and aerial **EXTENT** (0-100 %) of the various landuse activities on the wetland system

Landuse Activities on the wetland	Ranking	Weighting	Rating (0-5)	Extent (0-100%)	Impact Score	Weighted Impact Score	*Confidence Rating (1-5)*	*Notes (describe the details of impacts here)*
Mining/Excavation	1	***100***	3	30	0.9	0.9	**3**	
Infilling/Backfilling	2	***70***	2	10	0.2	0.14	**2**	
Vegetation Clearing/Loss/Alteration	3	***60***	3	40	1.2	0.72	**3**	
Weeds or Invasive plants	4	***50***	3	10	0.3	0.15	**3**	
Percentage in Reference State	6	0	0	10	0	0		
VEGETATION ALTERATION SCORE				100		**1.91**	***Confidence:***	
					PES %:	**61.8**	***2.6***	
					PES Category:	**C/D**		

Total Extent must always be 100%!!! If there is a site with two types of impact in the same location; score according to the larger impact weighting.

Reference State: this is what the site would have looked like without the landuse activities and without the on-site and catchment hydrology, geomorphology and water quality alterations/impacts which have occurred.

Description of the Reference State:

HYDROLOGY

	Ranking	Weighting	Weighted Rating	*Confidence Rating (1-5)*
Catchment	1	100	1.5	*2.7*
Within-wetland Effects	2	70	2.1	*2.8*
TOTAL HYDROLOGY PES		170	**1.8**	***Confidence:***
		PES %:	**64.8**	***2.8***
		PES Category:	**C**	

If the weighted value of the "within-wetland effects" exceeds 3.5, then a threshold value is exceeded and this affects the overall PES score. This is to ensure that where wetlands are highly degraded due to on-site impacts, the resultant scores are not masked by good catchment conditions

Catchment Effects	Ranking	Weighting (0-100%)	Rating	*Confidence Rating (1-5)*	Impact Score	Weighted Impact Score	*Notes*
Changes in flood peaks/frequencies	1	***100***	1.0	**3**	1	0.4	
Changes in base flows	2	***60***	-2.0	**3**	1.2	0.5	
Changes in seasonality	2	***60***	2.0	**2**	1.2	0.5	
Zero flows	3	10	1.0	**3**	0.1	0.0	
Sub-total		230		***2.7***		***1.5***	

Within-wetland Effects	Rating	Extent (0-100%)	Impact Score	*Confidence Rating (1-5)*	*Notes*
Connectivity - altered channel size/competency	3.0	50	1.5	**3**	
Increased water retention on the floodplain	0.0	0	0	**3**	
Decreased water retention on the floodplain	2.0	30	0.6	**3**	
Reference State conditions	0.0	20	0	**2**	
Sub-total		100	**2.1**	***2.8***	

Total Extent must always be 100%!!! If there is a site with two types of impact in the same location; score according to the larger impact rating.

Assessing Catchment Effects

Changes in flood peaks	
INCREASE? Is there catchment hardening (urbanisation) in the catchment?	no change
DECREASE? Are there many small dams, or a very large dam, upstream of the wetland?	none
Changes in base flow	
INCREASE: are there any interbasin transfers, or releases of elevated flows to cater for irrigation?	no change
DECREASE: is there extensive abstraction for irrigation, or extensively afforested areas, upstream of the wetland?	moderate decrease

GEOMORPHOLOGY

Importance of catchment vs on-site effects	Ranking	Weighting (0-100%)	Weighted Score	*Confidence Rating (1-5)*
Catchment	1	***100***	1.5	*3.0*
Within-wetland Effects	2	80	1.7	*3.0*
TOTAL GOMORPHOLOGY PES		180	**1.6**	***Confidence:***
		PES %:	**68.5**	***3.0***
		PES Category:	**C**	

If the weighted value of the "within-wetland effects" exceeds 3.5, then a threshold value is exceeded and this affects the overall PES score. This is to ensure that where wetlands are highly degraded due to on-site impacts, the resultant scores are not masked by good catchment conditions

Catchment effects	Ranking	Weighting (0-100%)	Rating	*Confidence Rating (1-5)*	Impact Score	***Notes***
Change in **SEDIMENT BUDGET** (calculate below)	1	100	**1.5**	**3**	1.5	
					1.5	

Within-wetland Effects	Ranking	Weighting (0-100%)	Rating (0-5)	*Confidence Rating (1-5)*	Impact Score	Weighted Impact Score
Erosional features	1	***100***	2.0	**3**	2	1.3
Depositional features	2	***50***	1.0	**3**	0.5	0.3
Sub-total		150		3.0		***1.7***

SEDIMENT BUDGET

If you don't know the answer, leave the cell blank

Increases in sediment supply	***Change?***	**Increase in sediment transport capacity**	***Change?***
Can you see evidence of extensive active erosion in the catchment?	small increase	Have flood peaks increased due to catchment hardening?	no change
Is there active bank erosion of the channel in the wetland?	small increase	Has an interbasin transfer scheme increased the erosive capacity of the flow?	no change
Are there many dirt roads in the catchment, and/or are the hillslopes under cultivation?	many	Have releases from upstream dams *increased* the erosive capacity of the flow? (e.g. sustained high flow releases below very large dams)	no change
Have any upstream dams or weirs been breached, causing an increase in sediment supply?	no change	Has the capacity of the channel been increased by, for example, levee construction along the channel edges, or channel deepening/widening and/or straightening?	small increase
Has the vegetation cover of the catchment decreased for any reason?	moderate decrease		
Decreases in sediment supply		**Decrease in sediment transport capacity**	
Is sediment being trapped by dams or weirs upstream of the wetland?	small decrease	Has the frequency and/or size of floods been reduced by an upstream dam?	no change
If there are upstream dams, are there any major tributary confluences between the dam and the wetland system that could introduce replace some sediment?	none	Has there been a decrease in flow due to diversions from the upstream channel?	small decrease
Are there weirs or causeways or other obstructions across the channel, upstream of the wetland, which would trpa sediment?	few		
Has there been sediment mining in any areas?	none		
Has there been an increase in the catchment vegetation cover?	no change		
Given the above, to what extent do you think the sediment supply to the wetland has changed? (-10 to +10)	3	**Given the above, to what extent do you think the transport capacity in the wetland has changed? (-10 to +10)**	-1
Adjusted sediment supply index	1.0	**Adjusted transport capacity index**	-0.3

Use the table below to assess the change in sediment budget (0-5) : **1.5**

Notes

CONSIDER THE IMPACT OF THESE ACTIVITIES ON WATER QUALITY:

Water Quality Components	Modified flow conditions	Inundation: Weirs	Inundation: Dams	Effluent: Urban areas	Effluent: Cultivation (agricultura activities; return flows)	Effluent: Industries	Effluent: Mining	Instream plants (macrophytes) & algae (incl. blue-green)	Forestry	Roads & crossings	Invasive riparian vegetation	Riparian vegetation removal	Bed disturbance: Bull dozing, sand mining, etc.	Bank disturbance: vegetation removal, artificial covering.	Solid waste disposal (rubbish disposal)	AVERAGE	MEDIAN	MODE	RATING (use avg, median or mode)
pH	X	X	X		0.5				0.5	X		X	X	X	X	0.5	0.5	0.5	0.5
Salts					0.5			X	X	X	X	X	X	X	X	0.5	0.5	#N/A	0.5
Nutrients					1.0				X	X	X		X	X	X	1.0	1.0	#N/A	1.0
Water Temp.	0.5				X				X	X			X	X	X	0.5	0.5	#N/A	0.5
Turbidity	0.5	0.5			1.0				0.0						X	0.5	0.5	0.5	1.0
Oxygen	0.0				0.5				X	X	X	X	X	X		0.3	0.3	#N/A	0.5
Toxics	X	X	X		0.5				X		X	X	X	X		0.5	0.5	#N/A	0.5

Water Quality	RATING	Weighting	Confidence (1-5)
pH	0.5	100	2
Salts	0.5	70	2
Nutrients	1.0	50	3
Water Temp.	0.5	10	2
Turbidity	1.0	10	3
Oxygen	0.5	10	2
Toxics	0.5	50	2

Water Quality: overall scores

Rating:	**0.6**	***Confidence:***	***2.2***
Percentage:	**88.0**		
PES Category:	**A/B**		

Notes

HGM Unit 4 data

Site name:	HGM Unit 4_ Upstream VhaVenda Bricks
Location (GPS co-ordinates):	22 59'53.60"S 30 22'08.69"E
1:50 000 topo map reference:	
EcoRegion:	Savannah
Geology (if available):	basaltic rock
Recorder:	TI Neswiswi
Date:	09/08/2018

To use this model: fill in the shaded cells as follows:

LIGHT YELLOW CELLS: *these formula are fixed and can not be altered by the user*

BLUE CELLS *show recommended values for this component, but these can be altered by experts or when confidence for the new value is high.*

WHITE CELLS: *Date inputs, or notes and comments, are required in here.*

Notes and/or Sketch of the site

WETLAND CLASSIFICATION

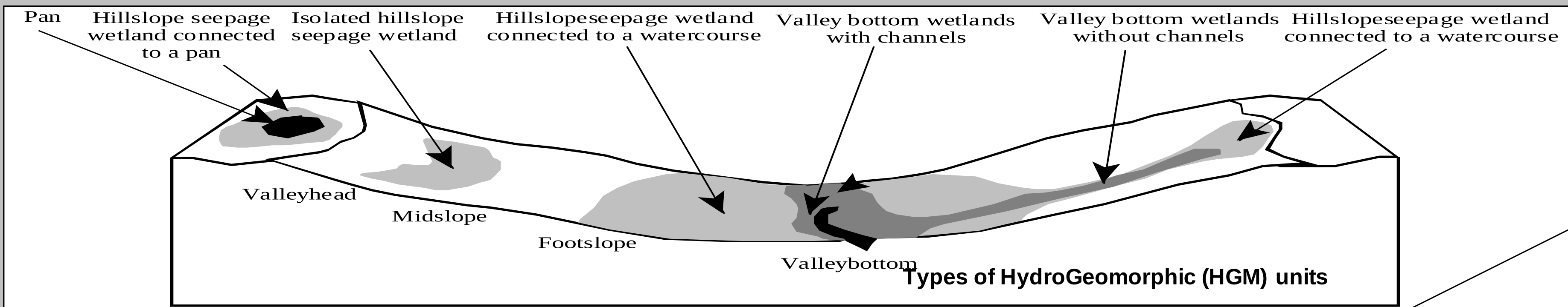
Level I	Level II			Level III
System	**EcoRegion**	**Dominant Geology**	**Landscape Position/ Setting**	**HydroGeomorphic Unit**
INLAND	Savannah	basaltic rock	Valley Bottom	River
				Lake
				Unchannelled Valley Bottom
				Channelled Valley Bottom
				Meandering Floodplain
			Slopes	Seepage (isolated)
				Seepage (connected)
			Crest	Seepage (connected)
				Pan

This model (WETLAND-IHI) is designed for the RAPID assessment of floodplain and channeled valley bottom wetland types, for the purposes of determining the PES.

PES (Present Ecological State) is an indication of the current ecological state of the wetland, relative to its Reference (natural) State - i.e. the deviation from the historic/pre-development condition of the wetland.

Type of wetland system:	**Channelled Valley Bottom**
Confidence in the assessment (1-5)	**3**

This current model is only designed for floodplains and channeled valley bottoms.



Types of HydroGeomorphic (HGM) units

VEGETATION ALTERATION - the impacts of landuse activities *within* the wetland on the vegetation of the wetland								
Estimate the impact **RATING** (0-5) and aerial **EXTENT** (0-100 %) of the various landuse activities on the wetland system								
Landuse Activities on the wetland	**Ranking**	**Weighting**	**Rating (0-5)**	**Extent (0-100%)**	**Impact Score**	**Weighted Impact Score**	***Confidence Rating (1-5)***	***Notes (describe the details of impacts here)***
Mining/Excavation	1	***100***	3	30	0.9	0.9	**3**	
Infilling/Backfilling	2	***70***	1	10	0.1	0.07	**2**	
Vegetation Clearing/Loss/Alteration	3	***60***	3	40	1.2	0.72	**3**	
Weeds or Invasive plants	4	***50***	3	10	0.3	0.15	**3**	
Percentage in Reference State	6	0	0	10	0	0		
VEGETATION ALTERATION SCORE				100		**1.84**	***Confidence:***	
					PES %:	**63.2**	***2.6***	
					PES Category:	**C**		

Total Extent must always be 100%!!! If there is a site with two types of impact in the same location; score according to the larger impact weighting.

Reference State: this is what the site would have looked like without the landuse activities and without the on-site and catchment hydrology, geomorphology and water quality alterations/impacts which have occurred.

Description of the Reference State:

HYDROLOGY

	Ranking	Weighting	Weighted Rating	*Confidence Rating (1-5)*
Catchment	1	100	1.3	*2.7*
Within-wetland Effects	2	70	1.5	*2.8*
TOTAL HYDROLOGY PES		170	**1.3**	***Confidence:***
		PES %:	**73.2**	***2.7***
		PES Category:	**C**	

If the weighted value of the "within-wetland effects" exceeds 3.5, then a threshold value is exceeded and this affects the overall PES score. This is to ensure that where wetlands are highly degraded due to on-site impacts, the resultant scores are not masked by good catchment conditions

Catchment Effects	Ranking	Weighting (0-100%)	Rating	*Confidence Rating (1-5)*	Impact Score	Weighted Impact Score	*Notes*
Changes in flood peaks/frequencies	1	***100***	1.0	**3**	1	0.4	
Changes in base flows	2	***60***	-2.0	**3**	1.2	0.5	
Changes in seasonality	2	***60***	1.0	**2**	0.6	0.3	
Zero flows	3	10	1.0	**2**	0.1	0.0	
Sub-total		230		***2.7***		***1.3***	

Within-wetland Effects	Rating	Extent (0-100%)	Impact Score	*Confidence Rating (1-5)*	*Notes*
Connectivity - altered channel size/competency	2.0	25	0.5	**3**	
Increased water retention on the floodplain	1.0	15	0.15	**3**	
Decreased water retention on the floodplain	2.0	40	0.8	**3**	
Reference State conditions	0.0	20	0	**2**	
Sub-total		100	**1.45**	***2.8***	

Total Extent must always be 100%!!! If there is a site with two types of impact in the same location; score according to the larger impact rating.

Assessing Catchment Effects

Changes in flood peaks	
INCREASE? Is there catchment hardening (urbanisation) in the catchment?	no change
DECREASE? Are there many small dams, or a very large dam, upstream of the wetland?	none
Changes in base flow	
INCREASE: are there any interbasin transfers, or releases of elevated flows to cater for irrigation?	no change
DECREASE: is there extensive abstraction for irrigation, or extensively afforested areas, upstream of the wetland?	small decrease

GEOMORPHOLOGY				
Importance of catchment vs on-site effects	Ranking	Weighting (0-100%)	Weighted Score	*Confidence Rating (1-5)*
Catchment	1	100	2.0	3.0
Within-wetland Effects	2	80	1.0	3.0
TOTAL GOMORPHOLOGY PES		180	1.6	*Confidence:*
		PES %:	68.9	3.0
		PES Category:	C	

If the weighted value of the "within-wetland effects" exceeds 3.5, then a threshold value is exceeded and this affects the overall PES score. This is to ensure that where wetlands are highly degraded due to on-site impacts, the resultant scores are not masked by good catchment conditions

Catchment effects	Ranking	Weighting (0-100%)	Rating	*Confidence Rating (1-5)*	Impact Score	*Notes*
Change in **SEDIMENT BUDGET** (calculate below)	1	100	2.0	3	2.0	
					2.0	

Within-wetland Effects	Ranking	Weighting (0-100%)	Rating (0-5)	*Confidence Rating (1-5)*	Impact Score	Weighted Impact Score
Erosional features	1	100	1.0	3	1	0.7
Depositional features	2	50	1.0	3	0.5	0.3
Sub-total		150		3.0		1.0

SEDIMENT BUDGET

If you don't know the answer, leave the cell blank

Increases in sediment supply	*Change?*	Increase in sediment transport capacity	*Change?*
Can you see evidence of extensive active erosion in the catchment?	small increase	Have flood peaks increased due to catchment hardening?	no change
Is there active bank erosion of the channel in the wetland?	small increase	Has an interbasin transfer scheme increased the erosive capacity of the flow?	no change
Are there many dirt roads in the catchment, and/or are the hillslopes under cultivation?	many	Have releases from upstream dams *increased* the erosive capacity of the flow? (e.g. sustained high flow releases below very large dams)	no change
Have any upstream dams or weirs been breached, causing an increase in sediment supply?	no change	Has the capacity of the channel been increased by, for example, levee construction along the channel edges, or channel deepening/widening and/or straightening?	small increase
Has the vegetation cover of the catchment decreased for any reason?	moderate decrease		
Decreases in sediment supply		**Decrease in sediment transport capacity**	
Is sediment being trapped by dams or weirs upstream of the wetland?	no change	Has the frequency and/or size of floods been reduced by an upstream dam?	no change
If there are upstream dams, are there any major tributary confluences between the dam and the wetland system that could introduce replace some sediment?	none	Has there been a decrease in flow due to diversions from the upstream channel?	small decrease
Are there weirs or causeways or other obstructions across the channel, upstream of the wetland, which would trpa sediment?	few		
Has there been sediment mining in any areas?	none		
Has there been an increase in the catchment vegetation cover?	no change		
Given the above, to what extent do you think the sediment supply to the wetland has changed? (-10 to +10)	2	**Given the above, to what extent do you think the transport capacity in the wetland has changed? (-10 to +10)**	-1
Adjusted sediment supply index	**0.7**	**Adjusted transport capacity index**	**-0.3**
Use the table below to assess the change in sediment budget (0-5) :			**2**

Notes

		CONSIDER THE IMPACT OF THESE ACTIVITIES ON WATER QUALITY:																		
		Modified flow conditions	Inundation: Weirs	Inundation: Dams	Effluent: Urban areas	Effluent: Cultivation (agricultural activities; return flows)	Effluent: Industries	Effluent: Mining	Instream plants (macrophytes) & algae (incl. blue-green)	Forestry	Roads & crossings	Invasive riparian vegetation	Riparian vegetation removal	Bed disturbance: Bull dozing, sand mining, etc.	Bank disturbance: vegetation removal, artificial covering.	Solid waste disposal (rubbish disposal)	AVERAGE	MEDIAN	MODE	**RATING** (use avg, median or mode)
Water Quality Components	pH	X	X	X		0.5				0.5	X		X	X	X	X	0.5	0.5	0.5	0.5
	Salts					0.5			X	X	X	X	X	X	X	X	0.5	0.5	#N/A	0.5
	Nutrients					1.0				X	X	X		X	X	X	1.0	1.0	#N/A	1.0
	Water Temp.					X				X	X			X	X	X	#DIV/0!	#NUM!	#N/A	
	Turbidity					2.0				0.5						X	1.3	1.3	#N/A	1.0
	Oxygen					0.5				X	X	X	X	X	X		0.5	0.5	#N/A	0.5
	Toxics	X	X	X		0.5				X		X	X	X	X		0.5	0.5	#N/A	0.5

		RATING	Weighting	Confidence (1-5)
Water Quality	pH	0.5	100	2
	Salts	0.5	70	2
	Nutrients	1.0	50	3
	Water Temp.	0.0	10	2
	Turbidity	1.0	10	4
	Oxygen	0.5	10	2
	Toxics	0.5	50	2

Water Quality: overall scores

Rating:	**0.6**	***Confidence:***	***2.2***
Percentage:	**88.3**		
PES Category:	**A/B**		

Notes

Appendix B: Wet-Health

HGM Unit 5

Wet-Health	LEVEL 1 ASSESSMENT	Version 2.0

PAGE 2: HGM UNIT 5

STEP 2: ASSESS HYDROLOGICAL HEALTH OF THE WETLAND

STEP 2A: EVALUATE CHANGES TO WATER INPUT CHARACTERISTICS FROM THE CATCHMENT

Nature of Alteration	Intensity rating guidelines	Alteration Class Score	Land-use factors contributing to impacts, and any additional notes
Reduction in flows (water inputs)	Table 5.1	-4	Abstraction of water via a borehole for community water supply within the 50metres radius of the wetlands
Increase in flows (water inputs)	Table 5.1	0	
Combined impact Score		**-4**	
Change in flood patterns (peaks)	Table 5.2	-4	
Magnitude of impact Score	Table 5.3	**7.0**	Note: Separate tables are provided for combining the scores for (a) floodplain and channelled valley bottom wetlands and (b) other HGM settings.

STEP 2B: EVALUATE CHANGES TO WATER DISTRIBUTION & RETENTION PATTERNS WITHIN THE WETLAND

	Intensity rating guidelines	Extent (%)[1]	Intensity (0 - 10)	Magnitude[2]	Land-use factors contributing to impacts, and any additional notes
Gullies and artificial drainage channels	Table 5.5	20	2	0.4	
Modifications to existing channels	Table 5.6	30	3	0.9	
Reduced roughness	Table 5.7	40	3	1.2	Road crossing and tramppling
Impeding features (e.g. dams) – upstream effects	Table 5.8	0	0	0	
Impeding features – downstream effects	Table 5.9	0	0	0	
Increased on-site water use	Table 5.10	30	3	0.9	
Deposition/infilling or excavation	Table 5.11	30	3	0.9	
Combined impact Score [3]				**4.3**	

1 Extent refers to the extent of the HGM unit affected by the modification expressed as a percentage of the total area of the HGM unit

2 Magnitude = Extent /100 x Intensity

3 Calculated as the sum of magnitude scores across all modifications

STEP 2C: DETERMINE THE OVERALL HYDROLOGICAL IMPACT SCORE OF THE HGM UNIT BASED ON INTEGRATING THE ASSESSMENTS FROM STEPS 2A AND 2B

Changes to water distribution & retention patterns	**Table Reference**	**4.3**	**Any additional notes**
Changes to Water Input charachteristics		**7.0**	
Combined Hydrology Impact Score	Table 5.12	**7.5**	

STEP 2D: DETERMINE THE OVERALL PRESENT HYDROLOGICAL STATE OF THE WETLAND BASED ON INTEGRATING SCORES FROM INDIVIDUAL HGM UNITS

See summary page Table 5.28 - integrates hydrological impact scores from each HGM unit

STEP 2E: ASSESS THE ANTICIPATED TRAJECTORY OF CHANGE OF THE WETLAND HYDROLOGY

HGM Trajectory of Change score	Table 5.27	**0**

STEP 3: ASSESS GEOMORPHOLOGICAL HEALTH OF THE WETLAND

STEP 3A: DETERMINE THE PRESENT GEOMORPHIC STATE OF INDIVIDUAL HGM UNITS

Impact type	Applicability to HGM type	Extent rating guidelines	Extent (%)[1]	Intensity rating guidelines	Intensity (0 - 10)	Magnitude [2]	Land-use factors contributing to impacts, and any additional notes
Daignostic component							
(1) Upstream dams	Floodplain	See below [3]	0	Table 5.14	0	0.0	
(2) Stream diversion/shortening	Floodplain, Channeled VB	See below [4]	10	Table 5.15	2	0.2	
(3) Infilling	Floodplain, Channeled VB	See below [5]	10	See below [5]	2	0.2	
(4) Increased runoff	Non-floodplain HGMs	Table 5.16	30	Table 5.16	4	1.2	
Indicator-based component							
(5) Erosional features	All non-floodplain HGMs	Table 5.17	20	Table 5.18	2	0.4	
(6) Depositional features	All non-floodplain HGMs	Table 5.19	40	Table 5.20	3	1.2	

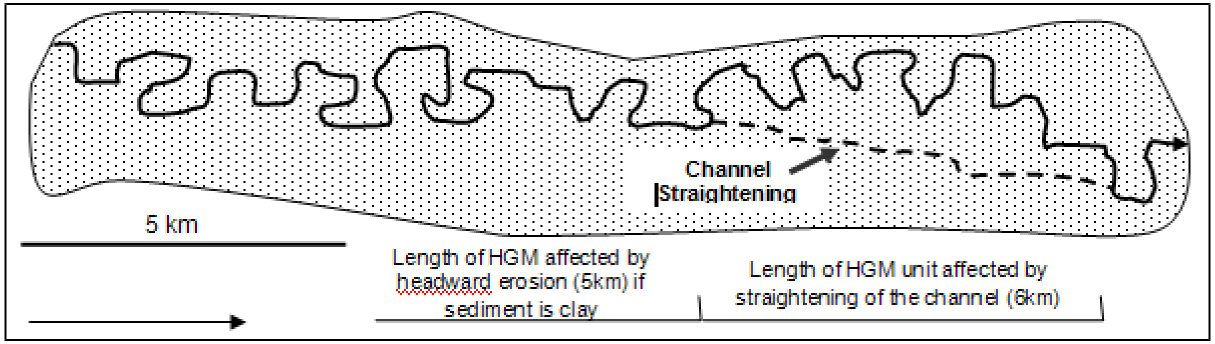
(6) Loss of organic matter	All non-floodplain HGMs with peat	see below[6]	10	Table 5.21	1	0.1	
Combined Impact Score based on a sum of all magnitude scores[7]						**1.7**	

1 Extent refers to the extent of the HGM unit affected by the modification, expressed as a percentage of the total area of the HGM unit

2 Magnitude = Extent (%)/100 x Intensity

3 Extent is determined based upon the area of the HGM unit that is flooded (in the case of a dam in the HGM unit) and the area of the HGM unit area downstream of the dam (for a dam upstream of the HGM unit, this will be 100% of the HGM unit).

4 Extent of area affected by stream straightening is expressed by measuring the length of the wetland affected by stream straightening and expressing this as a percentage of the overall length of the HGM unit. Extent of the wetland affected by stream diversions is determined based upon a distance upstream of the point of diversion along the channel of 20 km if the sediment is sandy and 5 km if it is clayey (or to the upstream end of the HGM unit if this is less than the specified distance). The specified distances are given based on the fact that headward erosion in the stream channel advances much more readily through sand than through clay. Assume that in the example given below the sediment was clayey, then the length of wetland affected by diversion and straightening would be 5 + 6 km, which, expressed as a proportion of the total length of the wetland, would be 11/17 km= 65%.



5 Extent of area affected by infilling is based on the following guideline: for a small stream (i.e., 1st to 2nd order stream), filled area + 1 km upstream and downstream, and for a large stream (i.e. > 3rd order) 2 km upstream and downstream. Intensity of impact is based on the extent to which flow is blocked by embankments given as a percentage of the HGM width, divided by 10 to give a score ranging from 0 to 10. For example, if embankments block flow across 1.4 km of an HGM unit that is 2 km wide (70% of width) then intensity of impact is 70÷10=7.

6 Extent of the area affected by organic matter reduction is based on the extent of peat subject to desiccation, ground fires or extraction, expressed as a percentage of the HGM unit.

7 If no information on on-site indicators are available, this score is simply calculated as a sum of scores from the diagnostic assessment. Where information on both diagnostic & indicator assessments is available, the combined score is calculated by averaging the combined scores from each of these components.

STEP 3B: DETERMINE THE OVERALL PRESENT GEOMORPHIC STATE OF THE WETLAND BASED ON INTEGRATING SCORES FROM INDIVIDUAL HGM UNITS

See summary page Table 5.28 - integrates geomorphic impact scores from each HGM unit

STEP 3C: ASSESS THE ANTICIPATED TRAJECTORY OF CHANGE OF THE WETLAND GEOMORPHOLOGY

HGM Trajectory of Change score	Table 5.27	**0**