Full Length Research Paper

Geology and structure of the dryland Mutubuki wetland of Gutu, Zimbabwe

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The study aimed at understanding the geological factors that led to the formation of Mutubuki wetland in the Gutu District of Zimbabwe. Most studies of dryland wetlands focus on contributions from ecology, biology, and hydrology ignoring their structure and geology. As a result geology of wetlands have remained little understood yet improved understanding of the geological and sedimentological processes governing their development, is vital for the design of sustainable management guidelines for these diverse and fragile areas. The study used field surveys to gather data at a micro-catchment level and GIS techniques to combine and analyse the digital elevation model derivatives and geological map of the area. The results showed that the wetland was located at the point of contact of gneiss and granite basement rock, the wetland also sits at an interfluve which is its major recharge zone, it also occurs on a depression at the edge of higher ground has gentle slopes. It was also observed that the wetland contained a thick layer of clay and the interfluves contained sandy soils.

Keywords: Wetland geology, Interfluves, Digital Elevation Model, GIS Techniques

INTRODUCTION

Wetlands are areas that are periodically or continuously inundated by shallow water or have saturated soils, and where plant growth and other biological activity are adapted to the wet conditions (Owen et al, 1995).Wetlands occupy an intermediate position between terrestrial and fully aquatic ecosystems (Zoltai, 1988; Finlayson and van der Valk, 1995; Rogers, 1995; Mulamoottil et al., 1996), and fulfil important hydrological and biogeochemical functions while supporting high biodiversity (Mitsch and Gosselink, 2000). In Zimbabwe, they cover approximately 1.28 million hectares of land in which 25% is in communal areas (Whitlow, 1985; Owen et al, 1995). Wetlands are known as mapani or vleis in Zimbabwe, as dambos in eastern and central Africa, as mbungas in Tanzania and fadamas in northern Nigeria and inland Sierra Leone (Owen et al, 1995).

Wetlands are poorly documented features of many landscapes, and there is often little understanding of the geological controls on their origin, development and characteristics. They possess a diverse range of geological and sedimentary features that defy simple definition, characterization or classification (Scott and Jones, 1995; Semeniuk and Semeniuk, 1995).

Drylands are areas characterised by high but variable levels of aridity, reflecting low ratios between precipitation and potential evapotranspiration (UNCCD, 2012). Drylands are a collective term that includes sub humid, semiarid, arid and hyper arid regions and incorporates almost 50% of the global land area and nearly 20% of the global population (UNEP, 1992; Middleton and Thomas, 1997). Wetlands on drylands can only exist on areas where there are locally positive surface water balances for all or part of the year. Most wetlands in drylands are maintained by factors that serve to impede drainage or reduce infiltration, including faulting, rock outcrops, swelling soils, and ponding (Scott and Jones, 1995).

Wetlands have recently become the focus of intense conservation interest, largely in response to growing pressures for increased data to inform management decisions regarding conservation, rehabilitation or

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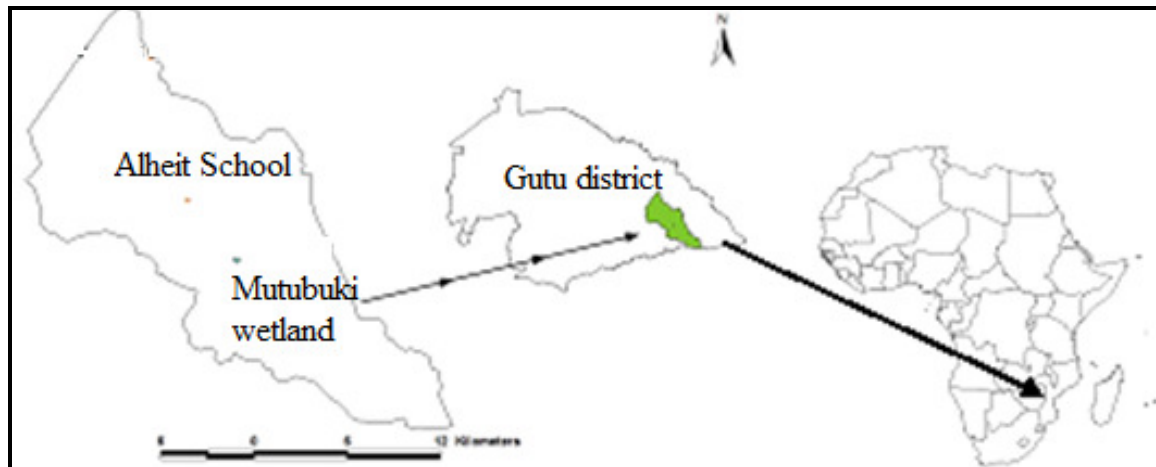
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Figure1. Location Mutubuki Wetland and micro-catchment

artificial construction of wetlands, and particularly in view of the potential adjustments that may result from global climate changes (Winter, 2000; Burkett and Kusler, 2000) and also since the establishment of the Convention on Wetlands of International Importance (1971),(Mulamoottil et al., 1996; Mitsch and Gosselink, 2000).

It has been estimated that more than 50% of the original global extent of wetlands have been degraded or destroyed by land-use practices like overgrazing and overburning, by development pressures e.g drainage modification, land reclamation, or by exotic invasive vegetation or feral animals (Dugan, 1993; Mulamoottil et al., 1996; Mitsch and Gosselink, 2000). Urban, agricultural and water resource developments still threaten many wetlands, with other threats coming from the possible negative effects of global climate change on wetland structure and function (Winter, 2000; Burkett and Kusler, 2000). Due to prolonged periods of lower than average rainfall, many wetlands in Zimbabwe appear to be dying out. There is therefore a need for an appropriate and scientifically tested technical package that can stop degradation, reclaim and improve the nature and productivity of wetlands in Zimbabwe (Owen et al, 1995). It is therefore important that research on wetlands considers the catchment area, the wetland itself and the downstream outflow as a unit.

In many countries, however, there is now also increasing recognition of the beneficial functions and resource potential of wetlands, such as their role in carbon sequestration, water storage, flow regulation, water quality improvement, groundwater recharge, provision of wildlife habitat, and revenue (Mitsch and Gosselink, 2000).The benefits of wetlands are particularly evident in drylands, as they typically represent the only reliable sources of water in otherwise largely dry settings (Begg, 1986; Scoones, 1991; Hughes, 1996).

Wetlands research has been mostly interdisciplinary in nature especially involving contributions from ecology, biology, and hydrology. These disciplines bring many valuable perspectives to wetlands research but tend to focus their descriptions and analyses on timescales that are relevant to such wetland phenomena as fish spawning, bird nesting, or plant flowering/seeding cycles like months, years or decades. By contrast, only a few studies have looked at the geological and sedimentological factors that impact upon wetland origin and structure. As a result, wetlands remain poorly understood features of many landscapes (McCarthy and Hancox, 2000), yet the geologicall and sedimentological processes governing their development is vital for the design of sustainable management guidelines for these diverse yet fragile areas.

Many semi arid areas in Zimbabwe host a diverse range of perennial, seasonal or ephemeral wetlands. The geological and sedimentological characteristics of which have been little documented and understood. This paper thus aims to outline the geological factors influencing the formation of the dryland Mutubuki wetland in Gutu District and to consider the implications of these findings for the management of wetlands in the area.

The key question that this research seeks to answer is:

1) What are the geological factors influencing the location and form of Mutubuki wetland?

Study area

Figure.1 shows the study area of the research. The study area is the Mutubuki wetland and its micro-catchment. The Mutubuki wetland is located on the south-western corner of Gutu district in Zimbabwe. The wetland covers an area of 59 328 m^2 and is used by the local Chingombe community to provide drinking water for people and animals, and watering their community garden, which is an important source of nutrition and income for this community in this semi arid region. The area receives an average of less than 450mm of rainfall per annum and average potential evapo - transpiration

between 600-900mm which by far exceeds the available water supply. The area has got an aridity index of between 02-0.5 (UNCCD, 2012) which means that it is semi-arid.

The wetland used to be perennial and provided a reliable source of water for the community until 2007 when it dried up and now supplies water during the rainfall season and a few months afterwards before it dries up again.

In order to understand better the reasons for the drying up of the wetland and prescribe sound remedial action for rehabilitation of the wetland, the geological structure of the rocks that lead to the occurrence and the form of the wetland need to be unravelled.

MATERIALS AND METHODS

Materials

1. 30m*30m digital elevation model (DEM) for the area from theUSGS,(2001).
2. Aster satellite images for the area with a spatial resolution of 15m*15m.
3. The geological map of Zimbabwe from the Surveyor General of Zimbabwe.
4. A hand held global positioning systems.
5. Borehole and deep well depth data.
6. ILWIS GIS
7. Arcview GIS

Methods

The polygon shape of the wetland was first demarcated using a handheld GPS. The micro-catchment area of the Mutubuki wetland was then extracted from an Aster Satellite image for the area. This was done by overlaying the wetland polygon with an aster satellite imagery of the area. This was then followed by digitising the catchment area of the wetland by following interfluves that demarcate streams which drain in and around the wetland area.

The digitised geological map of the Mutubuki wetland micro-catchment was then obtained by sub-setting the obtained catchment area from the geological map of Zimbabwe in a GIS. The Mutubuki micro-catchment geological formations were then overlain with the wetland location and the spatial distribution of boreholes in the area in order to determine the geological context of the wetland.

A digital elevation model (DEM) is a digital representation of topography. The DEM was used to calculate the flow direction, accumulated flow, contour and the slope maps of the micro-catchment using ILWIS GIS functions.

Before using the DEM to calculate the above maps, it

was first filtered in the X and Y directions so that local depressions (sinks) are removed. The operation removed depressions that consist of a single pixel, i.e. any pixel with a smaller height value than all of its 8 neighbouring pixels and depressions that consist of multiple pixels, i.e. any group of adjacent pixels where the pixels that have smaller height values than all pixels that surround such a depression. When a depression of a single pixel is encountered during filtering, the height value of this pixel will be increased to the smallest value of its 8 neighbour pixels. When a depression of multiple pixels is encountered then the height values of this depression will be increased to the smallest value of a pixel that is both adjacent to the outlet for the depression, and that would discharge into the initial depression. The above operation was meant to make the DEM hydrologically usable by eliminating outliers because they cause distortion in the calculation of DEM derivatives.

The sink-free DEM was then used to run the flow direction operation. The operation determines into which neighbouring pixel any water in a central pixel will flow naturally. Flow direction is calculated for every central pixel of input blocks of 3 by 3 pixels, each time comparing the value of the central pixel with the value of its 8 neighbours. The output map contains flow directions such as N (to the North), NE (to the North East. Flow directions for the central pixels were calculated by steepest slope which finds the steepest downhill slope of a central pixel to one of its 8 neighbour pixels.

The accumulation water flow map algorithm in ilwis GIS mimics the flow of water on or below the surface. It is from the flow direction grid that the flow accumulation grid is calculated as a second order derivative. When water flows down slope, it will follow the path of with the largest gradient (steepest slope). In a DEM grid structure, there exist at most 8 cells adjacent to each individual grid cell at regularly spaced horizontal intervals. The flow accumulation operation then performs a cumulative count of the number of pixels that naturally drain into outlets resulting in the drainage pattern of a terrain and an idea of how water flows on and below the ground surface.

The slope map was derived from the DEM by first calculating height differences in the X-direction and in Y-directions through linear filters dfdx and dfdy. Secondly the slope map in percentages was derived from formulae 1.

$$SLOPEPCT = 100 * HYP(DX,DY)/PIXSIZE(DEM)\dots\dots\dots\dots\dots\dots1$$

The contour map of the area was derived from the DEM by creating the lines of equal height through the use of the DNR hydrology extension in Arcview GIS.

The borehole and deep well data from in and around the wetland were used to measure the vertical profile of the wetland in terms of the depth to the water table, depth of the clay, sandy soils layers and depth to the parent rock basement.

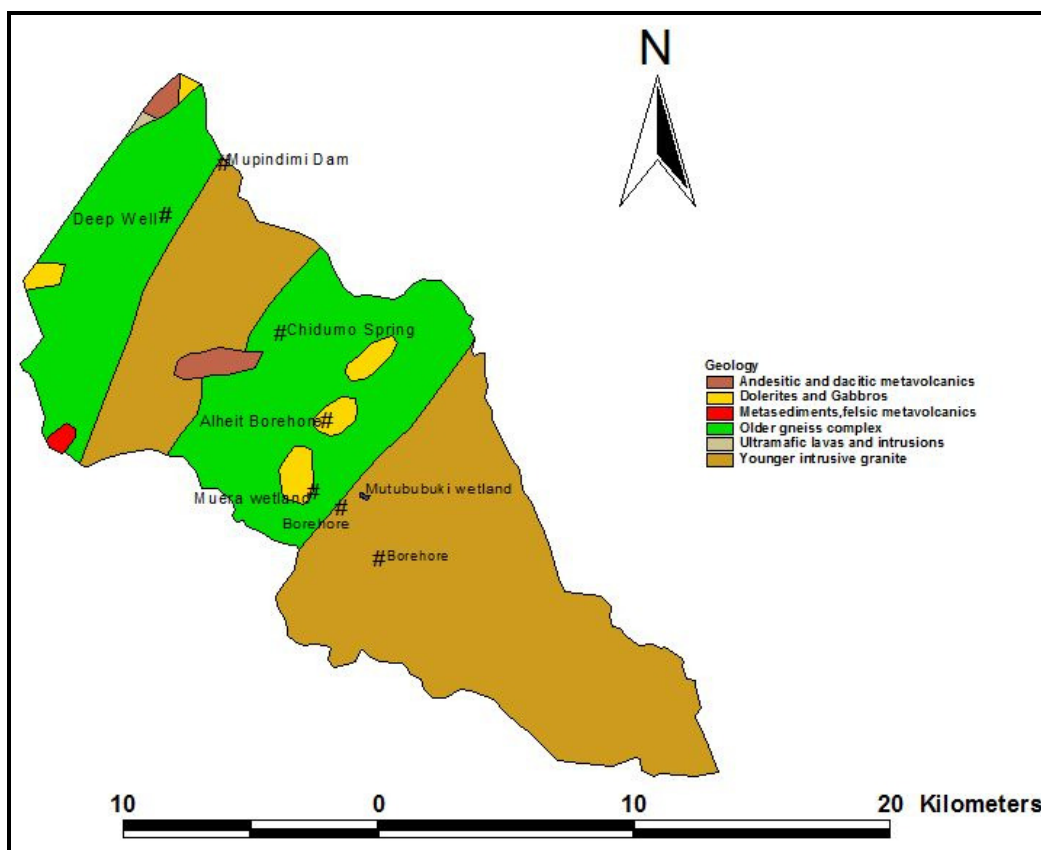The hand held GPS was used to take the coordinates

Figure 2. the Geology of Mutubuki wetland and its micro-catchment

of all the boreholes in the area and try to analyse patterns of their locations and whether they supply water throughout the year or dry out.

Geological Formations

Figure 2 shows the geological structure of the Mutubuki micro-catchment. The micro-catchment consists of mainly young intrusive granite rocks, older gneiss complex rocks and dolerite intrusions. The wetland is situated on an area close to the point of intersection of the young intrusive granite and the older gneiss complex rocks. Young intrusive granite rocks cover mostly the lower catchment of the wetland and a narrow belt sandwiched with an older gneiss complex on the upper catchment of the wetland (figure 2). Granite is an igneous rock, generally pink coloured, coarse and massive. It is composed essentially of quartz, feldspar and biotite. The grain is medium course, with occasional tendency to porphyrytic feldspar crystals (Acres et al., 1985, Whitlow, 1988; McFarlane, 1989).

The gneisses are metamorphic rocks which form under great heat and pressure. Gneiss rock complex covers the upper and middle parts of the Mutubuki micro-catchment (figure.2). The rock is foliated and banded in places especially close to Chimombe secondary school. The rocks are usually grey in colour, and richer in ferro-magnesian minerals than the massive granite (McFarlane, 1989).

Dolerite occurs in pockets inside the middle catchment belt of gneiss rock complex figure 2. It is an igneous rock that occurs as dykes and sheets and in many places, the dolerites are porphyrytic and form much of the highest ground in the granitic terrain where they form a protective capping as they are resistant to weathering (McFarlane, 1989). The dolerites weather into spheroidal boulders. The dolerites give rise to bright red soils often littered with the dark brown boulders (Owen et al, 1995).

RESULTS

Figure 3 (a) shows the accumulated flow map of the Mutubuki micro-catchment. Most of the water accumulates and flows in a south western and south eastern direction from the inter fluves on the micro-catchment. Figure 3 (a) mimics the flow of water mainly on the surface but groundwater has also been proven to follow similar patterns (but not always). Of importance, figure 3 (a) clearly shows the interfluves or watershed areas which are potential recharge zones of groundwater.
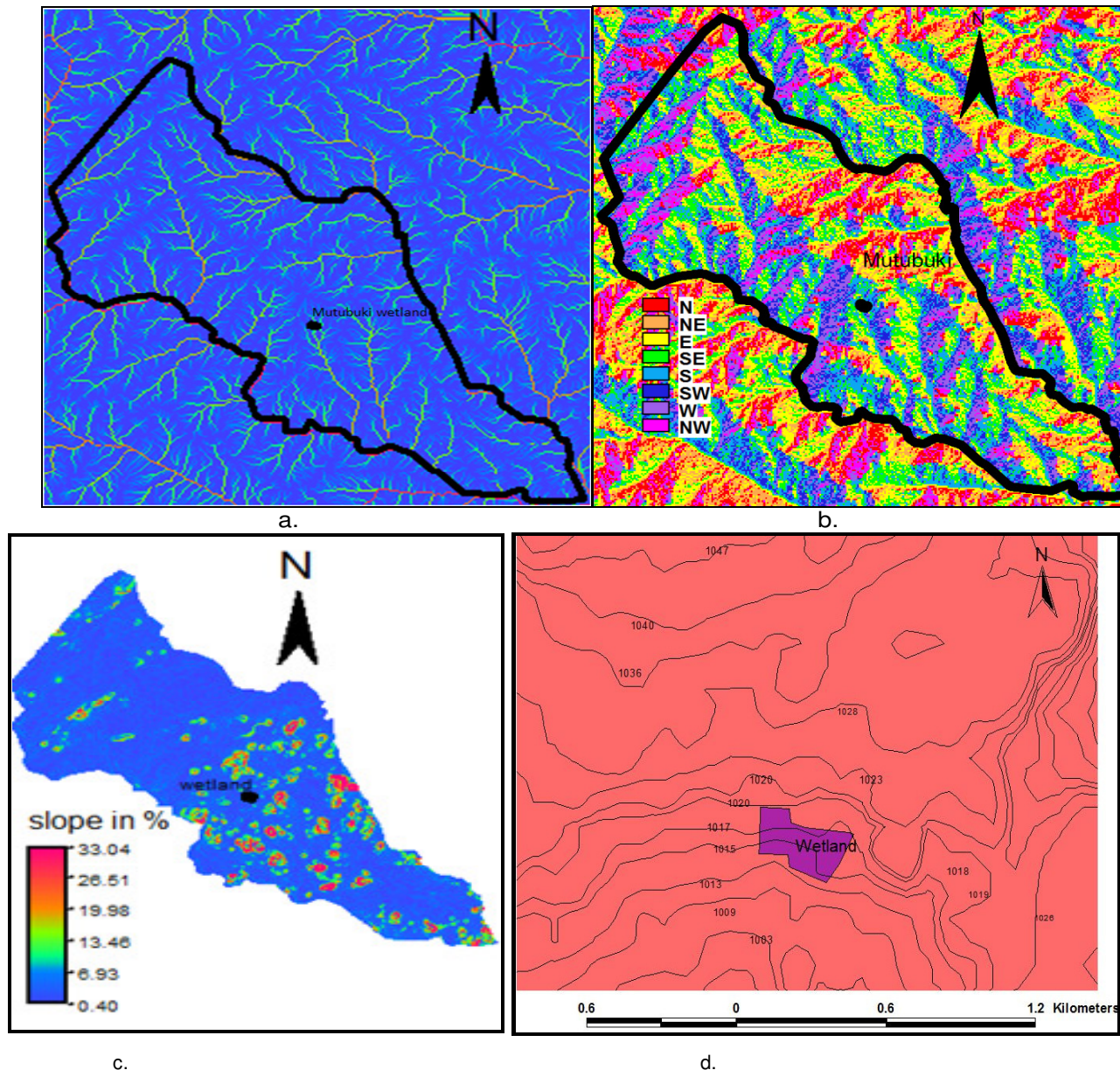
Figure.3: a) flow accumulation b) flow direction c) Slope measurements and d) contour maps (in metres) of Mutubuki wetland micro-catchment.

Figure 3(b) shows the flow direction map of the Mutubuki micro-catchment. Figure 3(b) shows the structure and form of the land surface and how it influences the flow direction to water in the catchment. The figure helps determine the origin of water that eventually accumulates on the wetland. Figure 3(b) shows that the Mutubuki wetland is on a depression and at the edge of a long ridge like feature which forms part of the interfluves of the micro-catchment. The general flow directions of water on the catchment are south west and south east.

Figure 3(c) shows the slope map of the catchment. The slope map is expressed in percent, meaning the number of units the land falls (or rises) in 100 units of horizontal distance. The higher the percent, the steeper the slope. It describes relief by expressing the ratio between the difference in level and horizontal distance. A 3% slope, for example, means a difference in level of 3 m over a horizontal distance of 100 m. The wetland is on depressed ground generally surrounded by higher ground on the southern parts of the micro-catchment.

The importance of calculating the slopes on the catchments is that it determines the direction of flow of water, the speed at which it flows on the catchment and how it gathers on certain areas than others. Generally, the slopes on the micro-catchment show flat land or depressions less than 0.5% to very gentle (0.5%-2%) especially on the areas around the wetland, gentle (2%-5%) to moderate(5%-9%) and pockets of steep to abrupt ≥ 9% especially on the middle to lower potions of the micro-catchment.

Figure 3(d) shows the contour map of the wetland and surrounding areas. Figure 3(d) shows that the wetland is located at a lowland and height of the area declines as one moves from north to south towards the wetland and from east to west. All this shows that the area around the wetland is at low altitude i.e. at 1013m as compared to 1047m to the north of the contour map therefore water accumulates in the wetland because it is depressed
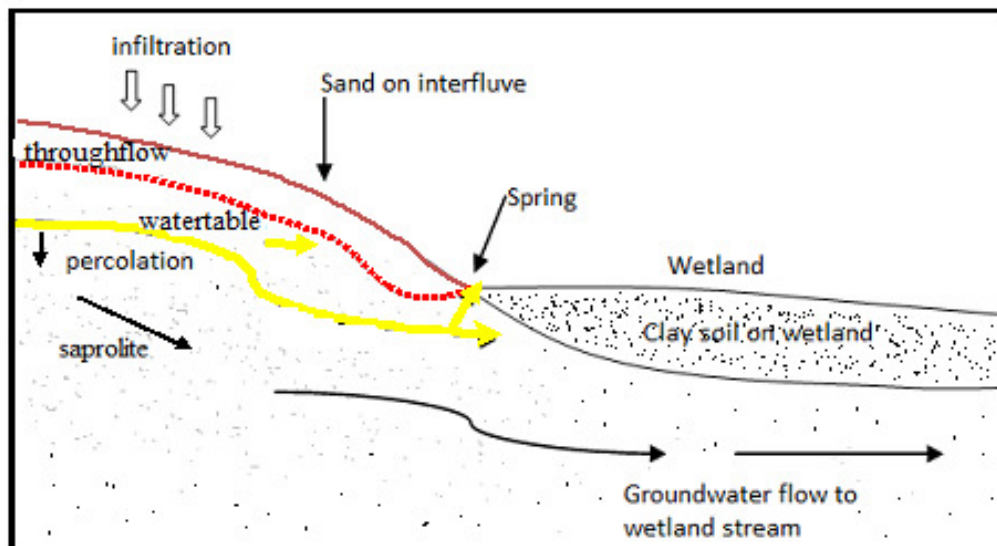
Figure 4. Cross-section of Mutubuki wetland

Figure 4 shows the cross sectional area of the wetland. The wetland occurs where free flowing ground water that is in transit down slope meets local resistance and is forced to the surface. The point at which groundwater merges from the surface is a point of weakness were permeable sand meets with a thick layer of impermeable clay(about 40cm) to produce springs around the areas. The high infiltration rates of the interfluves combine with some form of groundwater flow barrier down the land slope to produce a groundwater seepage zone where infiltrated water is forced to the surface creating the wetland.

DISCUSSION

The Mutubuki wetland occurs on an interfluve, which is an area of higher ground surrounded by lower ground and is a place where most of the drainage originates. interfluves are places of high water tables underlain by deep weathered rock, drain freely and have high hydraulic transmissivity. Headwaters on the interfluve are high and all of the boreholes and deep wells on them have high yields that support large populations e.g Alheit Mission School which has over a thousand students, two hundred stuff members and their families. The borehole at Alheit Mission also supplies water to the nearby communities and never dry up figures 2 and 1(a). Interfluves are potentially high recharge zones of the wetland because the sandy soil on them have high infiltration rates, the areas are on high ground with high transmissivity hence water easily flows down slope to the wetland and usually th interfluves have more vegetation cover than the surrounding areas because they are on mountains, the vegetation cover thereby increases the rate of runoff infiltration and further recharge of groundwater.

This if also confirmed by Whitlow (1988) who acknowledged that areas of granitic rocks, especially along the watershed (interfluves), may contain wetlands or dambos on more than one third of the area because of surface runoff and seepage of groundwater from catchment areas over impermeable substratum towards lower laying areas together with incident rainfall. Therefore deforestation of interfluves increases soil crusting thereby reducing infiltration, increasing surface runoff and reducing groundwater recharge.

The main machanisms of recharge of the Mutubuki wetland are subsurface throughflow from the interfluves and overland flow from the interfluves. Direct precipitation into the wetland is unlikely to have a significant contribution because the area receives low average rainfall. The wetland catchment average rainfall amount is less than 450mm per year (Vincent and Thomas, 1960, Unganai, 1996). This is in contrast to Balek and Perry (1973), Balek (1977) and Whitlow (1985) who described direct precipitation input as the dominant source of water to the wetlands they investigated, with subsurface inflow constituting less than one-quarter of the inflow budget. However, several authors consider groundwater and subsurface flow the dominant hydrological input to the dambo (Hindson, 1962; e.g., Bell et al., 1987; McFarlane, 1992; McCartney et al., 1998)

The relationship between the Mutubuki micro-catchment, the wetland and the streams which originate from the wetland is that the micro catchment collects water during a rainfall event, retains the amount it can hold and releases any excess slowly to the wetland, the wetland in turn holds the amount it can retain and releases any excess to streams that deliver it eventually to other rivers.

The Mutubuki wetland is associated with granite,

gneiss and dolerite rock formations as shown on figure 2. Many other wetlands in Zimbabwe and Southern Africa are associated with the same rock formations, Acres et al., (1985) mentions that the wetlands are generally associated with the African crystalline Basement Complex. Whitlow (1985) shows that 90% of Zimbabwean wetlands occur on the granites and gneisses forming part of the Basement Complex. McFarlane, (1989) shows similar wetland geology in Malawi, with the structures predominantly associated with schists, gneisses and other basement lithologies.

Generally young granitic rocks are more resistant to weathering than older gneisses rocks therefore gneiss rock complexes generally have deeper weathered rocks than the granitic rocks. In a situation where the softer rock (upstream) borders the harder rock downstream, local resistance to lower catchment movement of groundwater will occur and will force the water to pile up and flow to the surface along lines of weakness like the point of contact of sand soils of the interfluves and clay soils of the wetland. This is the case of the Mutubuki wetland as shown on figures 2 and 4. The water that fails to merge on the surface will be released from the wetland as stream flow on the lower parts of the wetland were the parent rock is near the surface because it resists deep weathering. It is essential that gullies do not form at the lower parts of the wetland because they will increase the rate at which groundwater leaves the wetland and then increases the rate at which it dries up.

The saprolite of the basement rock is typically less than 20 m thick but is generally thicker in the gneisses than in the granites which means that weathering generally more pervasive under gneiss and on granite rocks. Borehole depths under granite rocks generally range from 40-60 m and depth to water levels range from 10-20 m below ground level. Under gneiss rocks borehole depths are generally deeper, up to 85 m and depth to water levels mostly lie between 15 and 30 m (Wright 1989; Barker et al., 1992; Owen et al, 1995). Typically when granite weathers chemically, it produces clay which further reduces the permeability and transmissivity of the wetland and encouraging water logging and the continued presence of the wetland (Barker et al., 1992).

Mutubuki Wetland clay content is generally higher than that of the surrounding interfluves and increases in thickness as one move towards the centre of the wetland. Boast, (1990) also found clay to increase towards the wetland centre, McFarlane (1989) ascribes this increase to an in situ weathering process, with advanced bedrock weathering at the wetland centre and Whitlow (1985), attributes the increase in wetland clay content to transportational sorting in addition to the more favourable clay-forming conditions at the wetland centre.

The presence of the dolerite close to the wetland is an important factor in the groundwater recharge and movement processes. On figure. 2, the   intrusion of

dolerite dykes on a relatively weaker gneiss rock means the outstanding dolerite rocks outcrops act as flow barriers and, in conjunction with the greater fissuring commonly associated with dykes, may enhance the accumulation of water impeding the process of surface runoff in the area and encourage water infiltration and groundwater recharge on relatively deeper weathered gneiss rock. The wetland falls within the direct path of groundwater channelled down the catchment at the gaps between two dolerite rock outcrops (figure.2).

Chilton and Foster, (1995) also concur with the fact that the dolerite dykes are important zones for groundwater occurrence. Contact zones of dolerite dykes and the gneisses or granite provide moderate to high groundwater potential. This is the reason why boreholes and wells that are within 25 m of dykes is more productive compared to wells further away. For example the Alheit school pump located close to the point of intersection between the dykes and gneiss rock formation (figure. 2) so productive that it supplies water to over a 1000 student and teachers daily. Just a kilometre away, boreholes and deep wells dry up and do not provide water throughout the year. A further attempt to drill a second borehole for the school about 500m from their first borehole failed after drilling all the way to the parent rock about 65m deep but yielded no groundwater.

Figure 3(b) shows that the Mutubuki wetland occurs at an area that is at the edge of higher ground or an inland valley and figure 3(c) shows that the area is a depression with slopes than 0.5%. The gentle relief results in low-energy surface runoff that enables water infiltration, thus decreasing erosional and channel forming processes. The location of the wetland is consistent with what Acres et al. (1985), Whitlow, (1985); McFarlane, (1989); Bullock, 1992 and Owen et al, (1995) found to be the locations associated with wetland formation. They describe wetland profiles as primarily concave, with shallow slopes and gradients less than 2% possessing low hydraulic conductivity and permeability, owing to the accumulation of clays. Thus these soils are poorly drained and largely form an impermeable barrier to vertical movement of water between the wetland surface and the underlying regolith.

CONCLUSIONS

Geological factors governing the occurrence of wetlands must be first understood in order to design sound management tools of degraded wetlands. The Mutubuki wetland occurs where deep weathered and softer gneiss rocks meet with harder younger granitic rocks. The presence of dolerite dyke outcrops on gneiss rock further increases the accumulation of groundwater by encouraging infiltration of surface water and recharging the wetland. The interfluve of the micro-catchment where the wetland occurs was also identified as an important

recharge zone. The wetland occurs at the edge high ground where further down slope movement of groundwater is impeded and forced to the surface by a thick layer of clay on the wetland.

ACKNOWLEDGEMENTS

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