A review of the mires of Lesotho: bogs or fens?

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SUMMARY

The highlands of Lesotho form part of the Great Escarpment of southern Africa with an elevation ranging from 2000–3482 m a.s.l. This mountainous landscape contains many wetlands which, although small in extent individually, together likely exceed thousands of hectares with some of them peat-forming, therefore, mires. They form the headwaters of the Senqu River, a major tributary of the Orange-Senqu river basin. Earlier research described these wetlands as raised bogs based on high rainfall in the Maloti Mountains. More recent studies recognised the importance of groundwater as the driving force behind the hydrology of these mires. The present study attempts to review the contradictory information and classification of these mires in the literature and to establish an understanding on the functioning of these mire types in order to inform their protection and management. Second, this review aimed to explore the hydrology, chemical composition and morphology of the mires and revise their subsequent characterisation. Results indicated that these mires are dependent on surface and groundwater flows; their water pH varies between 5.0 and 7.0. Exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) are generally high, supporting vegetation that is highly productive and comprises herbs and sedges. The weight of evidence suggests that the mires of Maloti Mountains are fens and not bogs.

KEY WORDS: morphology, recharge, water chemistry, highlands

INTRODUCTION

Lesotho is a land-locked country within South Africa with a land area of 30,588 km^2 (Olaleye *et al*. 2014) and four distinct physiographic zones, namely the mountains/highlands (2000–3482 m a.s.l, covering 59 % of the land area), the lowlands (<1800 m a.s.l, accounting for 17 % of the land area), the foothills (1800–2000 m a.s.l., occupying 5 % of the land area) and the Senqu river valley (1000–2000 m a.s.l., constituting 9 % of the land area) (ORASECOM 2014).

Wetlands can be found in all the physiographic zones of Lesotho (Olaleye & Sekaleli 2011) and are presently estimated to cover 0.92 % of the land area (FAO 2023). They have been reduced from a previously estimated land area coverage of 1.1 % (FAO 2017). More than 50 % of the wetlands are concentrated in the highlands of the country (Figure 1). At an altitude of 2100–3300 m a.s.l, Backéus (1989) identified these wetlands as mires. Smaller ones are found at an altitude of 2100–2900 m a.s.l and larger ones from 2900–3300 m a.s.l (Schwabe 1985, Backéus 1989, Grundling *et al*. 2015). They occur as seeps on valley mid-slopes, and in river heads (Backéus 1988, Grundling *et al*. 2015). They can easily be identified across the mountain landscape as green patches that result from their distinct vegetation (Chatanga & Seleteng-Kose 2021). According to Van Zinderen-Bakker & Werger (1974), Schwabe (1985) and Grab & Deschamps (2004), the mires are dominated by mat-forming lawns consisting of herbs (*Haplocarpha nervosa*, *Athrixia fontana*, *Cotula paludosa*, *Sebeae marlothii*, *Helichrysum flanaganii*), grasses (*Merxmuellera disticha*) and sedges (*Isolepis angelica)*. More recent studies (Sieben *et al*. 2010, du Preez & Brown 2011, Chatanga & Sieben 2020) point out that the most dominant plant functional types (PFTs) in the mires of Lesotho are grasses and sedges which are adapted to the high-altitude environment. Kahlolo *et al*. (2021) recorded the following dominant mat-forming herb (*Trifolium burchellianum*, *Haplocarpha nervosa*, *Cotula paludosa*), sedge (*Ficinia cinnamomea*), and grass (*Eragrostis caesia*) species in the wetland at Letseng-la-Letsie. This agrees with previous studies (Van Zinderen-Bakker & Werger 1974, Schwabe 1985, Grab & Deschamps 2004, Sieben *et al*. 2010, du Preez & Brown 2011, Chatanga & Sieben 2020) which confirm that herbs, grasses and sedges dominate the plant communities of Lesotho's mires.

A notable physical feature of the Maloti Mountains mires is the presence of hummocks which result in a raised mire landform (Van Zinderen-Bakker & Werger 1974). According to Kotze & O'Connor (2000), the hummocks are formed by activities of earthworms. Van Zinderen-Bakker & Werger (1974) further state that hummocks will develop because of the ongoing seasonal frost action which causes the expansion (due to freezing) of the patches of ground that are less covered by vegetation. Dimensionally, the hummocks may be as much as 30 cm wide, 20 cm high (Kotze & O'Connor 2000) and 60 cm long (Grenfell *et al*. 2019).

Definition of the mires of Lesotho and their function must be taken in context with accepted terminology documented in the literature. The Ramsar Convention (1971) defined wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water of which the depth at low tide does not exceed six metres". A peatland is an area with an accumulated peat layer of at least 30 cm depth, and where the peatland is actively forming peat it is called a mire (Joosten *et al*. 2017, Lindsay 2018). Peatlands provide the largest store of carbon in the world's terrestrial ecosystems (Lourenco *et al*. 2022). According to Joosten & Clarke (2002), peat is an organic layer (with at least 30 % organic matter) that has accumulated sedentarily under anoxic conditions. The process of peat formation involves the accumulation of dead organic material under inundated or near saturated conditions on the surface, while in the layers below, the dominant process is slow decomposition of the organic matter under anoxic conditions (Malmer & Wallen 1999). This differs with histosols that contain at least 12–18 % organic carbon (20–30 % organic matter) in the upper 40 cm of the soil or any thickness if that rests on a rock (Andriesse 1988).

Mires are classified into bogs and fens (Rydin & Jeglum 2006). The distinguishing feature between a bog and a fen is the type of water that feeds them: a bog is raised above the surrounding landscape and receives water only from precipitation (ombrogenous), while a fen is situated in a depression and receives water that has been in contact with mineral bedrock or soil (geogenous) (Keddy 2010, Grootjans *et al*. 2012, Joosten *et al*. 2017, Lindsay 2018). Fens (geogenous mires) are divided into the following categories (Sjörs 1948, Joosten *et al*. 2017): (1) limnogenous, which develop from wet conditions caused by inundation or permanent influence of water from lakes and rivers; (2) lithogenous, which receive water from precipitation and deep groundwater; (3) soligenous,

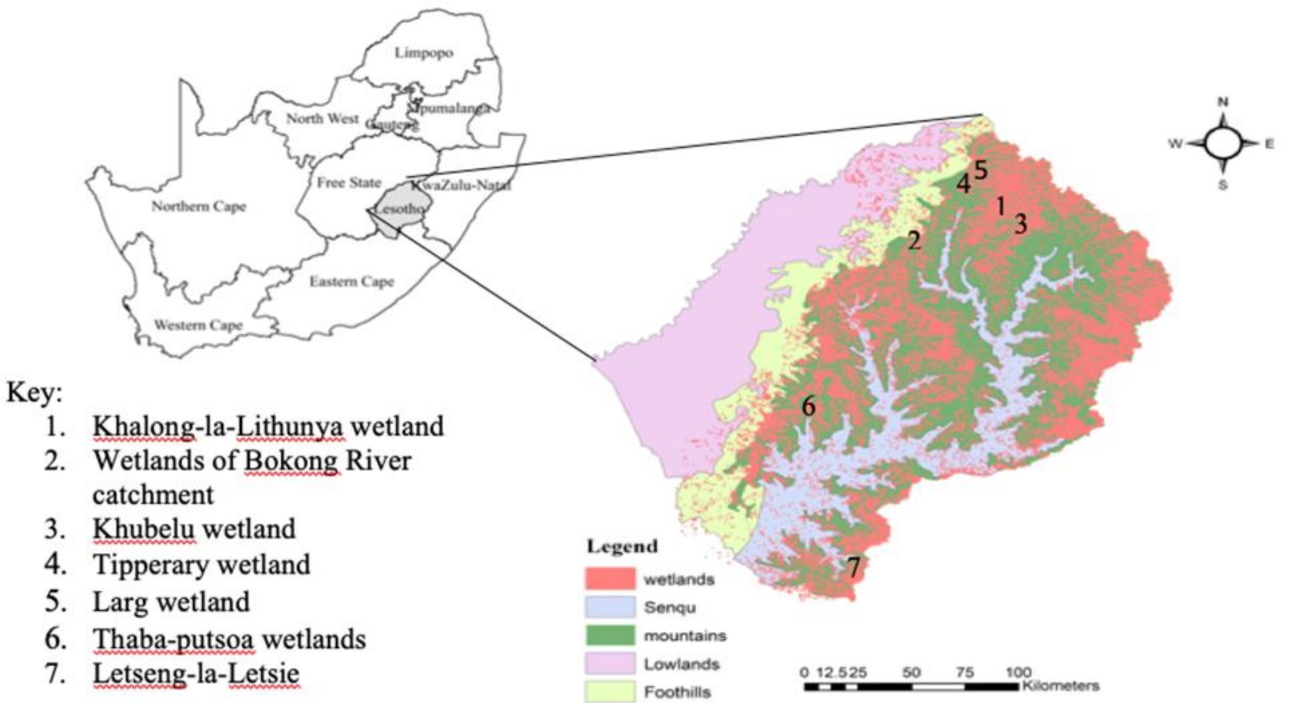

Figure 1. Wetlands in the physiographic zones of Lesotho and the location of study areas (map developed using ArcGIS).

which receive water from precipitation and surface water. Soligenous mires receive telluric water, i.e., water that has had contact with mineral soil including surface runoff, and with meteoric water, i.e., precipitation (Money *et al*. 2009). Soligenous mires are recharged when rainfall intensity exceeds the rate of infiltration at the soil surface, or the topsoil is already water saturated and then runoff via overland flow will occur (Lin *et al*. 2008) leading to surficial water inflow into the mire. Again, a mire will be recharged when the combination of rainfall intensity and duration raises the water table and returns to the surface as return flow seepage or groundwater discharge as in lithogenous mires (Steenhuis *et al*. 2005).

Bogs and fens are further differentiated by their nutrient levels and chemistry. The plant-available nutrients and water chemistry (pH and chemical composition) of a bog and a fen are determined by their water origin (Joosten *et al*. 2017). Wassen & Grootjans (1996) state that infiltration of precipitation water, discharge of groundwater, and surface runoff all contribute differently to the specific ionic composition of the wetland. The concentrations of Ca^{2+}, Mg^{2+}, Fe^{2+}, Na^{+}, K^{+}, $HC0_3^{-}$, $S0_4^{2-}$ and Cl^{-} are often used to distinguish between the different sources of water (Grootjans *et al*. 2012). The presence of higher concentrations of these ions suggests stronger groundwater inputs as may occur in fens, whereas low concentrations suggest ombrogenous conditions as occur in bogs. The presence of cations, particularly Ca^{2+} and Mg^{2+} may increase the pH, and therefore affect the trophic status of the system. According to Havlin (2005) exchangeable cations increase with pH ≥6.5. A bog is characterised by a low pH (<5.5) and is ombrotrophic. Peat mosses, more than almost any other plant species, are adapted to such wet, acidic and nutrient-poor conditions and therefore dominate the bog vegetation (Eurola *et al*. 1984). Fens, on the other hand, are slightly acidic to neutral (pH>5.5) (Van der Valk 2006), mesotrophic to eutrophic and are mainly characterised by a more productive vegetation, consisting of helophytes, grasses and sedges, and in some cases by mosses (*Hypnacaea*) (Joosten & Clarke 2002).

Earlier research from the 1960s–1990s (Jacot-Guillarmod 1963, Van Zinderen-Bakker & Werger 1974, Grobbelaar & Stegmann 1987) described the wetlands in the highlands of Lesotho as rainwater-dependent raised bogs based on high rainfall. The more recent studies (Grundling *et al*. 2015, Mapeshoane & van Huyssteen 2016, Mots'ets'e *et al*. 2017), however, recognised the importance of groundwater sources in the hydrology of these wetlands, suggesting they are not bogs. Considering the contradictory findings in the literature on the classification of Lesotho mires, this study aims to review the current state of knowledge on these mires and establish an understanding of the functioning of the different mire types, namely bogs and fens. A clearer understanding of their functioning can better inform land managers for their protection and sustainable use. The following mires will form the basis of this review: Larg mire, Tipperary mire, Khalong-la-Lithunya mire, and Bokong River Catchment mires (Figure 1). Although the Khubelu, Thaba-putsoa and Letseng-la-Letsie mires are cited in this review there is limited information and data for their broader analysis and discussion.

RESEARCH ON THE MIRES OF LESOTHO

Larg and Tipperary mires

Morphology

The Larg wetland (Figure 2) is an elongated mire of approximately 17 ha, situated on an open hillslope at Mahlasela pass (Jacot-Guillarmod 1963). It is within 10 km of Tipperary mire (Figure 3) which covers approximately 23 ha. Larg mire is positioned at 3018–3214 m a.s.l. while Tipperary mire is at 2493–2562 m a.s.l. These two mires are representative of the general mires of the Maloti Mountains in that some mires are located on seepage areas on steep mountain slopes (Larg mire) and others within the headwaters of rivers (Tipperary mire), where they can receive storm water in-flow (Van Zinderen-Bakker & Werger 1974). Jacot-Guillarmod (1963) described the morphology of the two mires: both mires are described as raised above their surroundings. Larg mire, despite being situated on a hillslope, is unlikely to be affected by the inflow of surface runoff water because of its raised position, while Tipperary mire rises 46 cm above an adjoining storm water channel. Nonetheless, Tipperary mire, in contrast to Larg mire, is a headwater mire situated on a drainage channel that collects much of the run-off water from the hillslopes surrounding the mire and is thus likely to occasionally become flooded.

Mire recharge

In order to understand how the Larg and Tipperary mires are recharged, it is important to note that the water that recharges a sloping and headwater-positioned mire is both telluric and meteoric (Wassen *et al*. 1996). Jacot-Guillarmod (1963) suggested neither Tipperary nor Larg mires receive runoff water because she considered them to be "raised bogs" but noted they must be groundwater-fed because several springs occur within them (notwithstanding the current definition of bogs as entirely ombrogenous). According to Jacot-Guillarmod (1963), the groundwater enters the Larg mire through a spring welling up within it, while the Tipperary mire receives groundwater from several springs that flow into channels and spread to cover the surface of the mire, while some springs form pools of water within the mire (Jacot-Guillarmod 1963). No water chemistry is available for these systems.

Khalong-la-Lithunya mire

Morphology

The Khalong-la-Lithunya mire represents a large headwater wetland of approximately 20 ha, situated at 3149–3197 m a.s.l. and surrounded by gentle basalt hillslopes (Figure 4). It is approximately 330 m wide on the valley head and 1100 m long, is covered by low, dense, mat-forming vegetation and has hummocks that create a micro-relief (Van Zinderen-Bakker & Werger 1974). According to Grobbelaar &

Figure 2. Google Earth image (2023) showing Larg mire (indicated by yellow line).

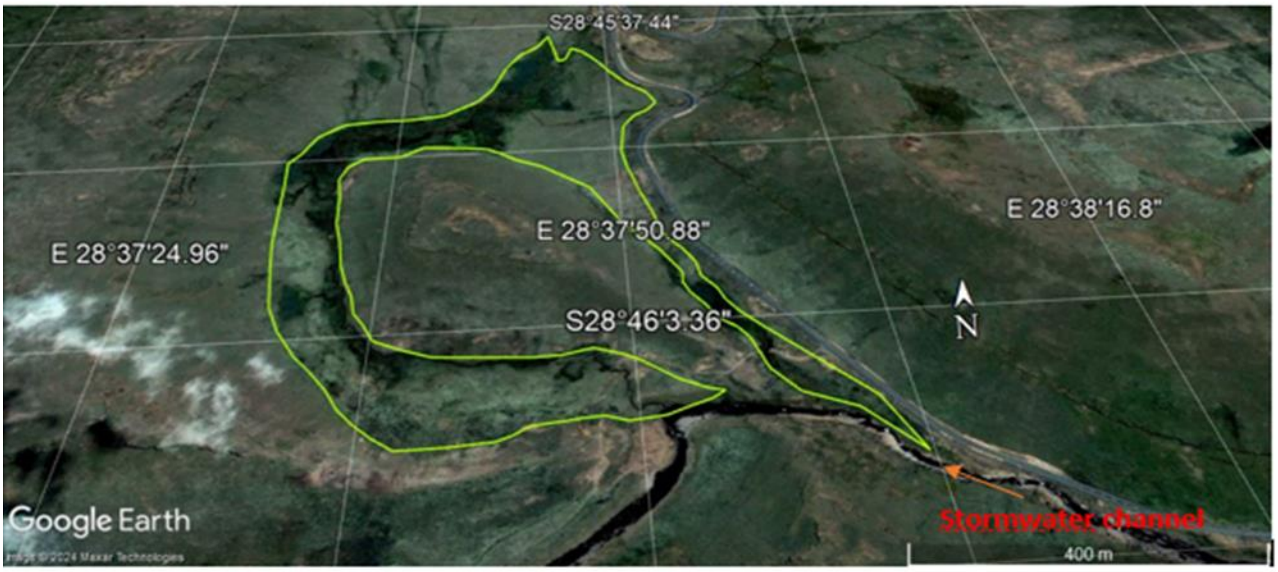

Figure 3. Google Earth image (2023) showing Tipperary mire (indicated by yellow line).

Stegmann (1987) it has shallow streams draining it and several pools scattered over the mire but concentrated in the central area; also, deep gullies occur in the mire, up to 0.5 m deep in some of the streams and up to 1 m in pools.

Mire recharge

The Khalong-la-Lithunya mire receives overland flow from springs at the top of the mire and this flows through small stream channels to the lower parts of the mire (Grobbelaar & Stegmann 1987). During heavy rains in summer, the overland flow in the mire forms a sheet flow without building channels (Van Zinderen-Bakker & Werger 1974). According to Grobbelaar & Stegmann (1987), in winter, streams and pools in the mire dry up completely with only a small amount of water leaving the mire. In summer, however, heavy rainfall flushes out the streams and pools, influencing the chemical composition of the water.

In a more recent study of Khalong-la-Lithunya mire by Mots'ets'e *et al*. (2017), the authors noted an elevated water table even after rainfall had long stopped and attributed this to sub-surface flow recharging the wetland. However, no groundwater measurements were made by the authors to quantify how much water inflow occurred after rainfall had stopped. Instead, Mots'ets'e *et al*. (2017) measured natural isotopes (δ^2H and $\delta^{18}O$) of groundwater, stream flow and rainfall. Based on the negative mean isotope ratio ($^0/_{00}$) distribution of δ^2H and $\delta^{18}O$ for groundwater drawn from piezometers (-18.39 for δ^2H and -3.92 for $\delta^{18}O$) and the stream (-1.35 for δ^2H and -1.39 for $\delta^{18}O$) compared to the positive values for rainfall (64.0 for δ^2H and 10.28 for $\delta^{18}O$), they concluded that the wetland is fed by groundwater, contrary to Grobbelaar & Stegmann (1987) who emphasised rainfall dependence.

Water chemistry

The results of chemical analysis of water samples collected from rainfall and selected streams and pools in the study of Khalong-la-Lithunya mire by Grobbelaar & Stegmann (1987) are presented in Table 1. Rainfall water is more acidic than the water from pools and streams in the mire, which is only slightly acidic to neutral. Where electrical conductivity is low, such as in rainfall, ion concentrations are low but where electrical conductivity is much higher as in pools (1 and 2) and streams (1 and 2), ionic composition is higher. Ion concentrations in rainfall are low compared to streams and pools, with the highest concentration of ions dominated by Ca^{2+}, Na^+, K^+ and Mg^{2+}. Generally, the concentrations of N (the plant available forms NH_4^+ and NO_3^-) and S compounds (SO_4^{2-}) are highest in streams and pools. Grobbelaar & Stegmann (1987) did not investigate the interactions of groundwater with surface water in the system.

In the same study of Grobbelaar & Stegmann (1987), chemical analysis of soil-water (pore-water) (Table 2) indicates high concentrations of dissolved minerals on the surface at the top-end and bottom-end of the mire compared to other parts where rock rubble was sampled. The main base-cations in all the sampling points are Ca^{2+} and K^+, while the anions are

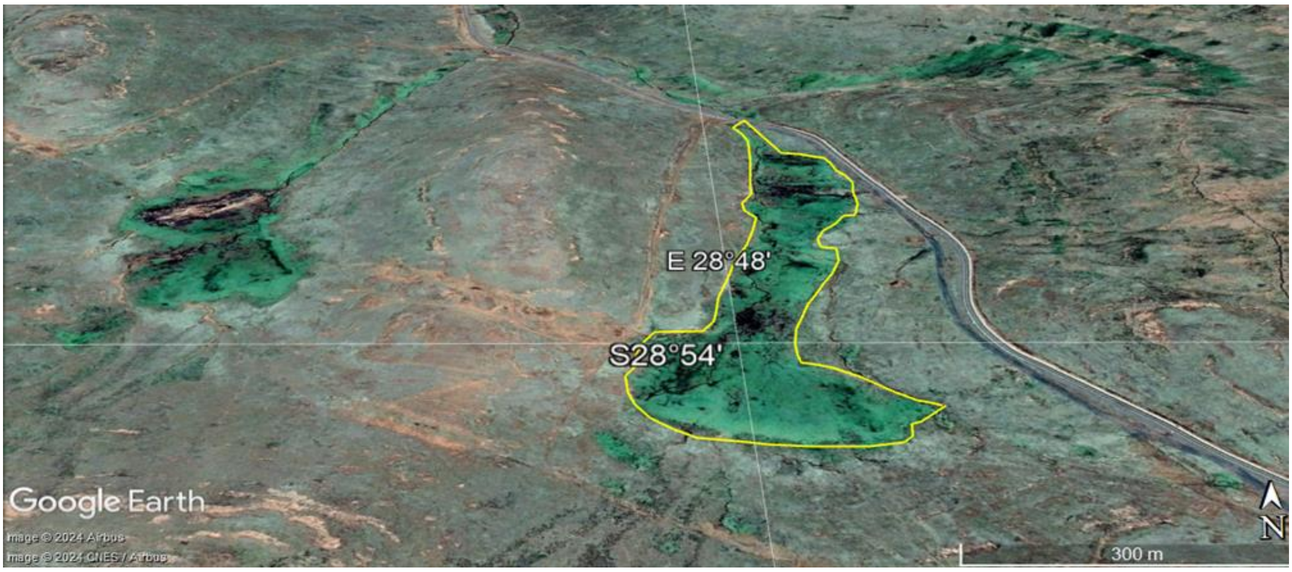

Figure 4. Google Earth image (2023) showing Khalong-la-Lithunya mire (indicated by yellow line).

dominated by SO_4^{2-}. Generally, soil pH is comparable in all the sampling points and is slightly acidic. This is similar to the mires of the Thaba-putsoa range where pH ranges in seepage zones were 6.1–6.2, 6.2–6.4, 6.5–6.7 and 6.9–7.3 while pH ranges in inundated zones were 6.6–6.9, 6.8–7.1 and 7.2–7.9 (Backéus 1988).

The chemical composition of water collected at a depth of 0.5 m from December 2010 to March 2011 (rainfall season) at Khalong-la-Lithunya mires by Olaleye *et al*. (2022) showed high values of K^+ (70.73 mg/L), and Mg^{2+} (43.12 mg/L), while Na^+ (2.44 mg/L) and Ca^{2+} (0.63 mg/L) were low. These values were similar to those measured at nearby Khubelu mire (location shown in Figure 1), which also showed low levels of Ca (6.25 mg/L) compared to other base cations including Na^+ (10.68 mg/L), and Mg^{2+} (9.42 mg/L) (George & Ngole-Jeme 2022). The observed differences in ionic values between Grobbelaar & Stegmann (1987) and Olaleye *et al*. (2022) appears to emanate from the depths at which the samples were taken. Olaleye *et al*. (2014) measured the pH of Khalong-la-Lithunya mire for four years (2009–2012) and recorded a slightly acidic pH (6.13–6.44), while Mots'ets'e *et al*. (2017) reported a pH of 5.7. Slightly acidic pH was also found at Khubelu, ranging from 6.32–7.11 (George & Ngole-Jeme 2022) and Lets'eng-la-Letsie (pH of 5.52; location shown in Figure 1) (Kahlolo *et al*. 2021).

Bokong River catchment mires

Mire recharge

Another study that investigated the hydrology of the mires of Lesotho is provided by Mapeshoane & van Huyssteen (2016), who observed water levels in

Table 1. Chemical analysis of water at Khalong-la-Lithunya from different sampling points (Grobbelaar & Stegmann 1987). Units are mg/L except for pH and EC.

Sampling points	pH	EC (mS/m)	Na	K	Ca	Mg	Si	Fe	Cl	SO_4^{2-}	PO_4^{3-}	NH_4^+	NO_3^-
Stream 1 ($\bar{x}$)	6.99	4.62	1.48	0.13	4.80	2.16	6.20	0.08	0.06	3.82	0.0	0	30
Stream 2 ($\bar{x}$)	6.45	6.94	1.62	0.4	5.26	2.99	6.78	2.18	1.03	3.39	0.3	10	60
Pool 1 ($\bar{x}$)	6.28	3.97	0.84	0.11	3.98	1.73	5.80	1.19	0.28	8.10	0.7	10	50
Pool 2 ($\bar{x}$)	6.24	4.18	1.59	0.56	4.25	1.85	5.33	1.14	1.25	7.14	0.3	30	60
Rainfall ($\bar{x}$)	5.20	1.10	0.43	0.25	0.54	0.11	-	-	0.05	0.93	-	-	-

Table 2. Chemical analysis of soil-water at Khalong-la-Lithunya mire: soil surface and beneath the soil surface (Grobbelaar & Stegmann 1987). Units (except for pH): mg/200 g.

Sampling points	Description	pH	Na	K	Ca	Mg	Fe	Cl	SO_4^{2-}	NH_4^+	NO_3^-
Western face ($\bar{x}$)	Rock rubble (30 cm deep)	6.39	5.2	9.5	26.5	6.60	2.50	1.70	41.7	1.31	1.47
Northern face ($\bar{x}$)	Rock rubble (25 cm deep)	6.50	7.5	3.6	26.0	7.60	1.24	0.71	21.3	1.40	0.86
Eastern face ($\bar{x}$)	Surface	6.21	4.9	8.5	17.3	5.07	3.00	2.64	20.7	1.43	0.87
Eastern face ($\bar{x}$)	Rock rubble (30 cm deep)	6.60	7.2	3.3	17.8	5.80	4.90	0.57	19.9	1.13	0.15
Top-end of the mire ($\bar{x}$)	Surface	6.70	16.8	38.5	35.5	14.80	39.20	0.69	120.5	5.24	34.27
Bottom-end of the mire ($\bar{x}$)	Surface	5.93	5.6	11.7	22.5	7.50	9.30	6.36	123.8	3.10	16.30

piezometers installed in triplicate at depths of 5 cm, 25 cm, 50 cm, 75 cm and 100 cm in ten wetlands in the Bokong River catchment (Figure 5). They showed dropping water levels in winter at the onset of the dry season in the deeper piezometers, but stable water levels in the shallow piezometers. Mapeshoane & van Huyssteen (2016) suggested wetlands were fens where the groundwater level rose in deep piezometers (75 and 100 cm) during the low rainfall season, and bogs where the groundwater level fell during the same season. Notwithstanding their classification, all these wetlands received surface water inflow (Mapeshoane & van Huyssteen 2016), contrary to the accepted definition of bogs being strictly ombrogenous. Confusion as to the classification stems from their reliance on soil carbon content, as described below.

Water chemistry and nutrients

Analysis of water chemistry in the mires of Bokong River catchment was done only for pH. Generally, the mires had a pH >5 (Mapeshoane & van Huyssteen 2016). Mapeshoane & van Huyssteen (2016) classified these wetlands based on their organic carbon content. Those that had >12 % organic carbon content were classified as bogs while fens were those with <12 % organic carbon content. Out of the ten wetlands in that study, four were classified as fens, three as bogs and the other three as hillslope seeps.

DISCUSSION

Given that a mire's geomorphic position and local climatic condition determine its water source and chemistry (Van der Valk 2006), it follows that Larg mire, situated on a steep slope and fed by springs, will be telluric and sustained by groundwater. It is more appropriate, therefore, that it is classified as lithogenous fen and not bog, as suggested by Jacot-Guillarmod (1963). The same classification applies to the Tipperary mire which receives groundwater seepage. The Khalong-la-Lithunya mire is base-rich and receives flow from springs that have water chemistry which is slightly acidic to neutral. This favours faster decomposition of organic matter (Neina 2019) leading to higher availability of nutrients in the mire, which supports the presence of vegetation dominated by helophytes, grasses and sedges (Van Zinderen-Bakker & Werger 1974, Schwabe 1985, Grab & Deschamps 2004, Sieben *et al*. 2010, du Preez & Brown 2011, Chatanga & Sieben 2020). In terms of hydrological classification, the mire is also lithogenous.

Water levels in the shallow piezometer in the mire at the Bokong River catchment were stable during the dry season while levels in the deep piezometers were dropping. The most likely explanation for this is in the properties of the subsurface layers of alternating peat, clay (or highly humified peat) and gravel beds

Figure 5. Google Earth image (2023) showing Bokong River catchment mires (indicated by yellow line).

in the profile, where peat and clay will store water for longer and release it slowly, but the deeper gravel layers are more permeable and will drain more rapidly. Furthermore, perched water tables will develop on top of the less permeable shallower peat and clay layers during rainfall events and subsequent surface inflow from adjacent hillslopes as alluded by Mapeshoane & van Huyssteen (2016). If these mires were classified based only on hydrology, they would be soligenous fens. However, given the low carbon contents of these soils with <18 % carbon (< 30 % in dry weight of dead organic material) does not qualify them as peat (Joosten and Clark 2002) but as histosols. Furthermore, the use of carbon content by Mapeshoane & van Huyssteen (2016) to classify mires as bogs or fens is contrary to the established methodology of using water origin and associated water chemistry.

It is important that the Maloti Mountains mires are correctly classified to ensure their proper management in setting conservation targets and utilization guidelines. Determining the hydrology is key in mire management because an altered source of water, for example, will impact differently on the functioning of either a bog or fen (Money *et al*. 2009). Fens are more sensitive than bogs to interventions occurring in their catchment area, and this affects their ability to perform ecosystem functions (Ellery *et al*. 2016). Essentially, before any restoration objectives are set, not only the wetland but also its surrounding landscape should be considered, especially its hydrology. The reinterpretation of the research presented in this review, using acknowledged mire typology, clearly indicates that the mires in the Maloti Mountains of Lesotho are fens and not bogs. All three parameters that were reviewed, namely morphology/topography of the mires, the source of water, and water chemistry, confirm minerotrophic and geogenous mires as opposed to ombrotrophic and ombrogenous systems.

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TSS: Conceptualisation and write-up; PLG: reviewing and editing; AJ: reviewing and editing

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