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REPORT

Combined electrical resistivity tomography and magnetic resonance sounding investigation of the surface-water/groundwater interaction in the Urema Graben, Mozambique

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Abstract This study focusses on the hydrogeology of Urema Graben, especially possible interactions between surface water and groundwater around Lake Urema, in Gorongosa National Park (GNP). Lake Urema is the only permanent water source for wildlife inside GNP, and there are concerns that it will disappear due to interferences in surface-water/groundwater interactions as a result of changes in the hydraulic environment. As the lake is the only permanent water source, this would be a disaster for the ecosystem of the park. The subsurface geology in Urema Graben was investigated by 20 km of electrical resistivity tomography (ERT) and three magnetic resonance sounding (MRS) surveys. The average depth penetration was 60 and 100 m, respectively. The location of the ERT lines was decided based on general rift morphology and therefore orientated perpendicular to Urema Graben, from the transitional areas of the margins of the Barue platform in the west to the Cheringoma plateau escarpments in the east. ERT and MRS both indicate a second aquifer, where Urema Lake is a window of the first upper semi-confined aquifer, while the lower aquifer is confined by a clay layer 30–40 m thick. The location and depth of this aquifer suggest that it is probably linked to the Pungwe River which could be a main source of recharge during the dry season. If a dam or any other infrastructure is constructed in Pungwe River upstream of GNP, the groundwater level will decrease which could lead to drying out of Urema Lake.

Keywords Electrical resistivity tomography · Magnetic resonance sounding · Unconsolidated sediments · Groundwater flow · Mozambique

Introduction

Gorongosa National Park (GNP) in Mozambique is under rehabilitation. The understanding of hydrogeological conditions is a key factor for better management (Beilfuss et al. 2007) because key ecosystems, particularly the mega-fauna, are strongly dependent on the perennial water of Lake Urema. The lake is considered a perennial groundwater-dependent ecosystem (GDE; Beilfuss et al. 2007) linked to groundwater discharges. The Urema Graben with its floodplains is host to many ecosystems supporting a rich biodiversity with a huge carrying capacity for large herbivores.

The sustainability of Lake Urema is sensitive to changes in surface-water/groundwater interactions that may change the prevailing hydraulic gradients; to climate variability leading to reduced recharge to the groundwater systems; and to removal of vegetation cover in the upstream areas, either by climate change or by anthropogenic pressures, leading to increased sedimentation and siltation in the floodplain. Understanding the hydraulics of the Lake Urema GDE is key to the sustainability of these ecosystems.

In the tropical climate in central Mozambique, the rainfall is strongly seasonal. On an annual basis, the evapotranspiration exceeds rainfall by 500–1,000 mm, causing a water deficit during the dry season, and resulting in the drying out of many small lakes and rivers (Beilfuss et al. 2007). An

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exception is the Lake Urema located in the terminal end of the Urema Graben, the southernmost extent in the East African Rift in Mozambique (Fig. 1). Lake Urema receives surface run-off from seasonal sources and has only a single outflow known as Urema River. Part of the contribution to the inflow to the lake originates from groundwater (Owen 2004); however, the groundwater inflow into the lake is small in the dry season (McCartney and Owen 2007). Isotope hydrology studies have shown that Lake Urema is maintained by water generated during the wet season. The flat planar graben valley floor has restricted outflow, and as a result forms a waterlogged area (Steinbruch and Weise 2014a). This zone stores water during the wet season, both as surface-water storage in shallow depressions and in a shallow sandy surficial aquifer. It releases this water through exfiltration and evaporation during the dry season, thus providing moisture for the formation of local dry-season rainfall as well as discharging groundwater into Lake Urema (Steinbruch and Weise 2014a, b). The hydraulic mechanisms of this surface-water/groundwater system have not been clearly identified.

A recent study by Arvidsson et al. (2011) measured river flow in the Nhandugue River as it flowed from the basement gneiss on the Barwe platform onto the sedimentary strata in the Urema graben. It was found that surface flow diminished from 564 to 74 L/s across this boundary, clearly signalling the rift margins as a major groundwater recharge zone. Rift valley margin sediments are comprised of coarse clastic materials such as conglomerates that are very permeable and form favourable groundwater recharge zones (e.g. Leeder and Gawthorpe 1987). Other streams discharging across the rift

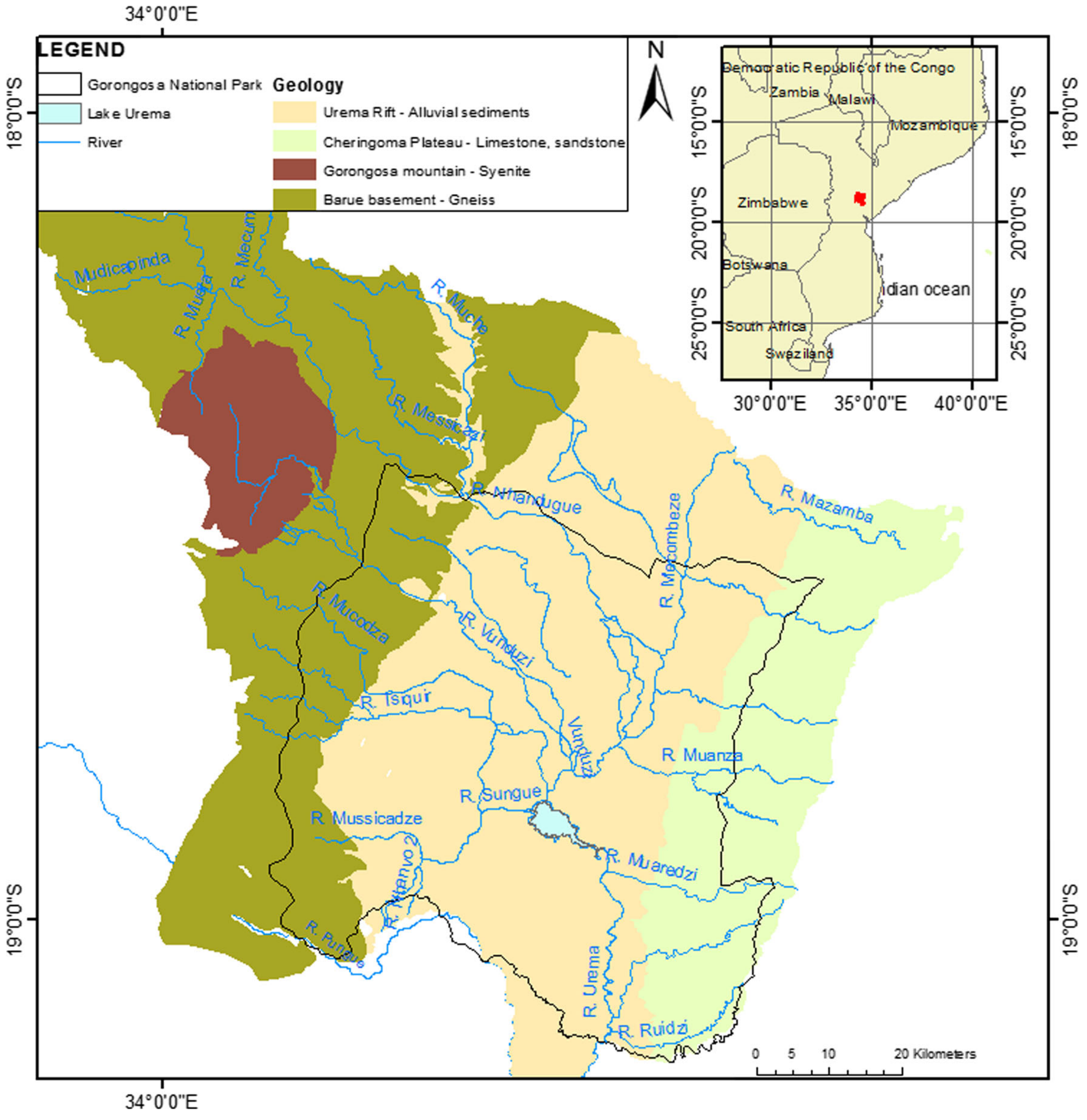

Fig. 1 Stratigraphical units of the Urema Catchment (from Steinbruch 2010)

margin from the Barwe platform such as the Vunduzi, show a major decrease in stream valley size, suggesting reduction in stream flow, presumed to be due to groundwater recharge into the coarse clastic wedge at the rift margin. However, the significance of this finding for the recharge of Lake Urema has not been established, and there is no information on the hydrogeological link between the rift margin and the valley floor beneath Urema Lake.

A promising approach is offered by geophysical methods used in hydrogeological studies. These methods provide spatially distributed models of physical properties in regions that are difficult to sample using conventional hydrogeological borehole methods (Linde et al. 2006). Many physical properties are indirectly sensitive to the amount of water in the ground; however, some geological constituents (e.g. water and clay) have sometimes similar or overlapping physical properties. It is therefore recommended to use more than one method to acquire a more unique signature of different geological units (Garambois et al. 2002). This research tests a combination of magnetic resonance sounding (MRS) with electrical resistivity tomography (ERT) methods extending the length of the electric lines by applying the roll-along technique (Dahlin 2001). The aim is to investigate the hydrogeological conditions in the graben floor and the mechanism of groundwater–lake recharge. Auguring and field observation yielded additional surface and near-surface data to support the findings from the geophysical survey. This method was successfully used for the characterization of aquifers in the Vientiane Basin in Laos (Perttu et al. 2011) and for interpretation of evapo-transpiration measurements in Bénin (Descloitres et al. 2011).

Study area

This work was carried out in the Urema Graben, inside the GNP in Sofala province, situated in the central part of Mozambique. The Urema Graben is located in the southernmost extent of the East African Rift system. The Urema catchment covers an area of approximately 9,300 km^2 that includes three major landscape units: the Rift Valley floor, the Gorongosa Mountain massif and the Cheringoma escarpment (Fig. 1; Beilfuss et al. 2007).

There are many seasonal rivers from Gorongosa Mountains feeding the Urema Lake. The main rivers feeding the lake are the Vunduzi, Mucodza, Sungue, Nhandugue and Mecumbedzi. The rivers Vunduzi, Mucoza and Nhandugue join Mecumbedzi River before it reaches the lake, while the Sungue River goes straight to the lake (Fig. 1). The Urema River is the only out flow of the lake and it is a tributary of the Pungue River. The main Pungue River, which is also the name of the catchment, drains directly to the Indian Ocean.

The local geology consists of four major parts: the Barue basement, the Gorongosa Mountain, the Urema Rift Valley and the Cheringoma Plateau forming the Urema catchment (Steinbruch 2010; Fig. 1). The Barue basement consists of granitic Precambrian rocks, and the Cheringoma Plateau consists of limestone and sandstone of Sena formation. Alluvial sediments cover the Urema Rift floor. The W–E cross section of the Urema Rift Valley is about 60 km and has a modest elevation variation between 14 and 70 m above sea level. The rift floor is almost flat with slopes below 1°, thus forming a water retention area. The sediments consist of heavy montmorillonite-rich clays and leached sands with different grain sizes with coarser sediments along the flanks. The mean grain size generally decreases when moving from the edges of the Urema Rift Valley towards the centre; however, along the major drainages within the Graben there appear to be channels with coarser sediments (Steinbruch 2010). There also exists a Precambrian gneiss inlier in a tectonic window of the rift floor (Steinbruch 2010) and a thermal spring, Nhambita hot spring, occurring along the western rift border with a water temperature above 40 °C (DNA 1987; Steinbruch and Merkel 2008).

Böhme (2005) collected five sediment cores in the bottom of the Urema Lake. The thickness of cores ranges from 0.17 to 0.28 m and four different layers were described: a layer rich in organics, pure sand layer, medium sandy clay layer and pure clay. The identified particle sizes of the sediments were used for the interpretation of the geophysical data presented here. Böhme (2005) also measured the electrical conductivity of the lake water, which can serve as reference to understanding the geophysical data. The reported conductivity values of 2.6–17.5 mS/m for freshwater would correspond to an estimated soil's resistivity of 58–320 ohm-m, and thus indicate the presence of freshwater in the subsurface.

Methods

The study was carried out in the dry seasons in July 2009 and August 2012, where ERT with multi-electrode equipment (Dahlin 2001) was used to obtain an overview of the geology. ERT data were produced and analysed for coherent features such as layered sedimentary formations and discontinuities. MRS was conducted in 2012 in order to partially overcome the difficulties with data interpretation because of the lack of hydrogeological reference data in the form of borehole log archives. Sample site locations are shown in Fig. 2.

Electrical resistivity tomography

The resistivity data were collected using a version of the ABEM Lund Imaging System based on Terrameter SAS 4000 in 2009, using multiple-gradient array (Dahlin and Zhou 2006). A 400-m-long electrode spread of 81

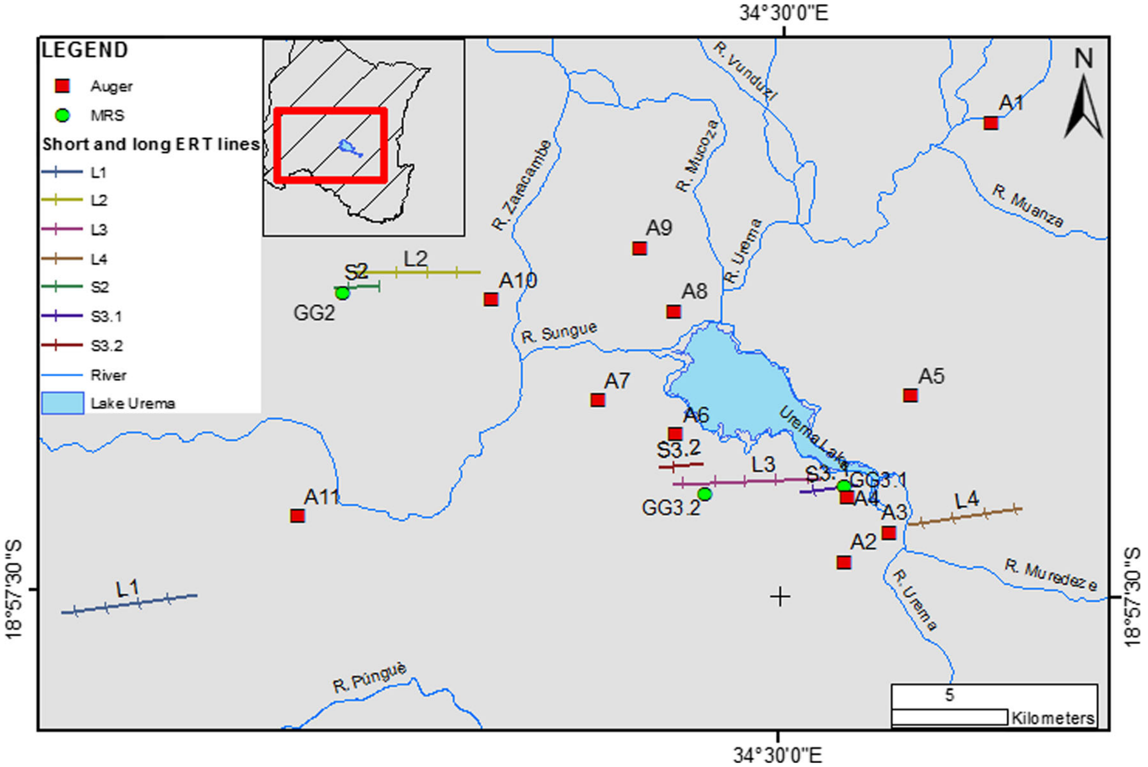

Fig. 2 Location of four long resistivity lines (*L1*–*L4*), three short resistivity lines (*S2*, *S3.1*, *S3.2*), three MRS sites (*GG2*, *GG3.1*, *GG3.2*) and 11 soil-auguring positions (*A1*–*A11*)

electrodes at 5-m separation was used for the measurements, and a roll-along technique was employed to extend the lines (Dahlin 2001). An ABEM Terrameter LS was used for the ERT data acquired in 2012. The length of the four ERT lines varied from 4,500 m in Muaredze up to 6,000 m in the power line clearing. The maximum depth of penetration of all profiles was around 75 m and was referenced in relation to mean seawater level.

The true resistivity was estimated through inverse numerical modelling (inversion). The software Res2dinv was used to generate a finite element model of a hypothetical vertical cross section through the ground and adjust the resistivity of each model cell until the apparent resistivity of the model response matched the data measured in the field (Loke et al. 2003). The difference between model response and measured data forms the mean residual which provides a measure of how well the model is fitted to the data. In this study the inversion was made using a robust constrain (L1-norm) because it performs better in handling noise in the data as well as strong resistivity contrasts compared to the otherwise used least-squares constrain (L2-norm; Loke et al. 2003).

The identified layers are labelled as 1, 2 and 3 from bottom to top. Each layer has indication of corresponding resistivity ranges as follows—X: less than 1 ohm-m; A: 1–10 ohm-m; B: 10–32 ohm-m; and C: above 32 ohm-m (derived from Palacky 1989 combining types of sediments and groundwater).

Magnetic resonance sounding

MRS is based on the principle of nuclear magnetic resonance. It indirectly measures the water content and the mean pore size, which in turn is related to the permeability of the ground (Shirov et al. 1991; Legchenko and Valla 2002). The instrument produces, by the steady increase of the current in the coil, scans of the MRS signal beginning at the soil surface to the limit of penetration in the subsurface.

The MRS measurements were carried out with the Numis-Plus Iris instruments using a 100 × 100 m coil with a maximum penetration depth of 100 m. Three sites were surveyed and analysed based on the least square solution with regularization with a smooth inversion using Samovar 11.3 software (Legchenko and Shushakov 1998). The result from an MRS is presented as free-water content (Φ_f) and decay time (T_2*; T_1) plotted versus depth. Free-water content is interpreted as non-adhesive water in voids per total rock volume and corresponds roughly to the effective porosity or the portion of water that is released under gravity or in the presence of a hydraulic head gradient (Lubczynski and Roy 2005). The decay time indicates connectedness of the pore space or how extractable groundwater is, and represents rock permeability (Lubczynski and Roy 2005). The MRS signal and penetration depth are highly influenced by the resistivity of the ground (Perttu et al. 2011); thus, it is necessary to have a geoelectrical model for each site for correct interpretation of the data.

Soil auguring and indicator of vegetation

A regular hand auger with T-handle and 1-m extensions was used to drill small-diameter holes ranging from 0.83 to 4.0 m depth. The technique worked well to the uppermost groundwater-bearing formations below which further penetration was impossible because of collapsing formations. The drilling was conducted at 11 locations surrounding Lake Urema.

The vegetation was also used as ground truth. The expected vegetation in a flood plain and its variation due to water content gives an indication of grain size of the surface soil and saturation of the ground (Van Wyk and Van Wyk 1997). The variation of the vegetation only gives surface information not the information in the subsurface. Green grass is an indication of soil moisture, and dry grass is an indication of water content below the wilting point; forest landscape typically is an indication of presence of groundwater but at greater depth. Short grass is an indication of temporary water logged areas. Ana tree (*Faedherbia albida*) together with elephant grass (*Pennisetum thunbergii*) are indications of the fringes of margins of floodplains, while the Lala palm (*Hyphaene coriacea*) occurs in dry areas or in well-drained areas.

Results

From the total W–E width of the Urema Graben, four subsections, each of 4.5–6 km length, were measured with ERT and produced four resistivity cross sections. L2 and L3 are in the valley floor, whereas L1 and L4 are at the west and east flank, respectively (Fig. 1). The location of L1 was selected to detect the change in the West flank from basement to rift-filling sediments known from the geological map and boreholes located in the national park's sanctuary (Steinbruch 2010). The L1 line crosses two seasonal rivers and the riverbeds are characterized by fine materials such as fine sand and clay (Steinbruch 2010) and L2 is part of the current floodplain, which was suspected to be a part of an ancient lake because of the presence of many abandoned river channels. L3 is perpendicular to the lake outflow and was chosen to study the variation of sediments at the transition between the floodplain and ancient Pungue River fan, while L4 was chosen to identify structural or geological features that may control the Urema out flow (Tinley 1977).

MRS was carried out at three sites considered as hydrologically relevant based on the ERT results. Also additional short ERT transects were carried out together with the MRS survey in order to link both datasets with each other to obtain more complete hydrogeological images of the sites.

Resistivity results

Figure 3 presents all four lines surveyed in the study area with Fig. 3a showing L1 which is characterized by a forest landscape and lies between 32 meters above sea level (masl) in the western part and 38 masl, with a lowest point of 31.73 masl. The profile shows two horizontal resistivity layers (1C and 2A) of the inverted section of L1. 1B has a thickness of at least 45–60 m and occurs from the surface at 36 masl to the maximum depth penetration of −28 meters below sea level (mbsl) and 2C is a discontinuous layer with a thickness varying from 10 to 15 m and occurs from the surface to 17 masl.

L2 is situated in the flood plain of the Urema Lake and stretches for approximately 5 km in a W–E direction laying between 21 masl at the beginning of the line to 26 masl at the end. The surface consists of clay covered with short green grass in the distance interval of 0–1,000, 1,500–1,700, 2, 300–4,300 m and tall dry grass from 1,500 m to the endpoint. Three horizontal layers can be identified in the inverted section (Fig. 3b). Layer 1A is 40–60 m thick, occurs in parts from the surface at 21 masl to the maximum penetration of the method but is covered by layers 2X and 3C from 1,100 m to the end of the profile. The layer 2X also occurs in parts in the surface but in some spots is covered by layer 3C (Fig. 3b). The thickness of layer 2X is 5–15 m, which corresponds to a maximum depth of 4 masl. The top and discontinuous layer 3C has a thickness of 2–5 m and appears in pockets and L3 in Fig. 3c has three layers 1C, 2A and 3C.

The results of L3 are illustrated in Fig. 3c. The profiles lie between elevations of 18 masl at the beginning of the line to 23 masl at the end. The surface is occupied by dense vegetation with Lala palm trees, Ana trees and elephant grass. The typical soils supporting such vegetation have a relatively high resistivity. Small streams and wetlands are present in the first 1,000 m. After 2,500 m, the grass becomes dry and dry forest vegetation changes into predominately Lala palm trees, which are abundant from this point up to the endpoint at 4,900 m. The vegetation beyond the endpoint is different, with Ana trees typical around the edges of floodplains and without grass. Three horizontal layers can be identified in the inverted section of L3 (Fig. 3c). The layer 1C was detected at depth of −39 mbsl and due to depth limitation the thickness of this layer in unknown. The layer 2A is 35–60 m thick and it can be observed in the surface from 900–1,000 m and from 1,700–1,800 m of the profile L3 (Fig 3c). The separation of 2A and 3C varies at depth, from 21 to 13 masl; 3C has a thickness varying from 3 to 10 m.

L4 (Fig. 3d) is parallel to the Muaredze River and it extends 4,400 m along the line (see Fig. 3), at an elevation that increases from 19 masl at the beginning of the line up to 89 masl at the end. The line starts at the eastern margin of the Urema River near the park's ranger station and goes along a mud road from W–E. The vegetation along this transect consists of

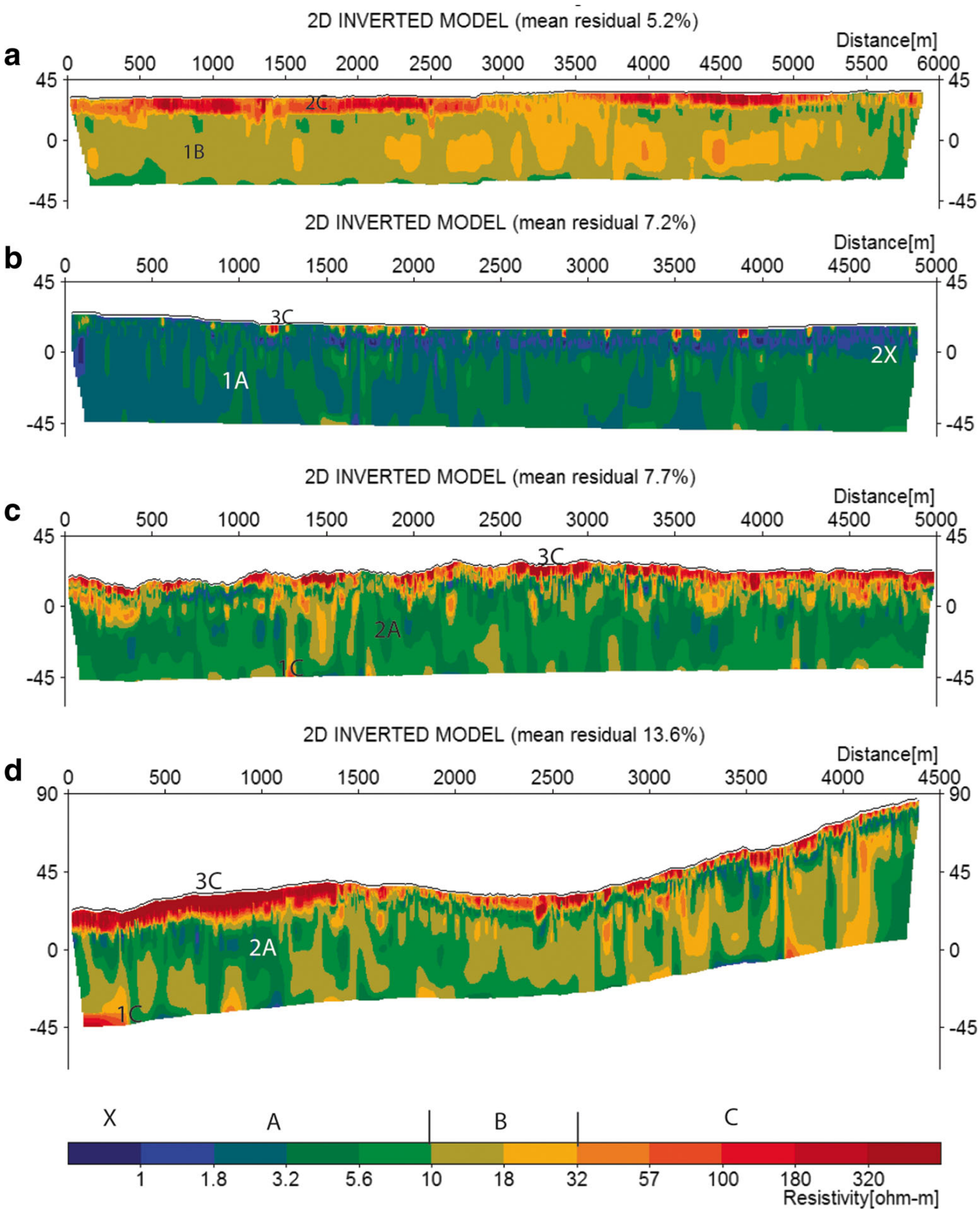

Fig. 3 Four ERT lines showing the length and resistivity values: **a** Line L1, **b** Line L2, **c** Line L3, **d** Line L4. Resistivity values—*X*: less than 1 ohm-m, *A*: 1 ≤10 ohm-m, *B*: 10 ≤32 ohm-m and *C*: 32–320 ohm-m

dense forest. Some depressions were observed at 1,400, 1,500 and 2,900 m, and a dried pond was crossed from 3,600 to 3, 700 m (Fig. 3d). Three horizontal resistivity layers are identified. At the bottom occurs a thick layer 1C which is at depth of −45 mbsl and its thickness is unknown due to the limitation of the methods. 2B is a layer, with a thickness that varies from 45 to 60 m, that is covered by 3C, which covers all the surface and has a thickness that thins from the beginning of the profile to the end.

MRS results

Figure 4 shows the results of the MRS at three different sites, indicated in Fig. 2. The fitting error (mean residual) ranges from 1.3 to 3.9 nV and thus suggests an acceptable quality of the inversion results. The free-water contents and decay times vary for each investigated site, indicating the presence of a diverse lithology across the Urema Graben floor.

The GG2 MRS measurement was made at the beginning of line L2 (Fig. 4a) with an elevation of 21 masl. Three evident layers can be identified from MRS. A shallow layer reaching from 2–3 m depth to 10 m depth with a free-water content of 7–10 %. The second layer from 10 m depth to about 30 m depth, has a free-water content of about 5 %. The layer below 30 m depth has a lower water content of about 7 %. No big variation was observed in decay time T_1 except from 2 to 3 m depth, which is in line with the variation observed in water content. MRS measurement GG3.1 (Fig. 4b), located at the end of line L3 (Fig. 2) with an elevation of 30 masl, is similar to the findings from the ERT of L3. It also shows three distinct

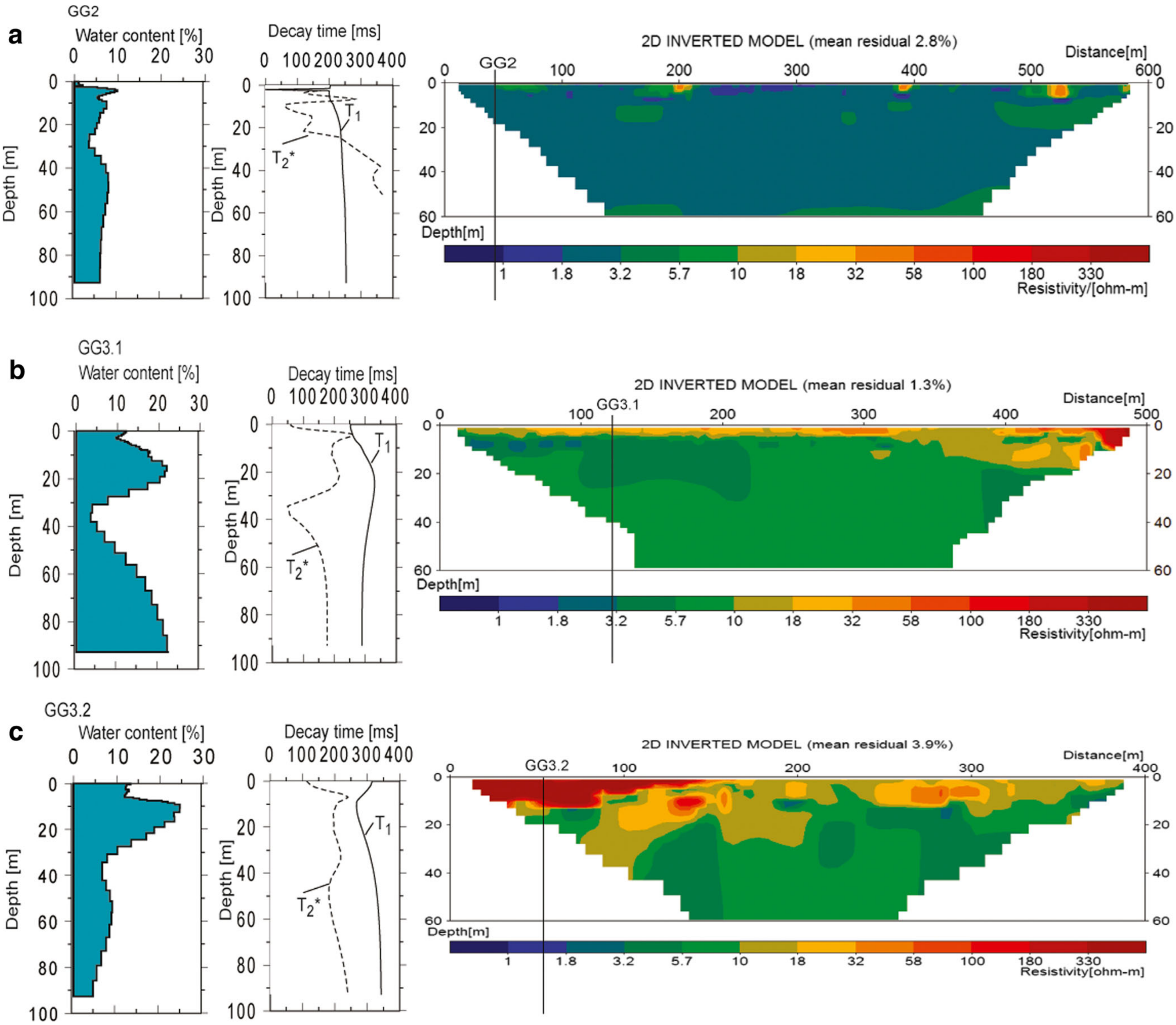

Fig. 4 MRS at points **a** GG2, **b** GG3.1 and **c** GG3.2 showing the water content, water content inversion fit, decay time and its position at the short ERT lines S2, S3.1 and S3.2, respectively (locations indicated in Fig. 2). It should be noted that the T_2* values vary greatly, but are more reliable for higher water content

layers: a shallow surface layer with a water content reaching 22 % with a thickness of 30 m; a second layer stretching from 30 to 40 m depth with less than 5 % of mobile water; and a third layer from 40 m depth with water contents which increase steeply by depth from 5 to 22 %. The decay time T_1 increases from 250 to 350 ms at 15 m depth and then decreases again to 250 ms; T_2* is similar to water content variation. The third sounding was made in the floodplain at the beginning of L3 (CG3.2, Fig. 4c). Four layers were identified with MRS. The topmost layer reaches from 0 to 8 m depth (10–18 masl) with a water content of 10–15 %. The second layer from 10 masl to −12 mbsl depth, has a water content of around 25 %. This layer is followed by the third layer stretching from −12 to −45 mbsl depth with a water content of almost 5 % (Fig. 4c). The water content increases below −57 mbsl depth downward to about 10 % forming the fourth layer. The decay time T_1 reduces from 325 to 250 ms at 10 m depth (20 masl) and increases again to 325 ms; T_2* is similar to water contend variation.

Results from augers

For the ground truth, 11 augurings were carried out in different locations on the Urema floodplain in August 2012. The equipment used is a regular hand auger with T-handle and extensions of 1 m each. The technique works well before reaching the groundwater level, but below that, sandy horizons collapse and prevent further penetration. The common characteristic of the floodplain is the first 25 cm of clay. The sand layer, where it was found, follows this thin clay layer.

Table 1 summarises the results of auguring in 11 sites along the floodplain where the depth penetration varies from 0.83 to 4 m. The water table was measured when it was stable and it varies from the surface to 3.19 mbs. In the middle of the flood plain, all the auger holes indicate clay as the main sediment type at shallow depth.

Discussion

The study was limited to a transect crossing the Urema floodplain, inside the conservation park, by means of four profiles and three MRS. Additionally the Urema floodplain lies in the southernmost part of the East African rift system. An interpreted conceptual model is presented in Fig. 5. The following can be inferred about the geology, depositional environment and hydrogeology.

Geological interpretation

The coarse sediments, which have high resistivity values, are present in the study area with high free-water content (22 %) and labeled as layers 1C and 3C. The coarse sediments layer has resistivity values typical of coarse to medium sand. The value of 32 ohm-m was also observed in other studies (Arvidsson et al. 2011; Descloitres et al. 2011; Perttu et al. 2011) for sand saturated with groundwater.

The fine sediments have low free-water content and resistivity values below 10 ohm-m. Sediments with this range of resistivity values were described by Arvidsson et al. (2011) as clay. This thick layer has been identified as clay in L2, L2 and L4. Auguring has detected a clay layer at the surface with less than 2 m thickness, which was not detected by MRS. A mixed layer observed only at L1 is interpreted as a mixing of fine sand, silt and sand, having an intermediate value of resistivity.

Depositional environment

The depositional processes in the study area are closely linked to rifting activities and deformation during Tertiary times (Fonseca et al. 2014). The Mesozoic rifting is linked to the breakup of the ancient supercontinent Gondwana, culminating with extrusion of sheets of basaltic lava. The Cretaceous to recent sediment layers overlie this basaltic basement. The epicentral location of micro-earthquakes in central Mozambique delineate a NNE–SSW linear pattern which was described by Fonseca et al. (2014) as a normal fault with a strike of N31E, which would be active (Lächelt 2004).

These tectonic activities are in line with the sequential deposition of coarse sediment after a faulting event or uplifting, with fine sediments deposited when the gradient has dissipated. It may also explain the variation observed between L1 and L2 that suggests a fault. As consequence of a possible fault, coarse sediments (3C) were deposited on top of layer 1A at L2 (Fig. 3b). The deposition indicates a change in gradient upstream.

Hydrogeological implication of the geological results at Urema floodplain

The correlation of the ERT profiles and MRS (Fig. 5) are believed to give an indication of four hydrogeological units at Urema floodplain. The first confined aquifer labeled as 1C has high water content (22 %), which is an indication of high permeability. The thickness of this layer is unknown because of the limitation of depth penetration of both ERT and MRS. The second hydrogeological unit is an aquitard labeled as 1A and 2A with low free-water content (5–10 %), indicating low permeability. This layer confines the aquifer 1C and partially

Table 1 Characteristics of 11 boreholes augured around Urema floodplain

Augered borehole name	Surface elevation (masl)	Borehole bottom elevation (masl)	Borehole depth (mbs)	Water-table depth (mbs)
A1	16	13.67	2.33	2.06
A2	19	18.17	0.83	0.83
A3	16	13.37	2.63	1.63
A4	15	12.3	2.7	2.03
A5	15	13.22	1.78	-
A6	11	7	4	-
A7	11	9	2	-
A8	14	12.06	1.94	1.84
A9	17	13.35	3.65	3.19
A10	19	15.35	3.65	-
A11	20	18.32	1.68	1.33

Elevation is given as masl and depth is given as mbs

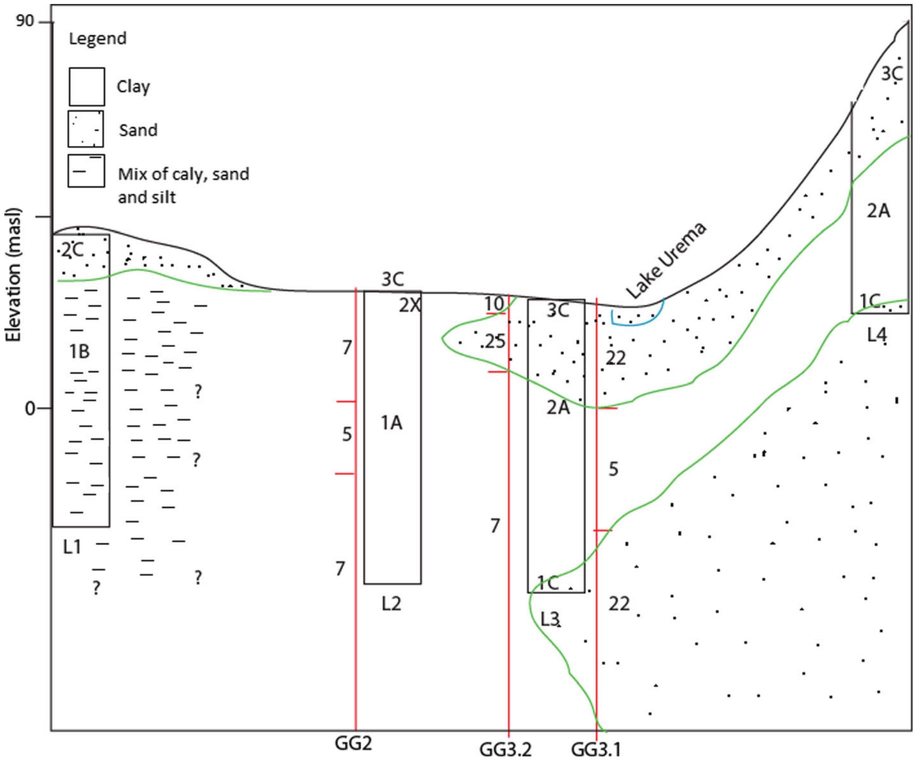

Fig. 5 Conceptual model of the Urema floodplain. No horizontal scale. *GG2*, *GG3.1* and *GG3.2* are the names of MRS measurement sites and *L1*, *L2*, *L3* and *L4* are the position of ERT profiles

the aquifer 3C. The third unit is the aquitard labeled as 1B. The extension and the thickness of this layer was not found due to limitation in depth of the ERT method. The fourth hydrogeological unit 2C is a semi-confined-to-confined aquifer. The variation in groundwater levels observed during the auguring is an indication of semiconfinement. The lake Urema is a part of this aquifer and may act as a recharge/discharge area for the semi-confined aquifer, depending on the seasonal variation in surface-water levels.

Uncertainties

L1 crossed the boundary fence of the sanctuary but there is no indication in the results of disturbances of this electrified fence. Due to dense forest, lines L1 and L3 were not completely straight, which leads to errors in the inverted model sections (Dahlin and Zhou 2006), but these are judged to be insignificant in relation to the resistivity variation. The levelling of all long ERT lines was done after the resistivity measurements and it is possible that some mismatches in positioning might have occurred.

The lack of reference data from drilling documentation and hydraulic tests is a problem, and a few boreholes in suitable locations would reduce the uncertainties for the interpretation of both resistivity and MRS results. Furthermore, both geophysical methods as configured in this study suffer from limited depth penetration and the decreasing of resolution with depth. MRS has, however, fairly good depth information for the study presented here.

Conclusions

Combined ERT and MRS geophysical investigations at Urema flood plain have been performed. Additionally auguring and vegetation description was performed to help the interpretation of geophysical data. As a result, four hydrogeological unites were identified. The thickness of the confined aquifer 1C was not determined in this study. The lateral separation of 1A and 1B between lines L1 and L2 is unknown. The change in lithology suggests a fault that also explains the deposition of layer 3C at L2 due to change in gradient.

The major finding of this study is the indication of the second aquifer (1C) identified by both ERT and MRS. The lake Urema is a window of the first upper semi-confined aquifer (3C), while the lower aquifer (1C) is confined by a clay layer 30–40 m thick. The location and depth of this semi-confined permeable aquifer suggest that it is possibly linked to the Pungwe River (downstream). If that is true, then the Pungwe River could be a main source of recharge during the dry season. This is an important finding because if a dam or any other infrastructure is constructed upstream of GNP in this river, the groundwater level will decrease which is likely to lead to drying out of Urema Lake. As the lake is the only permanent water source, this would be a disaster to the ecosystem of the park.

The depth penetration, geological borehole logging, and reference bibliography were the main limitations of the study; therefore, a deep borehole to confirm the presence of a confined layer would help to protect the wildlife in the case the lakes dries out, because this confined aquifer would be an option for water supply.

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