

Lithology and Geological Structures as Controls in the Quality of Groundwater in Kilifi County, Kenya

ABSTRACT

Aims: Saline and brackish water has been encountered in more than half of the boreholes across Kilifi County. The purpose of this study was to analyze the relationship between lithology and structural geology and the quality of water encountered in boreholes in the study area.

Study design: The study involved field observation of boreholes and collection of hydrogeological data and analysis of geological and structural setting and water quality.

Place and Duration of Study: Borehole data was collected between January and June 2012. Field observation of boreholes was carried out between June and September 2012. Data analysis was carried out between October 2012 and July 2013 at Masinde Muliro University and University of Nairobi.

Methodology: Drillhole information for 180 boreholes with depths ranging from 5 m to 300 m was obtained from the Ministry of Water and Irrigation Archives. Subsurface profiles for the individual boreholes representative of various locations were plotted using Strater software (by Golden Software). The quality of water encountered in the boreholes was related to the mode of deposition of the sediments and the faults or folds at the borehole site.

Results: The results indicate that the water quality in Duruma sediments is generally saline owing to the lacustrine deposition of the sediments while in the other rock types, the salinity is influenced by the rate recharge and pumping regime. Adjacent boreholes in areas where aquifers juxtapose against impermeable materials are found to have different qualities of water while slow and fast pumping regimes produce different qualities. Groundwater in the synclines and the Reef Complex is saline and brackish. Sea water intrusion occurs along the coast and the water levels in the wells remain the same throughout the year.

Conclusion: The quality of groundwater in Kilifi County is determined by the geological materials through which it travels the position of the well in relation to the geologic structures and also the natural recharge and pumping regimes.

Keywords: lithology, structural geology, sedimentary environment, groundwater quality

1. INTRODUCTION

Kilifi County is an administrative unit located north-west of Mombasa with its capital at Kilifi Town (Figure 1). It stretches 75 km along the Kenyan coast and for several tens of kilometres inland touching thirteen topographical maps of scale 1:50 000. Groundwater provides nearly 50% of the water in Kilifi County through more than 200 shallow and deep wells with depths ranging from 6 m along the coast to over 300 m inland. Groundwater flow direction is generally eastward; with recharge rate decreasing westward from the central part according to Kwas (Kilifi Water Assessment Study), (1995), Water Resources in the Greater Kilifi District: Collaboration between the Government of Kenya and the Republic of Netherlands, (unpublished). Saline and brackish water has been encountered in more than half of the boreholes across the study area. The purpose of this study was to analyze the relationship between lithology and structural geology and the quality of water encountered in boreholes in the study area.

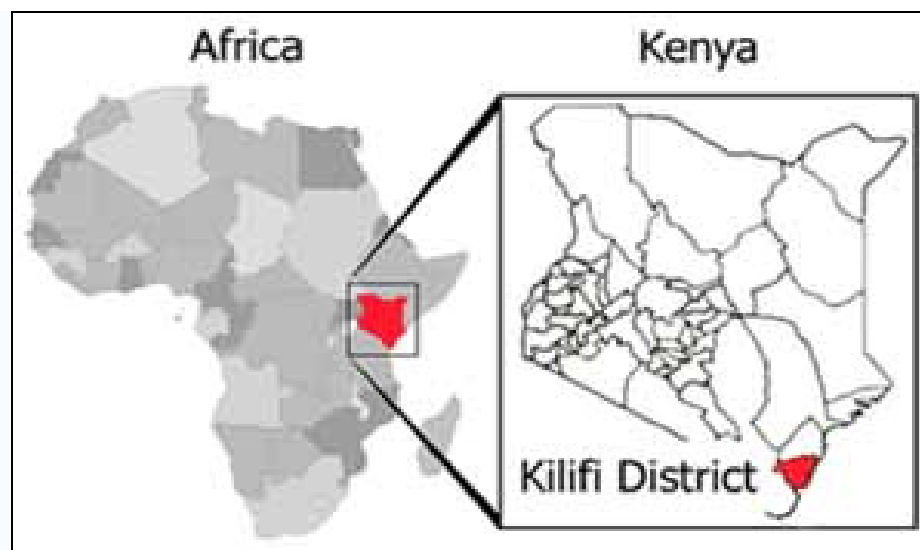


Figure 1: Location of Kilifi District

Many authors have made discussions in relation to lithology, stratigraphy and structural geology of Kilifi County. These include: [1, 2,3,4,5]. Much of the information written in other documents is collated from these researches. Of all the work that has been done, none has exclusively dealt with the relationship between the subsurface materials and the water quality.

The regional geological setting of Kilifi County is dominated by the rifting and break-up of the Palaeozoic Gondwana continent and the development of the Indian Ocean [6]. Upper Proterozoic gneisses of the Mozambique belt [3] form the basement of an intra cratonic basin, filled with continental Permo-Triassic clastics. Rifting during the early to middle Jurassic, presumably preceded partly by up-doming along the incipient rift, transformed it into a marine marginal basin at the trailing edge of the African plate [4].

Almost three-quarters of the area is underlain by the continental Permo-Triassic sediments assigned to the Duruma Group [1], which is generally considered as the Kenyan equivalent of the Karroo system of southern Africa [4]. The Duruma sediments essentially comprise grits, arkosic sandstones, and shales accumulated under lacustrine, sub-aerial conditions with minor marine ingressions in a broad, roughly NNE-SSW trending intra-cratonic trough, which formed towards the end of the Paleozoic within the Proterozoic gneisses of this part of the Gondwana [6].

During the initial development stages of this trough, down warping was fairly rapid, and the basal Taru formation that consists mainly of coarse-grained, poorly sorted arkoses intercalated with shales containing freshwater fauna was formed [5]. Intra formational reworking and sedimentary structures are widespread, and indicate rapid denudation and short transport with subsequent re-deposition in a high-energy lacustrine environment [3].

Towards the top, the grain size of the Taru sediments decreases and the generally fine-grained Maji-ya-chumvi formation overlies the Taru sediments along a slight unconformity. Current bedding and ripple marks are common and indicate deposition in shallow water [5]. A basal sequence, composed of fissile dark shales with thin intercalations of sandy

57 siltstones, frequently shows rain pits and desiccation cracks together with appreciable
58 amounts of precipitated salts [2]. It therefore indicates a period of arid climate during which
59 the trough apparently dried-up frequently. This facies is terminated by a marine ingressión
60 which deposited fish-bearing shales followed by flaggy, fine-grained argillaceous
61 sandstones, siltstones, and shales with a wealth of sedimentary structures (cross-, current-,
62 and convolute bedding, rippled laminations, slump folding, etc.); they contain Triassic fauna
63 indicating the return of brackish and even fresh-water conditions [4].

64 During the deposition of the Mariakani formation which conformably overlies the Mayi-ya-
65 Chumvi beds, erosion became more intensive and a rhythmic succession of fine to medium
66 grained sandstones and impure shales was deposited, probably again under lacustrine
67 conditions. Massive, fine-grained sandstones with distinct mottling prevail in the basal part of
68 the formation, flaggy arkosic sandstones with usually well developed cross-bedding in the
69 upper part [2].

70 More pronounced erosion persisted during the deposition of Mazeras formation which
71 unconformably overlies the Mariakani formation [1]. It starts with coarse-grained, cross-
72 bedded arkoses, with lenses of grits and minor siltstone/shale intercalations. The
73 sedimentation rate eventually surpassed the rate of subsidence of the trough, and dry areas
74 covered by forest emerged, as evidenced by a well-defined horizon containing abundant
75 fossil wood [4]. Coarse-grained, massive arkoses and grits of terrestrial origin with infrequent
76 sub-aqueous intercalations terminate the Mazeras formation. This decline of the subsidence
77 rate possibly already indicates incipient up-doming prior to the Jurassic rifting of Gondwana
78 [7].

79 After the termination of the Duruma sedimentation, major faulting and rifting led to the break-
80 up of Gondwanaland; it caused a fundamental facies change from a continental cratonic
81 trough to a marginal marine basin with sediments, located at the trailing edge of the
82 continent [4]. This transition is marked by a middle Jurassic marine ingressión. The basal
83 sediments of the Kambe formation were deposited under near-shore neritic and estuarine
84 conditions. Basal transgression conglomerates, largely composed of Duruma detritus, are
85 overlain by impure micritic limestones, occasionally with small bioherms, and near-shore
86 oolitic limestones, which were deposited in a shallow shelf environment with only moderate
87 terrigenous contamination.

88 Erosion prevailed during the Tertiary until the Upper Pliocene, when tectonic reactivation
89 resulted in increased erosion from structural [6]. Fluvial pebble beds, gravels and sands of
90 the Magarini formation were deposited on down-faulted and eroded Jurassic and Duruma
91 sediments. After a regression during the lowest Pleistocene, dunes which form the bulk of
92 the Magarini formation were blown-up. This led to the formation of Pleistocene sands. At the
93 same time, corals accumulated to form the Reef Complex along the coast. Figure 2 is an
94 outline of these geologic formations on a map.
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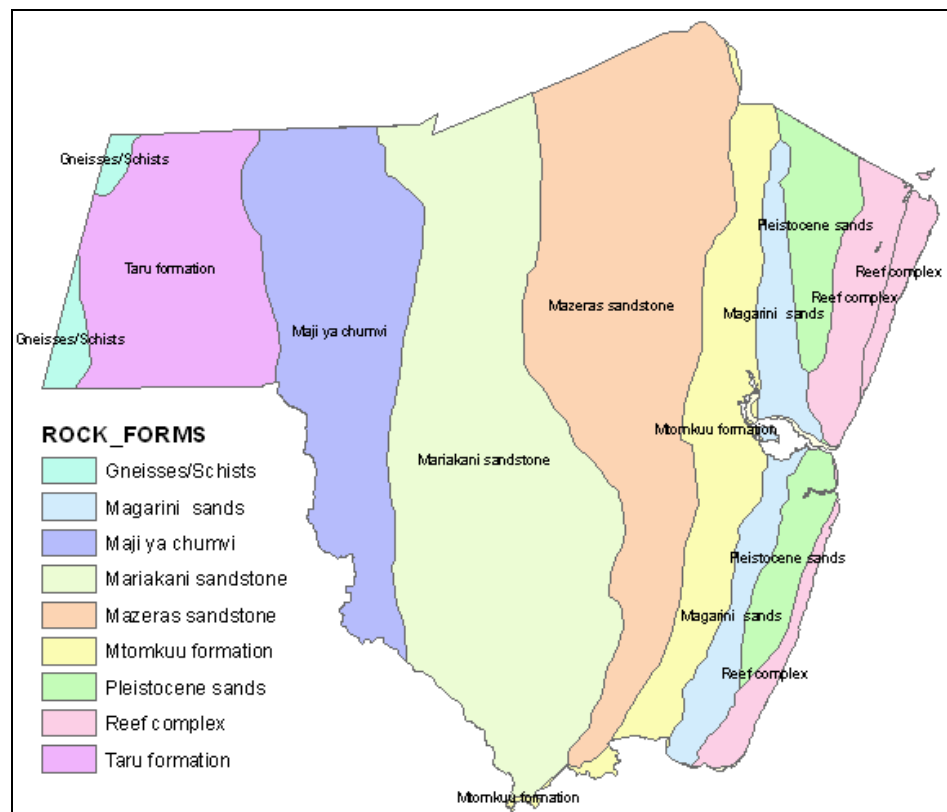


Figure 2: Map showing the geological formations of Kilifi County (from the geological map of Kenya)

The structural pattern of the area is dominated by vertical faults striking parallel to the coastline and displacing SE-dipping sediments downward to the east. The major faults, along which rifting and break-up of Gondwana did occur are located offshore [8, 9]. The faults generally trend NE and are thought to form the northward extension of the NNE striking Tanzanian "Tanga fault belt" [8].

2. MATERIALS AND METHODS

The study involved field observation of boreholes and collection of hydrogeological data and analysis of geological and structural setting and water quality. Borehole data was collected between January and June 2012. Field observation of boreholes was carried out between June and September 2012. Data analysis was carried out between October 2012 and July 2013 at Masinde Muliro University and University of Nairobi.

[Drillhole information for 180 boreholes with depths ranging from 5 m to 300 m was obtained from the Ministry of Water and Irrigation Archives.](#) The information provided for most borehole included: borehole number, owner, date drilled, location, total drilled depth, aquifer encountered, yield, water quality and remarks on the drilling process.

Borehole logs for the one hundred and eighty wells were analyzed to determine lithology, thickness and hydraulic characteristics of the aquifers. Geological information for each of the sample boreholes was typed in worksheets for purposes of plotting profiles. Each drill hole log consisted of the following information: borehole identity (BHID); geographic coordinates

(x,y); thickness of the stratum (from-to); the name of the geologic unit (formation) or hydrogeologic unit identity (HGUID) as well as description of the formation and code (HGUcode).

Subsurface profiles for the individual boreholes representative of various locations were plotted using Strater software (by Golden Software). At most three core logs could be presented in each borehole view. The boreholes within depth ranges of 10 m were presented in each view instead of using boreholes from the same locality. This was to ensure that the information was easy to compare on the depth scale and fault pattern. Information on each borehole view includes depth scale, core recovered, the description of the formation by the driller and the depth of encounter of water as well as the quality of water where available, locality and borehole identity. The quality of water encountered in the boreholes was related to the mode of deposition of the sediments and the faults or folds.

3. RESULTS AND DISCUSSION

Figure 3 presents subsurface information for boreholes drilled to depths between 20 m and 24 m at Kilifi, Mtwapa and West Roka. Aquifers at these depths occur within corals of the reef complex and Pleistocene sands and are encountered at 13 and 18 m. The water is mainly saline and very small drawdown is experienced during testing. The observations by most of the drillers were that the absence of drawdown indicated the possibility of sea water intrusion. Many of the boreholes drilled in Roka before 1960 struck water at 12 m to 18 m but were abandoned due to high salinity. The quality of water in Roka Settlement improved between 1960 and 1963, probably due to natural recharge; the quality of water in several boreholes such as C-3263 drilled in 1963 was found to be suitable for domestic use unlike in 1960 when majority of the drilled boreholes were abandoned due to salinity.

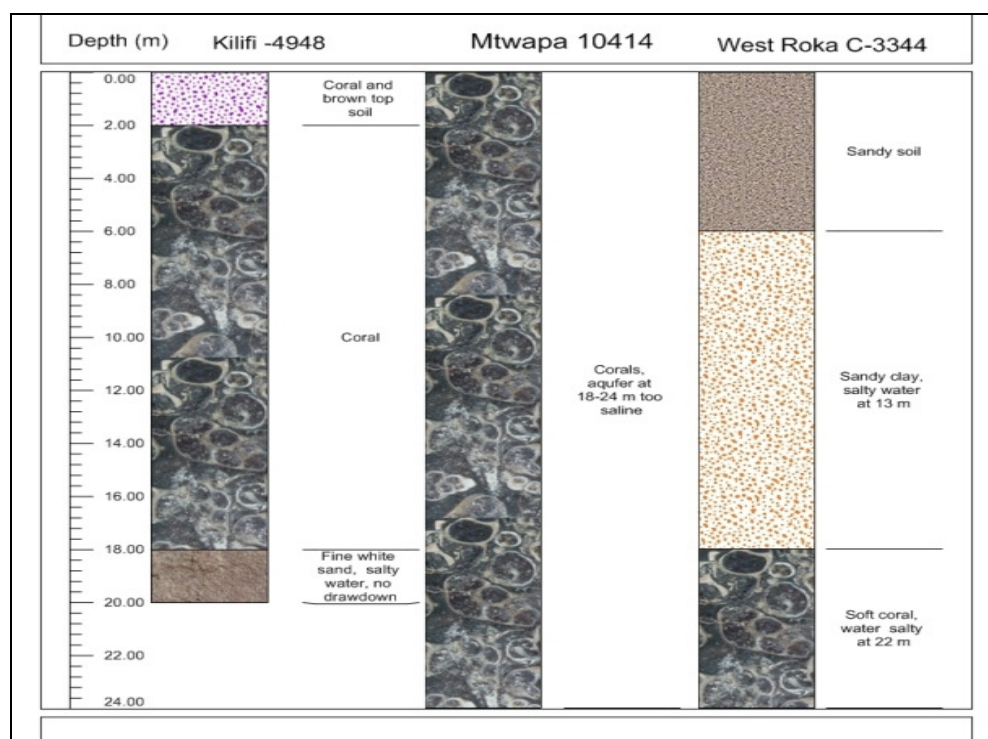


Figure 3: Subsurface information for boreholes drilled to 20 m and 24 m depths

The subsurface information presented in Figure 4 is for boreholes drilled to depths between 42 and 47 m at Mtwapa and Mazeras. Groundwater is encountered between 27 to 37 m within the sands and sandstones of Mariakani and Mazeras Formations. Caving of the sands is reported in many boreholes drilled to this depth. The groundwater is not too saline and is thus used for domestic purposes. The two boreholes at Mtwapa have different profiles, but are similar below 32 m where water is encountered within the sands. This is a clear indication of the presence of a fault. Displacements of up to 100 m have been observed at Mariakani [10]. Juxtaposition of aquifers against impermeable materials due to faulting has led to variable yields and water quality in this area. Also, the presence of faults restricts the inland movement of sea water [11].

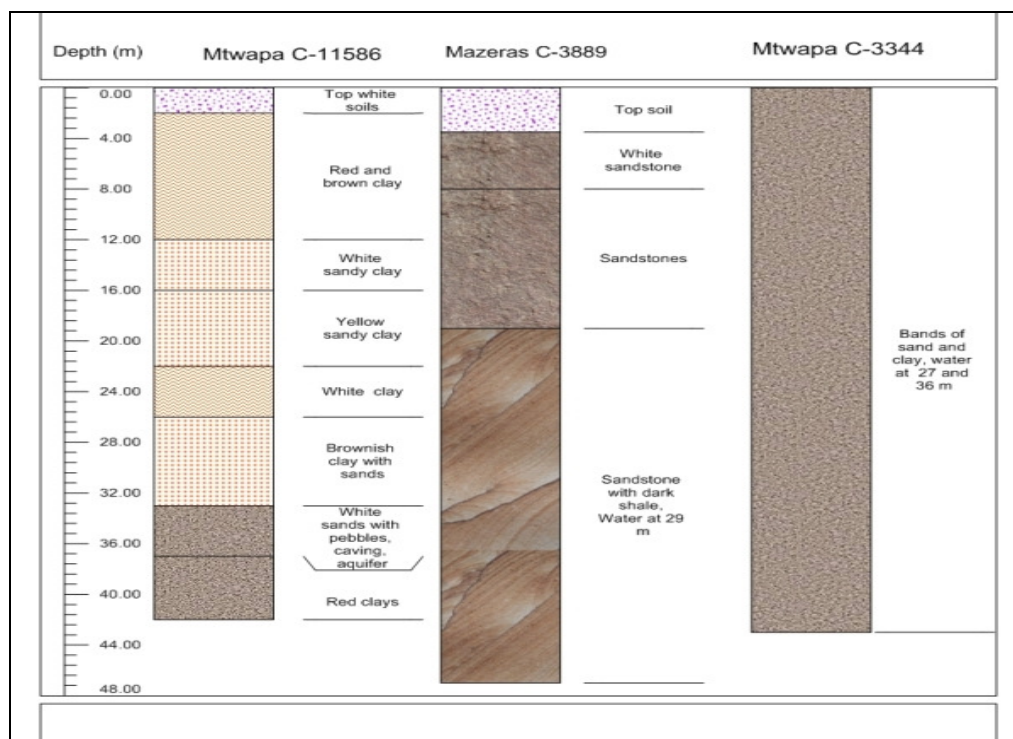
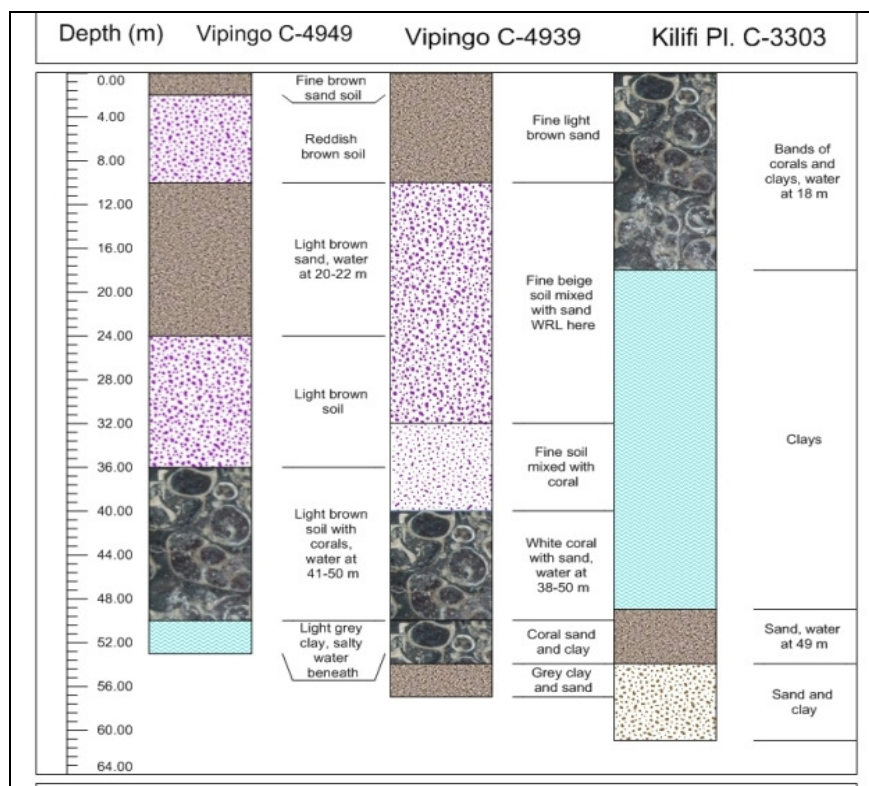


Figure 4: Subsurface information for boreholes drilled to 42 m and 47 m depths

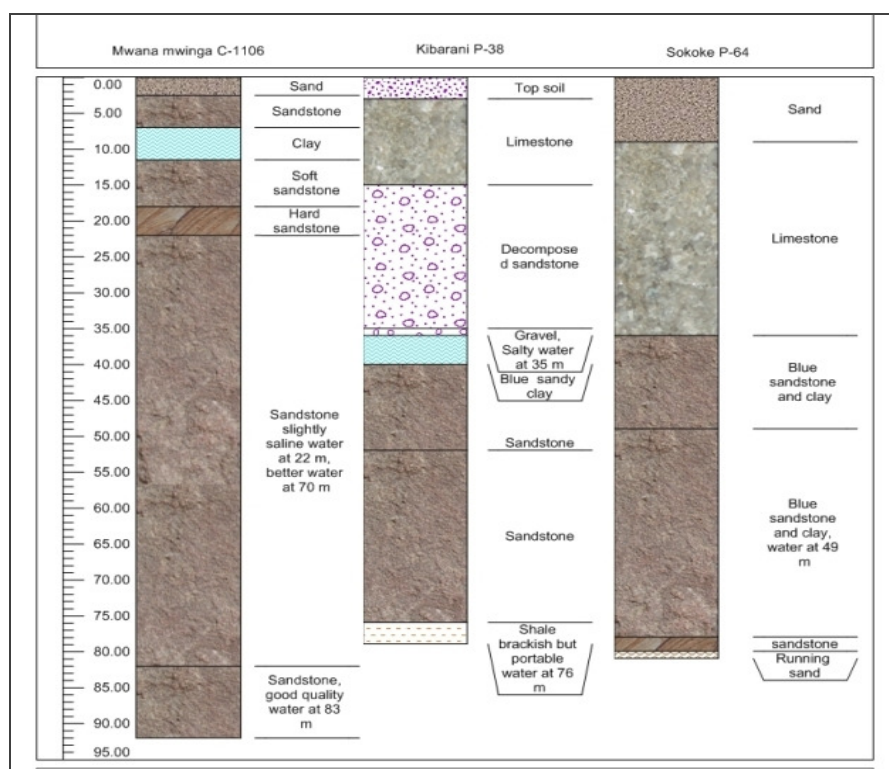
Figure 5 presents subsurface information for boreholes drilled to depths between 53 m and 61 m at Vipingo and Kilifi plantations. The water is encountered at two distinct depths: 18-22 m within bands of corals and clay or bands of sand and clay; 38 m-50 m within coral and clay bands or bands of sand and clay. Drilling through the clay band at depth in borehole C-4949 at Vipingo encountered very saline water and had to be quickly plugged to avoid contamination of water from the upper aquifers. Lateral influx of the saline water is probably restricted by the presence of the small displacement fault at Vipingo as indicated by the different profiles in the two boreholes. The presence of saline aquifers in the study area was found to reduce the area that can be regarded as having the potential for artificial recharge [12].

Information from boreholes drilled to depths of 78 to 92 m at Mwana Mwinga, Kibarani and Sokoke is presented in Figure 6. Three aquifers are encountered at depths between 22 m and 83 m within the sandstones, sand and shales. The first aquifer is encountered within the weathered sandstone that produces saline water. Good quality water is encountered in the third aquifer within the sands/sandstones at depths ranging between 76 and 83 m. Each of the three boreholes encountered at least two aquifers.



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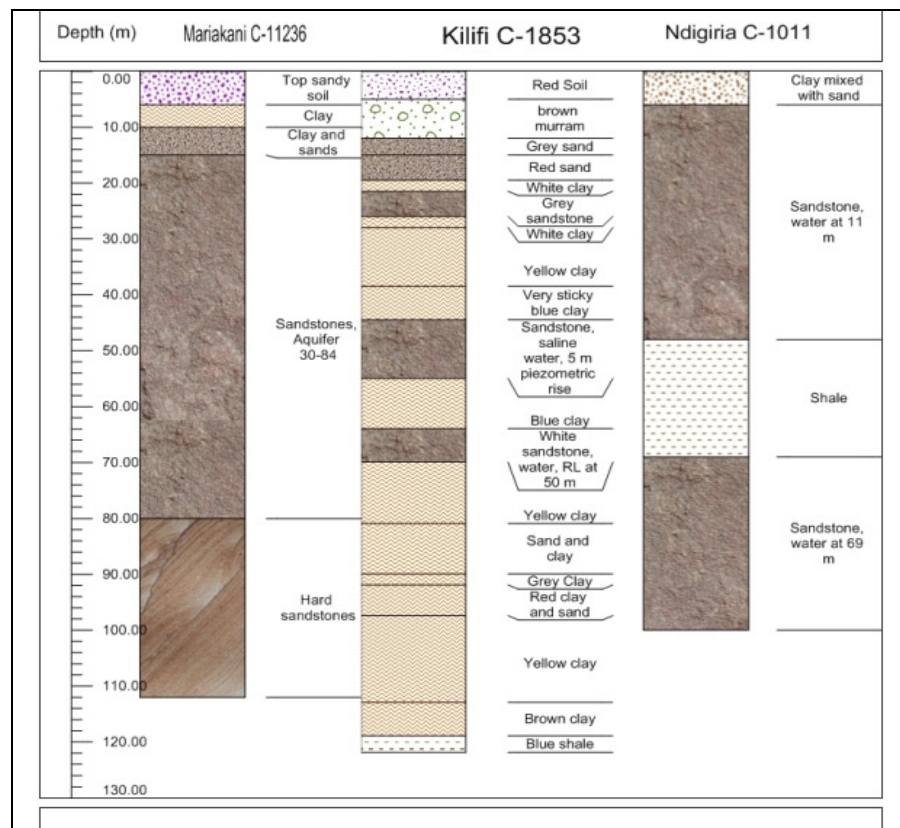
Figure 5: Subsurface information for boreholes drilled to 53 m and 61 m depths



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Figure 6: Subsurface information for boreholes drilled to 78 m and 92 m depths

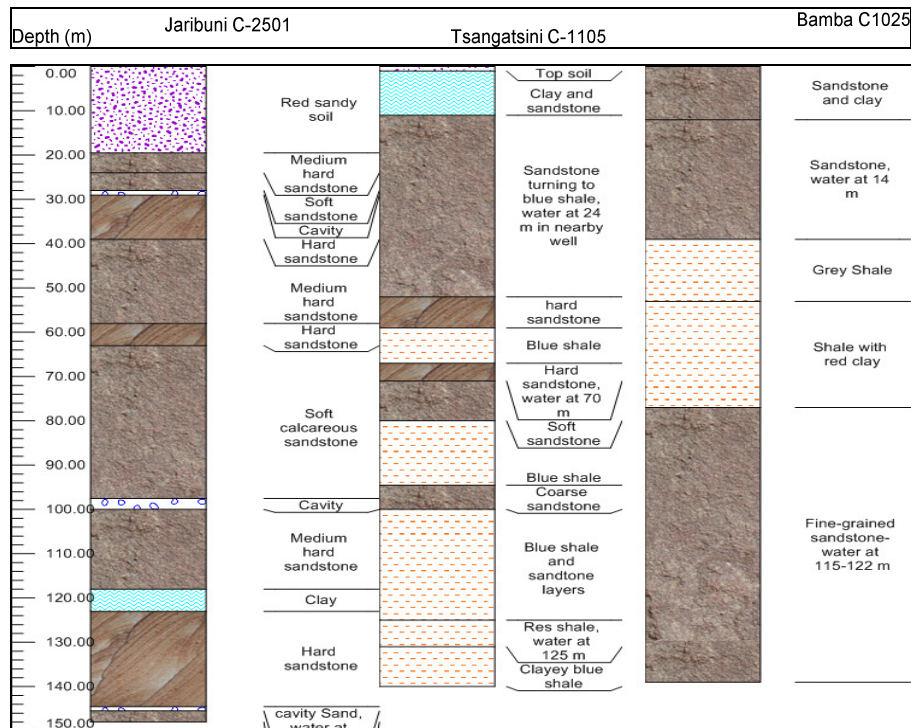
184 The Mariakani, Kilifi and Ndigiria boreholes presented in Figure 7 were drilled to depths
 185 ranging between 100 and 122 m. Aquifers were encountered within the Mariakani
 186 Sandstones intercalated with bands of clay. Water can be expected in the vicinity of 11 m,
 187 50 m and 70 m. The water is mainly saline. The salinity of the water can be related to the
 188 deposition of Mariakani sandstone in shallow basins susceptible to evaporation. A study on
 189 the potential for Aquifer storage and recovery from Mariakani sandstones and Maji ya
 190 Chumvi beds by [13] indicated that the recovered water could contain considerable amounts
 191 of salts. The aquifers in Mariakani are semi-confined and lead to piezometric rises of
 192 between 5 m and 15 m. Very few aquifers have the rest levels at the level of encounter of
 193 the first aquifer.
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 197 Figure 7: Subsurface information for boreholes drilled to 100 m and 122 m depths

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 199 Subsurface information for six boreholes drilled to depths ranging between 139 m and 152 m
 200 is presented in Figure 8 and 9. The profiles represent Jaribuni, Tsangatsini, Bamba,
 201 Vilagoni, Ganze and Kaloleni. The first aquifer is encountered within the sandstones at
 202 depths ranging between 11 m and 14 m. The second aquifer is commonly within the shales
 203 at 34 m to 35 m. The third and fourth aquifers are encountered within the sandstones in the
 204 vicinity of 70 m and 100 m to 125 m respectively. It has been observed elsewhere that
 205 Permian sedimentation occurred in broad basins leading to formation of shales in low-lying
 206 areas and limestones in high-lying areas. The restricted circulation in the basins led to
 207 calcium carbonate concentration [14]. In this kind of depositional environment ground water
 208 is expected to have different levels of salinity depending on the position of the sediments in
 209 the basin.
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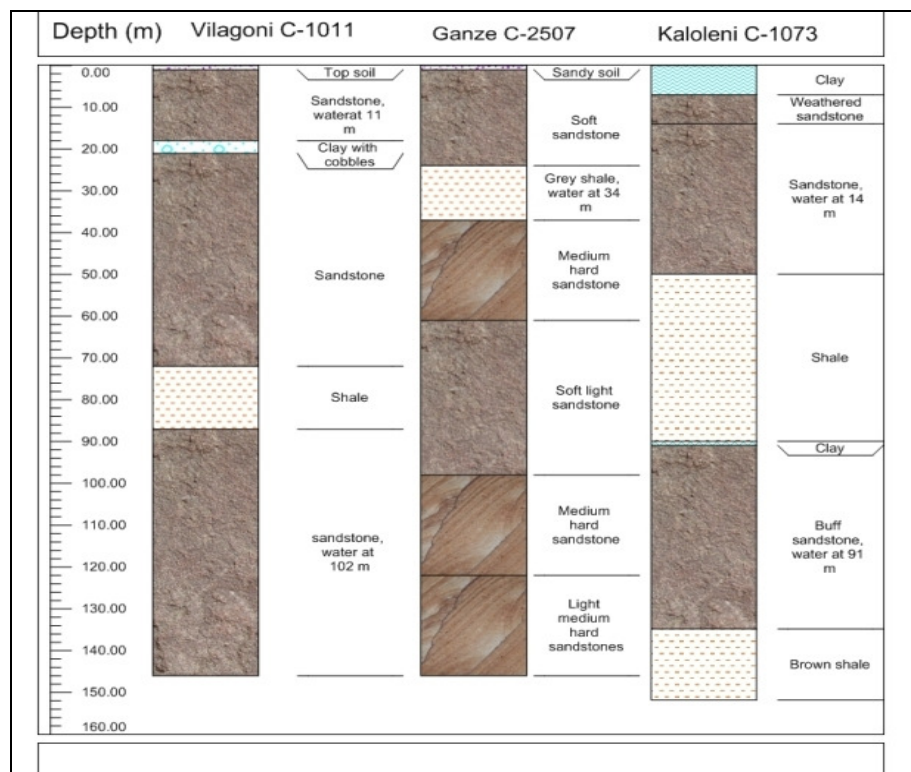
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213 Figure 8: Subsurface information for boreholes drilled to 139 m and 142 m depths

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216 Figure 9: Subsurface information for boreholes drilled to 148 m and 152 m depths

4. CONCLUSION

Groundwater provides nearly 50% of the water in Kilifi County through more than 200 shallow and deep wells with depths ranging from 6 m along the coast to over 300 m in the west. Geology of the study area comprises Upper Proterozoic Mozambique Belt metamorphic rocks, Permo-Triassic Duruma sediments, Plio-Pleistocene sands, Pleistocene Reef Complex and Recent Alluvium. Four main structural events can be recognized: initial faulting in the Lower Carboniferous that affected the metamorphic rocks; subsidence and down-warping in Upper Carboniferous – Lower Triassic; major faulting in Lower Jurassic and faulting in the Upper Pliocene. The geological formations are normally faulted with down-throws towards the Indian Ocean. Lithology and groundwater quality from 180 shallow and deep wells were considered in this study. Geologic profiles were drawn and the quality of water in each aquifer indicated on seven geologic sections. The results indicate that the water quality in Duruma sediments is generally saline owing to the lacustrine deposition of the sediments while in the other rock types, the salinity is influenced by the rate recharge and pumping regime. Adjacent boreholes in areas where aquifers juxtapose against impermeable materials are found to have different qualities of water while slow and fast pumping regimes produce different qualities. Groundwater in the synclines and the Reef Complex is saline and brackish. Sea water intrusion occurs along the coast and the water levels in the wells remain the same throughout the year.

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COMPETING INTERESTS

The authors have declared that no competing interests exist.

AUTHORS' CONTRIBUTIONS

Author² carried out the analysis of lithology and structural geology of the study area and reviewed the manuscript while Author¹ drew the subsurface profiles, carried out the analysis on the relationship between lithology and structural geology and water quality and wrote the first draft. Both authors read and approved the final manuscript.

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