5.2 Detailed Geological Survey

5.2.1 Aerial Photograph Interpretation and Field Geological Reconnaissance

(1) Aerial photograph interpretation

Aerial photographs were used to interpret the location and direction of the lineaments in the basement rock area focusing on the near-by areas of the candidate villages. The location map of the lineaments was utilized for arrangement of the geo-resistivity survey line (resistivity profiling across the lineament), because the promising area of groundwater exploitation is generally limited to a narrow zone along the faults or weak lines that are designated by the photo-lineaments.

Photo-lineaments have been observed everywhere in all of the districts in the basement rock area, although the distribution pattern (density and directions) of them is different by area. It was found that the most densely distributed area is the upper stream of the Lukuledi River, where lineaments of northeast-southwest direction are predominant at the northern part and those of northwest-southeast direction are predominant at the southern part. The lineaments of various directions are locally intersecting each other, and this distribution pattern indicates an occurrence of complicated structural movements in the past geological age, suggesting the existence of higher porosity zones than other areas of lower density lineaments. This means that a higher probability of groundwater development is expected in areas of dense lineaments.

Figure 5-2 represents the result of photo-lineament interpretation.

In spite of an abundance of groundwater, however, the problem concerning water quality must be pointed out in these areas. Especially in the northern part of the Lukuledi River basin (Nachingwea and Ruangwa Districts), water quality is poor and not good for drinking purposes because of high salinity and a high content of sulfate, which is mentioned in Section 6-2-4.

The reason why water in this area is saline was not investigated in this study, but it is presumed that the salt or sulfate compound was produced as a by-product of other minerals during a certain mineralization that took place in the geological age of the fissures being generated.

If so, the type or direction of the lineaments may have some relationship with the quality of water. The location map of the lineaments and existing boreholes shown in Fig. 5-2 do not give a definite indication concerning the relationship between the distribution pattern of lineaments and water quality, but suggests a certain correlation between them. Many of the existing wells with saline water (electricity conductivity exceeding 3,000 μS/cm) fall on clear lineaments (not on weak lines) of northwest-southeast and east-west direction.

Although this correlation is not clear, the fact that Chinongwe test well hit fresh water in this difficult area has given a hint in choosing the drilling point. At Chinongwe, the weaker lineament was chosen for the location of the drilling point. Moreover, the weaker anomaly point on the resistivity profiling was chosen for drilling. Whether success was based on a true correlation or just luck could not be confirmed in this study program, but the above said "hint" was taken into consideration in determining the drilling points in the basement rock area for the future project.

The direction of the main fissure for groundwater development of each candidate village is shown in the column of "Lineament" in Table 5-3 (1)-(8).

(2) Field geological reconnaissance

Emphasis was put on the following matters during the field geological reconnaissance:

i) Focusing on areas near the candidate villages, considering that the supply facility is to be a community-based independent one involving the supply source
ii) Reference to the well structure and production of the borehole wells located in similar geographic and/or geological circumstances to those of candidate villages
iii) Geological structure in relation with springing mechanism at the villages where the spring source is not so far from the center of the concerned villages
iv) Fixing of geophysical survey (resistivity sounding survey) points in the area of sedimentary formation to determine the depths of the wells to be drilled
v) Confirmation of the location of interpreted photo-lineament on the site in order to fix the survey line for the resistivity profiling survey in the basement rock area
vi) Conduct of geological field reconnaissance at the areas that represent geological characteristics for confirmation of interpreted hydrogeology on the concerned areas.

The summary of the hydrogeological characteristics of each geological unit is shown in Table 5-1, and the geology of 100 candidate villages is presented in Figure 5-1.

Groundwater in the basement rock area is fissure water, not a bedded aquifer, therefore the promising area for groundwater exploitation is generally limited to the fissure abundant zone, that is, along the faults or weak lines designated by the photo lineaments. It is difficult to determine the depth of the wells to be drilled only by the field geological reconnaissance and geophysical profiling survey. The depths of the wells in the basement rock area were determined based on the elevation and topography of the surrounding area and by referring to the structure/productivity of the existing wells.

The depth of the well to be drilled in each of the villages is given in the column of "Drilling depth" in Table 5-2 (1)-(8).

Major aquifers in the sedimentary rock area fall on sandstone and limestone layers, and on the beds of sand and gravel in the area of alluvium. The depth to the aquifer can be sounded by an electrical resistivity sounding survey by the difference of the apparent electrical resistivity by depth. However, the formations are cut into pieces by faults even in the sedimentary formations, especially in the older formations of Mesozoic Era, resulting in somehow complicated hydrogeological features; for example, the two wells closely located each other show quite different productivities.

5.2.2 Geophysical Survey

Electrical resistivity sounding by use of equally spaced 4-electrode method (vertical sounding method) was applied at the villages in the sedimentary rock areas, and the combination of resistivity sounding and the profiling method (horizontal resistivity survey method) across the interpreted photo-lineament was used in the basement rock areas.

In the vertical sounding method for differentiation of the formations by depth, attention was paid to comparatively higher resistivity layers, which designate higher porosity layers of probable aquifers like sandy or gravelly formations or sandstone and/or limestone beds. The layers of very low resistivity designate the lower porosity (low transmissivity) beds like silt, clay, mudstone or shale, which cannot be an aquifer. The summary of the resistivity range obtained through this survey is shown in Table 5-2. The depth of the wells to be drilled was determined in accordance with the depths to the higher resistivity, and they are tabulated in Table 5-4.

At the areas close to the coastal line, the graph showing the relation of resistivity-depth occasionally presents an inclination which is too steep and does not allow analysis of the resistivity value of the layers by depth. This is due to the extremely low resistivity value of seawater, which means that the area suffers from seawater intrusion. In this case, groundwater development by deep well construction is quite difficult. The depth of the wells in such areas should be shallower than the level of seawater.

In the basement rock areas where the resistivity profiling method was applied, attention was paid to the anomaly of comparatively lower resistivity. Whereas the resistivity value is usually very high in fresh and compact basement rocks, the points of comparatively lower resistivity suggest a higher porosity and/or higher transmissivity portion of the basement rocks, namely the fissure-abundant zones.

The most promising point and/or both the top two promising points for well drilling at each village are shown on the plain map of the individual village and its surroundings**,** which are attached in the Supporting Report.

Table 5-2 Summary of Resistivity Value by Rock Type

Geology	Rock (soil)	Resistivity (Ω/m sequence)
Alluvium	Sand (lateritic consolidated sand, gravel) clay – fine sand	15-60 over 100 4-16
Tertiary Sediments	Sandstone Limestone	10-60 20-900
Mesozoic Sediments	Sandstone Sandstone (aquifer)	over 200 30-50
Basement	Gneiss (weathered) Gneiss	20-100 over 500

5.2.3 Test Drilling and Pumping Tests

The sites for test-drilling were determined at the areas which represented the following geological formations in order to understand the condition of the aquifer distribution and the depth to the aquifer in the sedimentary formation, and to confirm whether the found fissure-zone has water or not; (JM1-5 and JL1-5 are the serial numbers of test boreholes in the Mtwara and Lindi regions, respectively)

JM-1 (Ziwani), JL-3 (Pande Plot): aquifer distribution in alluvium,

JM-2 (Mbawala), JM-3 (Arusha Chini), JM-4 (Litehu), JL-1 (Mnolela), JL-2 (Kilangala): aquifer condition in Tertiary and Mesozoic layer.

JM-5 (Nanyumbu): aquifer in fissure zone (with clear lineament of north-south)

JL-4 Ndomoni): aquifer in fissure zone (with clear lineament of east-west)

JL-5 (Chinongwe): aquifer in fissure zone (with weak lineament of southeast-northwest)

The results of the test drilling and pumping test are summarized in Table 5-4, and the well logs and pumping test data are filed in the Data Book.

In the basement rock area, the drilling sites were placed on the anomaly points of the resistivity profiling survey line across the interpreted lineament, and the drilling depth was set at 60-100m by reviewing the past record of near-by boreholes. As a result, 3 test-drillings in the basement rock area have confirmed a limited discharge of 3-6m^3/h, one of which (JL-4) hit saline water with extremely high electrical conductivity of 7,000 μS/cm. This borehole was, therefore, abandoned without installation of casing and screen.

Quality of water in the other 2 boreholes (JM-5 and JL-5) was good enough for drinking purposes. Accordingly, these boreholes were completed as the production wells to be used as the source of the pilot schemes. Hand-pumps were installed to these 2 wells because of the limited production amount.

The test-drillings in the area of the Tertiary and Mesozoic formations were conducted mainly for confirmation of the results of geo-resistivity and other surveys, such as the depth to the presumed aquifer and its thickness, materials of the aquifer beds, productivity of the aquifer, etc. At the site of JM-3 and JL-2, the aquifer was found at a larger depth than expected (24 m and 52 m, respectively). The discharge rate of the JM-3 well (Arusha Chini) was 25 m^3/h which is good enough for supplying water to more than 10,000 people.

The test-drilling JL-3 (Kilangala) hit a confined aquifer after drilling through a very thick confined layer of clayey material, resulting in a self-flowing well. However, the well was not properly completed due to the occurrence of big caving at the said confined layer. The screen has not reached the aquifer bed, but the water is coming up from the bottom of the borehole because the cave has been filled with gravel (more than 3.5 m^3 gravel was put into the borehole). Productivity of this well is limited to only 3.9 m^3/h, regardless of being a self-flowing well. That is probably due to the defective completion of the well. This well is being used for the Kilangala pilot scheme, but a new well should be constructed in the event of a full-scale project, because the lifespan of this well may be shorter than 2-3 years.

No good aquifer was found in the three drilling sites of JM-2, JM-4 and JL-1, which are located on the plateau. This indicates that the aquifer depth and its horizontal distribution varies locally in these areas even if there are certain data showing that the aquifer depth would be within target drilling depth. The thick clayey formation found in these boreholes presumably originates in dry lateritic clayey sandstone. If the drilling continued to tens of meters more, the aquifer would have surely been hit. Unfortunately, however, the capacity of the drilling machine used was not enough to drill deeper. Since this type of formation, i.e. hard and very sticky clay, usually causes heaving of the drilled hole-wall, a machine with a higher torque should be used.

JM-1 and JL-3 are in an area of an alluvium. The depth to aquifer is in fairly good agreement with the value estimated by the resistivity sounding. The discharge rates of these wells are high enough (JM-1=27 m^3/h and JL-3=31.70 m^3/h); therefore, the test wells were converted to production wells to be used as the sources of the pilot schemes. The water in JL-3 (Pande Plot) is so saline that it cannot be a source for drinking purposes. But, people in this village eagerly wish to use this well as a supply source, because salinity of the water presently used is higher than water of the test-well.

5.2.4 Problem Villages for Groundwater Development

Some problems have been pointed out through the above mentioned study and the water quality analysis,. Special attention should be paid to the following villages during the further study or at the implementation stage of the full-scale project:

a. As previously anticipated, the groundwater development in the villages located in the basement rock area involves a risk regarding whether the drilling will certainly hit water or not. Although the most promising sites have been pointed for each candidate village in this study program, trial-and-error in future drilling may be inevitable. The ratio of successful wells in terms of quantity will fall within a range of 65-70% in 49 villages.

b. The development of good quality water is presumed difficult at the villages distributed in the Lukuledi River basin even though test drilling at Chinongwe luckily hit fresh water.

   There are 14 such villages: **Nanganga, Chikoweti** in the Mtwara region, and **Somanga, Ndumbo, Lihimalyoao, Namakongoro, Nanganga, Chilangalile, Machanganja, Mihewe, Litama, Mkonjela, Rweje, Kipara Mtua** in the Lindi region. The need to re-drilling a second or third time will be common in many of above-mentioned villages, resulting in a very low success rate of 30% in terms of both quantity and quality. Thus, this low rate may draw down the average success ratio in the basement rock area to more or less 57%.

c. There are 14 villages where the water level in the well is presumed very low (deeper than 150m). Those are the villages of **Kitama, Mabeti, Nanjanga, Mkuti, Mnanje, Kilidu, Mnima, Namangudu, Likwaya, Mmulunga, Mdimba, Chiwonga,** and **Malatu** in the Mtwara region, all situated on the Makonde plateau. An artesian (confined) aquifer may be hit by drilling over 300m at more or less half of the 14 villages. In the remaining half of the villages, however, the operation cost of pumping may be considerably high, so autonomous O/M seems difficult. Two alternative plans are suggested for those villages. One is connecting two or three villages to the available water source, but since further studies are required for this plan, implementation will be postponed to the 2^{nd} phase of the project. The other is replacing the candidate village. In the event that the second and third drillings fails to hit an artesian aquifer, other villages of lower location shall replace these villages.

Table 5-3 (1) Summary of Hydrogeological Condition and Groundwater Development Plan by Candidate Village

Mtwara Rural District, Mtwara Region

Division	Village	Geology*	Rock Type** (surface soil)	River Basin	lineament (Direction)	Resistivity sounding result		Development Plan			Site Classification*** (Estimated Discharge m3/h)	Remarks
						value range (Ωm)	sequence (m)	Water Source	SWL (m)	Drilling Depth (Elevation)		
Nanyamba	Mbembaleo	Nt, P	Ls, Sds (sd)	Ruvuma East	-	15 - 20	18 - 200	BH	80	200 (200)	C (5-10)	
	Maranje	Nf, P, C	Mds (sd-silt)	Mbuo	weak (N80E)	30 - 40	60 - 80	BH	80	160 (120)	D (3-5)	
	Mtiniko	Nf, P, C	Sds (sd)	Mbuo	clear (N80E)	40 - 70	60 - 200	BH	60 - 120	150 (140)	E (1-3)	
	Malamba	Nf, P, C	Sds (sd)	Ruvuma East	weak (N50E)	10 - 20	30 - 150	BH	60	120 (170)	D (3-5)	
Ziwani	Ziwani	Nt	sd, clay	Likonde	-	15 - 25	30 - 50	(BH)	(28.60)	(68 (56))	B (27)	JM2
	Msimbati	Rd	Sds, Ls (sd)	Likonde	-	-	-	SW	-	-	-	Saline water will contaminate
	Msangamkuu	Rd	Sds, Ls (sd)	Likonde	-	-	-	SW	-	-	-	Saline water will contaminate
	Nanguruwe	Nf, C	Sds (sd)	Likonde	weak (N10E)	20 - 60	60 - 200	BH	60 - 130	180 (180)	E (1-3)	
	Mbawala	Nf, C	Sds, Mds (sd)	Mbuo	-	20 - 25	80 - 200	BH	150	200 (140)	C (5-10)	JM2(D=120, SWL=112, dry well)
Mayanga	Kawawa	Nf, P, C	Sds, Ls (sd)	Likonde	-	15 - 25	120 - 200	BH	10 - 20	140 (70)	D (3-5)	Anxiety of saline water
Kitaya	Kitaya	Nt, P	Sds, Ls (sd)	Ruvuma East	-			BH	30	60 (40)	B (10-30)	
	Arusha Chini	Nt, P	Sds (sd)	Ruvuma East	-	10 - 20	60 - 200	(BH)	(40.21)	(84 (41))	B (25)	JM3
	Mayambe Juu	Nt, P	Sds, Ls (sd)	Ruvuma East	-	80 - 115	70 - 140	BH	100	150 (140)	C (5-10)	
	Kitunguli	Nt, P	LS (sd)	Ruvuma East	-	20 - 30	60 - 200	BH	20	100 (15)	B (10-30)	Same BH will be used with Mahurunga
	Mahurunga	Nt, P	LS (sd)	Ruvuma East	-	20 -30	60 - 200	BH	20	100 (15)	B (10-30)	
Dihimba	Dihimba	Nf, P	Sds, Ls (sd)	Mbuo	clear (E-W, N-S)			BH	40	150 (90)	C (5-10)	Same BH will be used with Mpondomo
	Mpondomo	Nf, P	Sds, Ls (sd)	Mbuo	clear (E-W, N-S)			BH	40	150 (90)	C (5-10)	

Legend : Geology* Rd = Recent Deposits (Alluvium) Nt, Nf = Late Tertiary terrace, fluviatile deposits P = Early Tertiary marine seiments C = Cretaceous continental and marine sediments
J = Jurassic eatuarine and marine sediments M, K = Mesozoic continental sediments (Karoo) Xs = Archaeozoic metamorphosed series (Basement)
Rock (soil type)** sd = sand lat = laterite Sds = sandstone Mds = mudstone Cng = Conglomerate Shl = Shale Gn = Gneiss
Site Classification*** (for groundwater development) A = very good B = good C = fair D = fair (with small discharge) E = difficult F = very difficult G = no data to estimate the potential

Table 5-3 (2) Summary of Hydrogeological Condition and Groundwater Development Plan by Candidate Village

Tandahimba District, Mtwara Region

Division	Village	Geology*	Rock Type** (surface soil)	River Basin	lineament (Direction)	Resistivity sounding result		Development Plan			Site Classification*** (Estimated Discharge m3/h)	Remarks
						value range (Ωm)	sequence (m)	Water Source	SWL (m)	Drilling Depth (Elevation)		
Namikupa	Mihambwe	Nt, C	Sds (sd)	Ruvuma East	clear (N50W)	50 - 70	82 - 200	BH	90	180 (255)	D (3-5)	
	Kitama	Nf, C	Sds (sd)	Ruvuma East	-	35 - 45	15 - 200	BH	150	180 (280)	F (below 1)	
	Mitondi A	Nf, C	Sds (sd)	Ruvuma East	-	10 - 20	11 - 200	BH	80	180 (250)	E (1-3)	
	Misufini	Nt, C	Sds (sd)	Ruvuma East	-	55 - 65	120 - 200	BH	80	180 (180)	E (1-3)	
Litehu	Litehu	Nt, C	Sds, Mds (sd)	Mambi	-	40 - 50	70 - (120)	BH	80	200 (355)	E (1-3)	
	Mmeda	Nf, C	Sds, Mds (sd)	Mambi	-	20 - 25	100 - 200	BH	140	200 (350)	D (3-5)	
	Mabeti	Mf, C	Sds, Mds (sd)	Mambi	-	95 - 105	90 - 200	BH	200	250 (385)	E (1-3)	
	Mkwiti	Nf, C	Mds (sd - clay)	Lukuledi	-	over 300	150 - 200	SP			E (1-3)	2km from the spring source
	Namindondi Juu	Nf, C	Mds, Sds (sd - clay)	Lukuledi	weak (N40W)	70 - 75	10 - 20	SP			E (1-3)	0.5km from the spring source
	Nanjanga	Nf, C	Sds (sd)	Mambi	-	90 - 100	230 - 250	BH	200	400 (563)	G (difficult to estimate)	
	Mkuti	Nf, C	Sds (sd)	Lukuledi	-	75 - 80	230 - 300	BH	200	400 (535)	G (difficult to estimate)	

Legend : Geology* Rd = Recent Deposits (Alluvium) Nt, Nf = Late Tertiary terrace, fluviatile deposits P = Early Tertiary marine seiments C = Cretaceous continental and marine sediments
J = Jurassic eatuarine and marine sediments M, K = Mesozoic continental sediments (Karoo) Xs = Archaeozoic metamorphosed series (Basement)
Rock (soil type)** sd = sand lat = laterite Sds = sandstone Mds = mudstone Cng = Conglomerate Shl = Shale Gn = Gneiss
Site Classification*** (for groundwater development) A = very good B = good C = fair D = fair (with small discharge) E = difficult F = very difficult G = no data to estimate

Table 5-3 (3) Summary of Hydrogeological Condition and Groundwater Development Plan by Candidate Village

Newala District, Mtwara Region

Division	Village	Geology*	Rock Type** (surface soil)	River Basin	lineament (Direction)	Resistivity sounding result		Development Plan			Site Classification*** (Estimated Discharge m3/h)	Remarks
						value range (Ωm)	sequence (m)	Water Source	SWL (m)	Drilling Depth (Elevation)		
Newala	Mnanje	Nf, C	Sds (sd)	Mwiti - Mchauru	-	over 800		BH	200	350 (615)	G (difficult to estimate)	
	Kilidu	Nf, C	Sds (sd)	Mambi	-	45 - 55	15 - 200	BH	150	200(630)	G (difficult to estimate)	
Chilangala	Mnima	Nf, C	Sds (sd)	Ruvuma East	-	over 1200		(BH)	250	300 (800)	G (difficult to estimate)	
	Miyuyu	Nf, C	Sds (sd)	Lukuledi	-	over 900		BH	350	400	F (less than 1)	1km from spring source
	Namangudu	Nf, C	Sds (sd)	Mambi	-	High value		BH	350	400 (715)	G (difficult to estimate)	
Kitangari	Mitanga	Nf, C	Sds (sd)	Mambi	-	100 - 105	100 - 200	BH	150	250 (460)	F (less than 1)	
	Likwaya	Nf, C	Sds (sd)	Mambi	-	over 160	170 - 200	BH	200	300 (540)	G (difficult to estimate)	
	Malatu	Nf, C	Sds (sd)	Mambi	-	over 300	140 - 200	BH	150	250(650)	G (difficult to estimate)	
	Mdimba	Nf, C	Sds (sd)	Mambi	-	65 - 70	150 - 200	BH	180	250 (600)	F (less than 1)	
	Chiwonga	Nf, C	Sds, Cng (sd)	Mambi	-	over 350		BH	180	250 (640)	G (difficult to estimate)	
	Mmulunga	Nf, C	Sds (sd)	Mambi	-	110 - 120	180 - 200	BH	180	250 (460)	E (1-3)	

Legend : Geology* Rd = Recent Deposits (Alluvium) Nt, Nf = Late Tertiary terrace, fluviatile deposits P = Early Tertiary marine seiments C = Cretaceous continental and marine sediments
J = Jurassic eatuarine and marine sediments M, K = Mesozoic continental sediments (Karoo) Xs = Archaeozoic metamorphosed series (Basement)

Rock (soil type)** sd = sand lat = laterite Sds = sandstone Mds = mudstone Cng = Conglomerate Shl = Shale Gn = Gneiss

Site Classification*** (for groundwater development) A = very good B = good C = fair D = fair (with small discharge) E = difficult F = very difficult G = no data to estimate

Table 5-3 (4) Summary of Hydrogeological Condition and Groundwater Development Plan by Candidate Village

Masasi District, Mtwara Region

Division	Village	Geology *	Rock Type** (surface soil)	River Basin	lineament (Direction)	Resistivity sounding result		**Development Plan**			**Site Classification*** (Estimated Discharge m3/h)**	Remarks
						value range (Ωm)	sequence (m)	Water Source	SWL (m)	Drilling Depth (Elevation)		
Chikundi	Nanganga	Rd, Nt, Xs	Sds, Gn (sd)	Lukuledi	-	15 - 30	10 - 50	BH	10	50 (230)	C (5-10)	
Lisekese	Namkungwi	Xs	Gn (sd)	Mbangala	weak (N35E)	anomaly at HES P+160		BH	10	100 (414)	E (1-3)	BH location is 700m from the School
	Kilosa	Xs	Gn (sd)	Mbangala	clear (N30E)	anomaly at HES P+160		BH	10	80 (346)	D (3-5)	
	Chikoweti	Xs	Gn (sd)	Mbangala	weak (N40W)	75 - 80	20 - 95	BH	5	30 (420)	D (3-5)	Anxeity of saline water
	Mlingula	Xs	Gn (sd)	Mbangala	weak (N20E)	anomaly at HES P +60		BH	10	80 (380)	D (3-5)	BH location is 3km from the School
	Chiwale	Xs	Gn (sd)	Mbangala	Clear (N80E)	anomaly at HES P +60		BH	10	100 (455)	D (3-5)	BH location is 1km from the Dispensary
Nanyumbu	Nanyumbu	Xs	Gn (sd)	Mbangala	Clear (NE)	anomaly at HES P+200		(BH)	(4.76)	(80 (300))	C (6)	
	Namasogo	Xs	Gn (sd)	Mbangala	clear (N30E)	anomaly at HES P 0		BH	10	100 (330)	D (3-5)	BH location is 1.5km from the VO
Lulindi	Msanga	Rd, Xs	Sds, Gn (sd)	Mwiti - Mchauru	weak (N75E)	anomaly at HES P -160		BH	80	200 (530)	E (1-3)	BH location is 1km from the school
Chiungutwa	Mpeta	Xs	Gn (sd)	Mwiti - Mchauru	clear (N60E)	anomaly at HES P+110		BH	20	80 (280)	D (3-5)	BH location is 1km from the school
	Mitonji	Xs	Gn (sd)	Mwiti - Mchauru	weak	anomaly at HES P 0		BH	40	80 (240)	E (1-3)	

Legend : Geology* Rd = Recent Deposits (Alluvium) Nt, Nf = Late Tertiary terrace, fluviatile deposits P = Early Tertiary marine seiments C = Cretaceous continental and marine sediments
J = Jurassic eatuarine and marine sediments M, K = Mesozoic continental sediments (Karoo) Xs = Archaeozoic metamorphosed series (Basement)
Rock (soil type)** sd = sand lat = laterite Sds = sandstone Mds = mudstone Cng = Conglomerate Shl = Shale Gn = Gneiss
Site Classification*** (for groundwater development) A = very good B = good C = fair D = fair (with small discharge) E = difficult F = very difficult G = no data to estimate

Table 5-3 (5) Summary of Hydrogeological Condition and Groundwater Development Plan by Candidate Village

Kilwa District, Lindi Region

Division	Village	Geology *	Rock Type ** (surface soil)	River Basin	lineament (Direction)	Resistivity sounding result: value range (Ωm)	Resistivity sounding result: sequence (m)	Development Plan: Water Source	Development Plan: SWL (m)	Development Plan: Drilling Depth (Elevation)	Site Classification*** (Estimated Discharge m3/h)	Remarks
Pwani	Migeregere	C	Sds (sd)	Matandu	-	20 - 25	20 - 150	BH	100	150 (92)	C (5-10)	
Miteja	Mtandango	Rd, Nt	Ls (sd)	Rufuji	-	25 - 30	6月10日	BH	30	50 (20)	B (10-30)	affected by seawater from 50 m
	Somanga Ndumbo	Rd, Nt	Ls (sd)	Rufuji	-	15 - 20	50 - 100	BH	5	80 (10)	A (over 30)	
Pande	Pande Plot	Rd, Nt	Ls (sd)	Navuji	-	20 - 30	20 - 120	(BH)	(28)	(75 (30))	A (32)	JL-3
	Mtitimira	Rd, Nt	Ls (sd)	Navuji	-	15 - 40	10 - 150	BH	40	100 (60)	B (10-30)	
	Lihimalyoao	Rd, Nt	Ls (sd)	Navuji	-	30 - 35	4 - 20	BH	10	80 (40)	B (10-30)	
	Namakongoro	Rd, Nt	Ls (sd)	Navuji	-	15 - 25	5 - 50	BH	10	80 (40)	B (10-30)	
	Mandawa	J	Ls (sd)	Navuji	-	80 - 90	12 - 200	BH	10	100 (110)	B (10-30)	
	Kiwawa	P,C	Ls, Sds (sd)	Navuji	-	25 - 30	30 - 150	BH	20	150 (115)	C (5-10)	

Legend : Geology* Rd = Recent Deposits (Alluvium) Nt, Nf = Late Tertiary terrace, fluviatile deposits P = Early Tertiary marine seiments C = Cretaceous continental and marine sediments
J = Jurassic eatuarine and marine sediments M, K = Mesozoic continental sediments (Karoo) Xs = Archaeozoic metamorphosed series (Basement)

Rock (soil type)** sd = sand lat = laterite Sds = sandstone Mds = mudstone Cng = Conglomerate Shl = Shale Gn = Gneiss

Site Classification*** (for groundwater development) A = very good B = good C = fair D = fair (with small discharge) E = difficult F = very difficult G = no data to estimate the potential

Table 5-3 (6) Summary of Hydrogeological Condition and Groundwater Development Plan by Candidate Village

Lindi District, Lindi Region

Division	Village	Geology *	Rock Type ** (surface soil)	River Basin	lineament (Direction)	Resistivity sounding result: value range (Ωm)	Resistivity sounding result: sequence (m)	Development Plan: Water Source	Development Plan: SWL (m)	Development Plan: Drilling Depth (Elevation)	Site Classification*** (Estimated Discharge m3/h)	Remarks
Mtama	Chiwerere	Rd, C	Sds (sd)	Lukuledi	-	25 - 30	5 - 10	BH	30	80 (208)	E (1-3)	
	Nyengedi	Rd, C	Sds (sd)	Lukuledi	-	12 - 35	15 - 80	BH	10	80 (150)	C (5-10)	
	Mtumbya	C	Sds (sd)	Lukuledi	-	15 - 25	95 - 120	BH	60	180 (205)	E (1-3)	
	Kilimahewa (Muta)	Rd, C	Sds, Ls (sd)	Lukuledi	-	25 - 35	20 - 140	SP	-	-	B (10-30)	spring located at 1.5km from the VC
Sudi	Madangwa	Rd, P	Ls (lat)	Mambi	-	10 - 15	120 - 190	SP	-	-	C (5-10)	spring located at 2.0km from the VC
	Hingawali	Rd, P, C	Sds, Ls (sd)	Mambi	-	60 - 70	100 - 200	BH	60	180 (245)	D (3-5)	
Nyangamara	Madingo	C	Sds (sd)	Mambi	-	10 - 20	70 - 170	BH	50	180 (181)	D (3-5)	
	Chiuta	P, C	Sds, Ls (sd)	Mambi	-	15 - 20	23 - 150	BH	80	180 (350)	D (3-5)	
	Malungo	P, C	Sds, Ls (sd)	Mambi	-	15 - 20	100 - 120	BH	20	160 (300)	D (3-5)	
Mingoyo	Kiwalala	Rd, P	Sds, Ls (sd)	Lukuledi	-	60 - 90	20 - 40	BH	30	60 (75)	B (10-30)	
	Mnolela	Rd, P, C	Ls, Sds, Shl (sd)	Mambi	-	10 - 15	70 - 110	BH	50	200 (35)	C (5-10)	JL-1(D=130, SWL=65, Q=0.5m3/h)
Rondo	Chiodya	Nf, C	Sds (lat, sd)	Lukuledi	-	more than 500		SP			E (1-3)	at least 4 springs located at 2.0km from VC
Ngapa	Kinengene	Rd, C	Sds (sd)	Lupululu - Nangaru	-	[15 - 20]	[20 - 100]	BH	20 - 30	60 (40)	B (10-30)	
Mchinga	Kilangala	Rd, P, C	Ls, Sds (sd)	Lupululu - Nangaru	-	20 - 30	20 - 120	(BH)	(-0.5)	(134 (115))	D (3.9)	JL-2, Artisan
	Kilolombwani	Rd, P	Ls (sd)	Lupululu - Nangaru	-	[20 - 30]	[30 - 100]	BH	10	80 (110)	E (1-3)	
Mipingo	Lihimilo	C (J)	Sds (sd)	Mbemkuru	-	25 -30	60 - 240	BH	50	180 (100)	E (1-3)	
Nangaru	Chikonji	Rd, C	Sds (sd)	Lupululu - Nangaru	-	[20 - 30]	[60 - 120]	BH	Art	90	B (10-30)	

Legend : Geology* Rd = Recent Deposits (Alluvium) Nt, Nf = Late Tertiary terrace, fluviatile deposits P = Early Tertiary marine seiments C = Cretaceous continental and marine sediments
J = Jurassic eatuarine and marine sediments M, K = Mesozoic continental sediments (Karoo) Xs = Archaeozoic metamorphosed series (Basement)
Rock (soil type)** sd = sand lat = laterite Sds = sandstone Mds = mudstone Cng = Conglomerate Shl = Shale Gn = Gneiss
Site Classification*** (for groundwater development) A = very good B = good C = fair D = fair (with small discharge) E = difficult F = very difficult G = no data to estimate the potential

Table 5-3 (7) Summary of Hydrogeological Condition and Groundwater Development Plan by Candidate Village

Ruangwa District, Lindi Region

Division	Village	Geology *	Rock Type ** (surface soil)	River Basin	lineament (Direction)	Resistivity sounding result		Development Plan			Site Classification*** (Estimated Discharge m3/h)	Remarks
						value range (Ωm)	sequence (m)	Water Source	SWL (m)	Drilling Depth (Elevation)		
Ruangwa	Nanganga	Rd, Xs	Gn (sd)	Lukuledi	-			BH	10	80 (215)	D (3-5)	BH location is 1.5km from school
	Chilangalile	Xs	Gn (sd)	Mbwemkuru	clear (NW-SE)	anomaly at HES P +120		BH	30	80 (315)	E (1-3)	BH location is 2km from VO
	Machanganja	Xs	Gn (sd)	Mbwemkuru	weak (NW-SE)	anomaly at HES P -60		BH	10	80 (245)	D (3-5)	BH location is 1.5km from VO
	Liuguru	Xs	Gn (sd)	Mbwemkuru	Clear (NE-SW)	anomaly at HES P +160		BH	30	80 (300)	D (3-5)	BH location is 1.5km from VO
	Mihewe	Xs	Gn (sd)	Mbwemkuru	weak (NS)	anomaly at HES P		BH	20	80 (215)	D (3-5)	BH location is 500m from VO
Mnacho	Chinongwe	Rd, Xs	Gn (sd)	Lukuledi	weak (N70W)	anomaly at HES P +240		(BH)	(6.8)	(62)	D (3.2)	BH location is 1km from VO
	Litama	Rd, Xs	Gn (sd)	Lukuledi	weak (N70W)	anomaly at HES P		BH	10	80	D (3-5)	
	Likwachu	Rd, Xs	Gn (sd)	Lukuledi	weak (NW-SE)	anomaly at HES P +170		BH	20	80 (260)	E (1-3)	BH location is 1km from VO
	Ipingo	Rd, Xs	Gn (sd)	Lukuledi	weak (N20W)	anomaly at HES P		BH	30	80 (265)	E (1-3)	BH location is 1km from school
Mandawa	Chibula Mihuru	Xs	Gn (sd)	Mbwemkuru	weak (NS)	anomaly at HES P -50		BH	40	80 (369)	D (3-5)	BH location is 500m from VO

Legend : Geology* Rd = Recent Deposits (Alluvium) Nt, Nf = Late Tertiary terrace, fluviatile deposits P = Early Tertiary marine seiments C = Cretaceous continental and marine sediments
J = Jurassic eatuarine and marine sediments M, K = Mesozoic continental sediments (Karoo) Xs = Archaeozoic metamorphosed series (Basement)

Rock (soil type)** sd = sand lat = laterite Sds = sandstone Mds = mudstone Cng = Conglomerate Shl = Shale Gn = Gneiss

Site Classification*** (for groundwater development) A = very good B = good C = fair D = fair (with small discharge) E = difficult F = very difficult G = no data to estimate

Table 5-3 (8) Summary of Hydrogeological Condition and Groundwater Development Plan by Candidate Village

Nachingwea District, Lindi Region

Division	Village	Geology *	Rock Type ** (surface soil)	River Basin	lineament (Direction)	Resistivity sounding result: value range (Ωm)	Resistivity sounding result: sequence (m)	Development Plan: Water Source	Development Plan: SWL (m)	Development Plan: Drilling Depth (Elevation)	Site Classification*** (Estimated Discharge m3/h)	Remarks
Mnero	Mkonjela	Xs	Gn (sd)	Mbwemkuru	weak (NE-SW)	anomaly at HES		BH	40	80 (400)	E (1-3)	
Ruponda	Litula	Xs	Gn (sd)	Mbwemkuru	clear (N20W)	anomaly at HES P +140		BH	40	100 (395)	E (1-3)	
	Rweje	Xs	Gn (sd)	Mbwemkuru	weak (NE-SW)	anomaly at HES P +60		BH	30	100 (350)	C (5-10)	Anxiety of saline water existance. BH location is 2km from school
Nambambo	Naipanga	Xs	Gn (sd)	Lukuledi	weak (NE-SW)	anomaly at HES P +160		BH	10	80 (350)	E (1-3)	BH location is 3km from school
	Chiumbati Miembeni	Xs	Gn (sd)	Lukuledi	weak (NE-SW)	anomaly at HES P +220		BH	30	80 (380)	D (3-5)	
	Mandai	Xs	Gn (sd)	Lukuledi	weak (NW-SE)	anomaly at HES P -80		BH	20	80 (460)	D (3-5)	BH location is 2km from VO.
	Ndomoni	Xs	Gn (sd)	Lukuledi	clear (EW)	New HES shall be plan for other lineaments		BH	20	80 (350)	D (3-5)	JL4 (D=76, high salinity water)
	Kipara Mtua	Xs	Gn (sd)	Lukuledi	weak (NS)	New HES shall be plan for other lineaments		BH	30	160 (420)	D (3-5)	
	Mpiruka	Xs	Gn (sd)	Lukuledi	clear (N40E)	anomaly at HES P 0		BH	40	150 (480)	E (1-3)	BH location is 1.5km from VO

Liwale District, Lindi Region

Division	Village	Geology *	Rock Type ** (surface soil)	River Basin	lineament (Direction)	Resistivity sounding result: value range (Ωm)	Resistivity sounding result: sequence (m)	Development Plan: Water Source	Development Plan: SWL (m)	Development Plan: Drilling Depth (Elevation)	Site Classification*** (Estimated Discharge m3/h)	Remarks
Barikiwa	Mlembwe	Rd, K	Sds, Mds (sd)	Matandu	-	15 - 20	7 - 60	BH	40	80 (660)	C (5-10)	
Liwale	Mikunya	Nf	Sds (sd)	Mbwemkuru	-	15 - 20	4 - 30	BH	25	60 (420)	C (5-10)	
	Mihumo	Nf	Sds (sd)	Lukuledi	-	30 - 35	5 - 110	BH	20	50 (500)	B (10-30)	
	Mbaya	Rd, K	Sds, Mds (sd)	Marandu	-	30 - 35	3 - 70	BH	30	60 (440)	B (10-30)	
	Ngongowele	Nf	Sds (sd)	Lukuledi	-	10 - 15	40 - 150	BH	10	80 (600)	B (10-30)	

Legend : Geology* Rd = Recent Deposits (Alluvium) Nt, Nf = Late Tertiary terrace, fluviatile deposits P = Early Tertiary marine seiments C = Cretaceous continental and marine sediments
J = Jurassic eatuarine and marine sediments M, K = Mesozoic continental sediments (Karoo) Xs = Archaeozoic metamorphosed series (Basement)
Rock (soil type)** sd = sand lat = laterite Sds = sandstone Mds = mudstone Cng = Conglomerate Shl = Shale Gn = Gneiss
Site Classification*** (for groundwater development) A = very good B = good C = fair D = fair (with small discharge) E = difficult F = very difficult G = no data to estimate the potential

Table 5-4 Summary of Drilling and Pumping Test

Region	Well No.	Village Name (elevation) District	Drilled Depth (GL -m)	Screen Depth (GL -m)	Static Water Level (GL -m)	Dynamic Water Level (GL -m)	Drawdown (GL -m)	Discharge (m3/h)	Specific Capacity (m3/h/m)	Aquifer (Sequence GL-m)
MTWARA	JM-1	**Ziwani** (60m) Mtwara Rural	68.00	64.07	40.60	43.22	2.42	27.00	11.16	medium sand (20 - 24) fine - medium sand (44 - 56)
	JM-2	**Mbawala** (150m) Mtwara Rural	120.00	118.80	112.00	-	-	-		Discharge amout is very small
	JM-3	**Arusha Chini** (40m) Mtwara Rural	84.00	80.40	40.21	52.30	12.09	25.00	2.07	medium sand (24 - 42) fine - medium sand (52 - 76)
	JM-4	**Litehu** (350m) Tandahimba	142.50	142.00	-	-	-	-		Dry Hole
	JM-5	**Nanyumbu** (300m) Masasi	80.00	67.65	4.76	57.98	53.22	6.00	0.11	weathered gneiss (43.5 - 58.5)
LINDI	JL-1	**Mnolela** (160m) Lindi Rural	131.00	129.84	65.73	87.23	21.50	0.50	0.02	shale and sandsrone (118 - 131)
	JL-2	**Kilangala** (115m) Lindi Rural	132.00	94.50	+ 0.5 (Artesian)	58.50	58.00	3.90	0.07	limestone (120 - 132)
	JL-3	**Pande Plot** (30m) Kilwa	78.00	71.90	28.00	32.60	4.60	31.70	6.89	medium sand (48 - 62)
	JL-4	**Ndomoni** (310m) Nachingwea	76.50	-	-	-	-	-		abondoned due to high conductivity
	JL-5	**Chinongwe** (290m) Ruangwa	62.00		6.80	54.80	48.00	3.20	0.07	weathered gneiss (25.50 - 46.50)

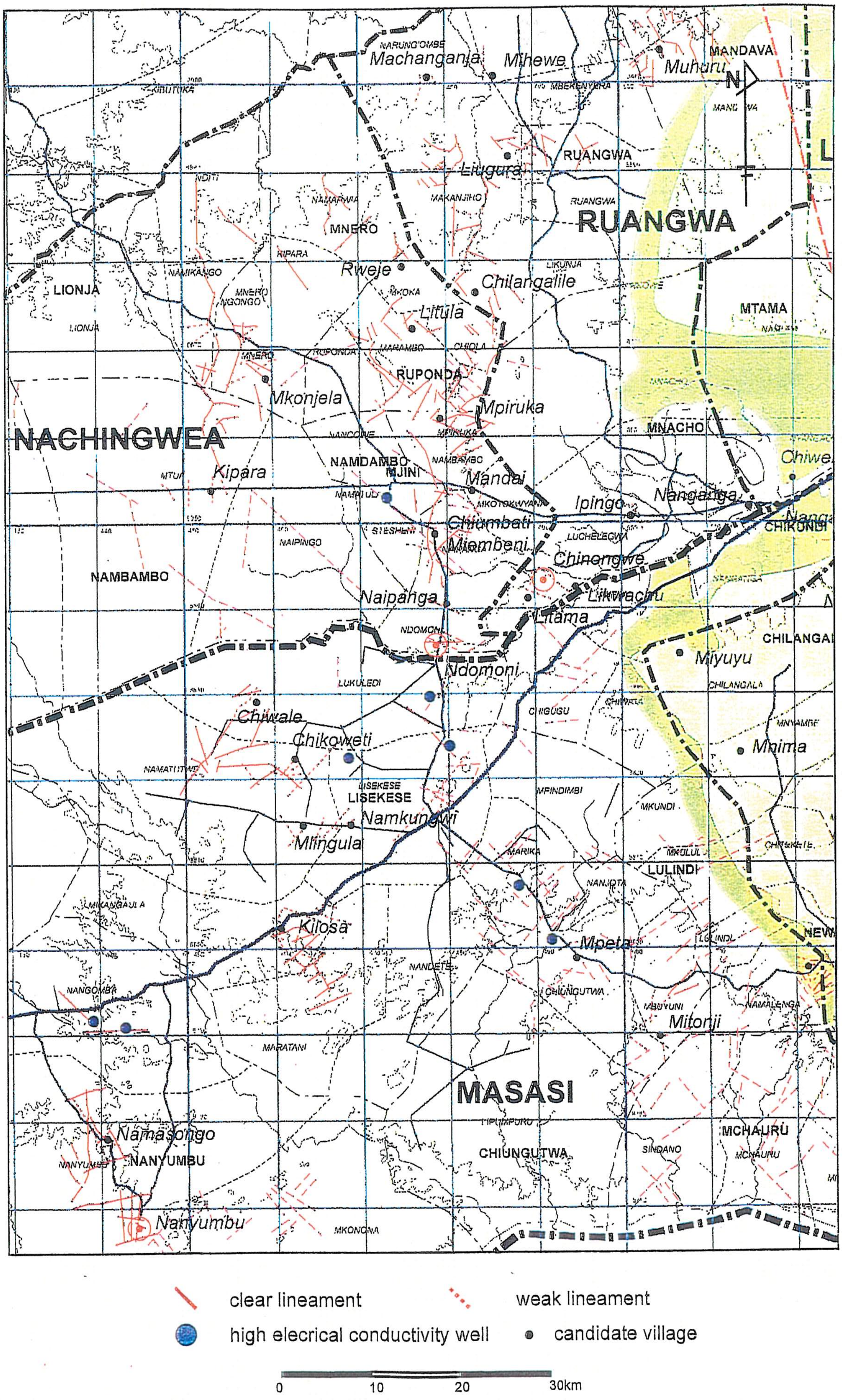


Figure 5-2 Lineaments of Basement Rock Area

5.3 Groundwater Development Potential by Area

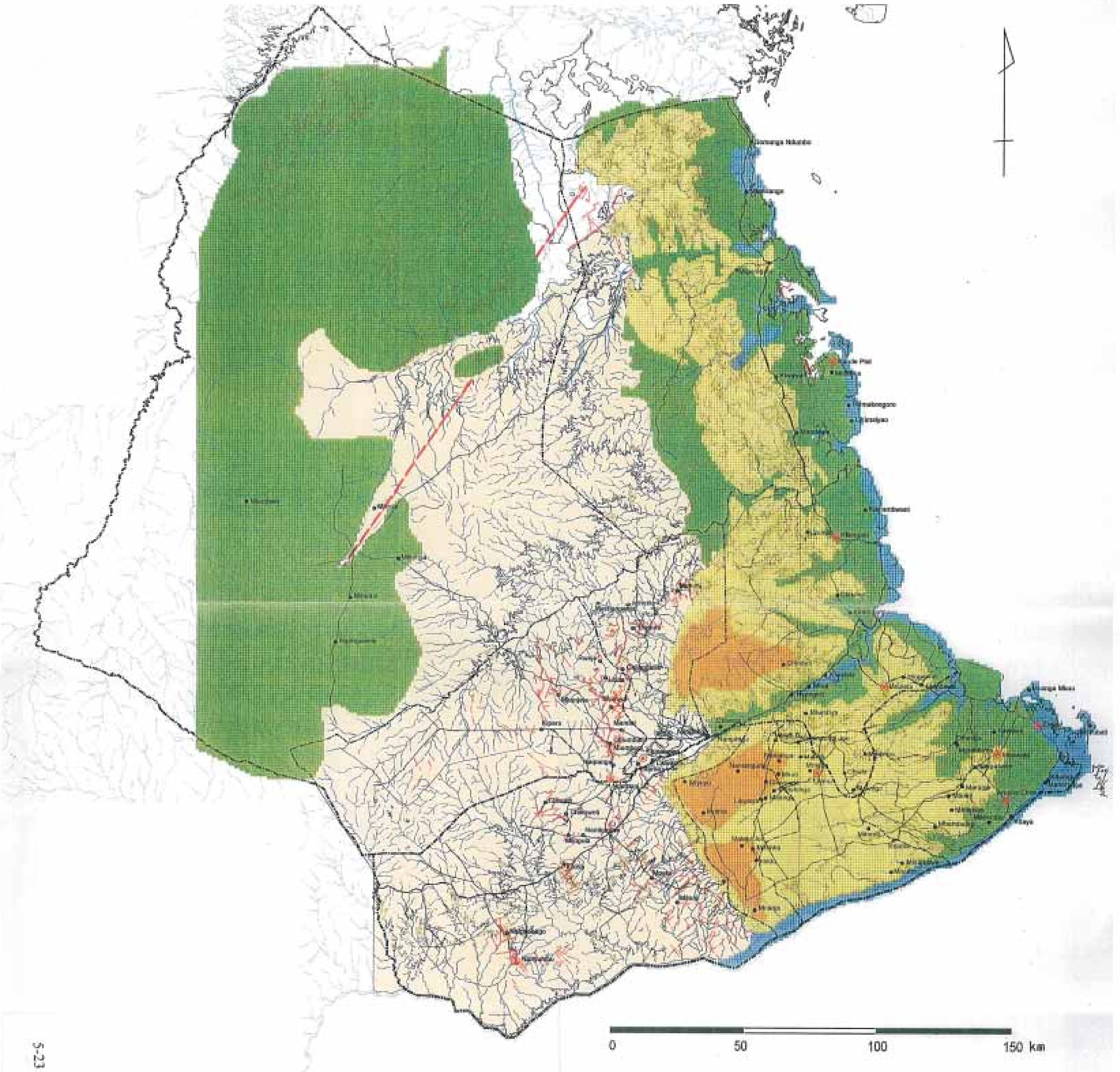
Groundwater development potential is limited to the fractured zones and the deep weathered portions in the basement rocks and Karoo Formations (Makonde and Rondo Plateau and their vicinities). Some borehole data show existence of artesian wells and wells with a static water level shallower than 40 m below ground surface. But, the number of these productive wells is very limited in the area because most of the wells are not properly located. Since the Masasi, Nachingwea and Liwale districts are situated in the difficult areas, a careful survey is required in order to distinguish the comparatively higher potential zones in these districts.

In the Coastal Sediment area, which extends in Newala, Tandahinba, Mtwara Rural in the Mtwara region and Lindi Rural, Kilwa and a part of the Ruangwa in the Lindi region, has aquifers in the porous sandstone beds. Although the expansion and depths of the aquifers are different place-to-place, groundwater potential is generally quite high in these areas. Also, since artesian levels are usually shallow (close to the ground surface) at the low-lying river valleys and coasts, shallow boreholes often hit confined aquifers resulting in self-flowing wells. Therefore, these areas are not only high potential area but also areas of economical exploitation of groundwater.

On the other hand, the highly elevated areas of Makonde and Rondo Plateau have a deeper static water level. Although the potential for groundwater development is not low in these areas, the cost is very high (not economical). Consequently, groundwater development potential apparently seems low (the southern area of the Newala and Tandahimba districts, and at the boundary of the Lindi and Ruangwa districts). These areas contain possible shallow aquifers in the weathered surface portion (shallower than 10-20m from the ground surface). Dug wells are common on the Plateau. However, the quantity of water is usually unstable, and the wells are often exposed to contamination from intrusion of dirty surface water. Therefore, development of deep groundwater must be done in spite of the fact that it is costly.

In the basement rock areas, the high potential area is limited to the portion of the lineament structures that indicates fissure abundant zones. It must be mentioned, however, that the fissures that produce non-potable water are not in the high potential zones.

The groundwater development potential in the study area is presented in Figure 5-3**.** This figure presents the high potential area in terms of economical groundwater development in the sedimentary formations, and high potential zones in the basement rock areas without differentiation of good or bad quality of fissure water.



Legend

- national boundary
- regional boundary
- district boundary
- ward boundarly
- river
- road
- contour
- village
- Test Drilling Site

Depth to the Confined Aquifer from the Surface Level

Depth (m)	Potential for Groundwater Development
50 > D > 0	High (suffered from seawater intrusion along the sea coast)
150 > D > 50	High
300 > D > 150	Medium
over 300	Poor
Xs	Archaeozoic metamorphosed series (Basement)

fissure with water quality problem

Figure 5-3 Depth of the Confined Aquifer and Potential Fissures