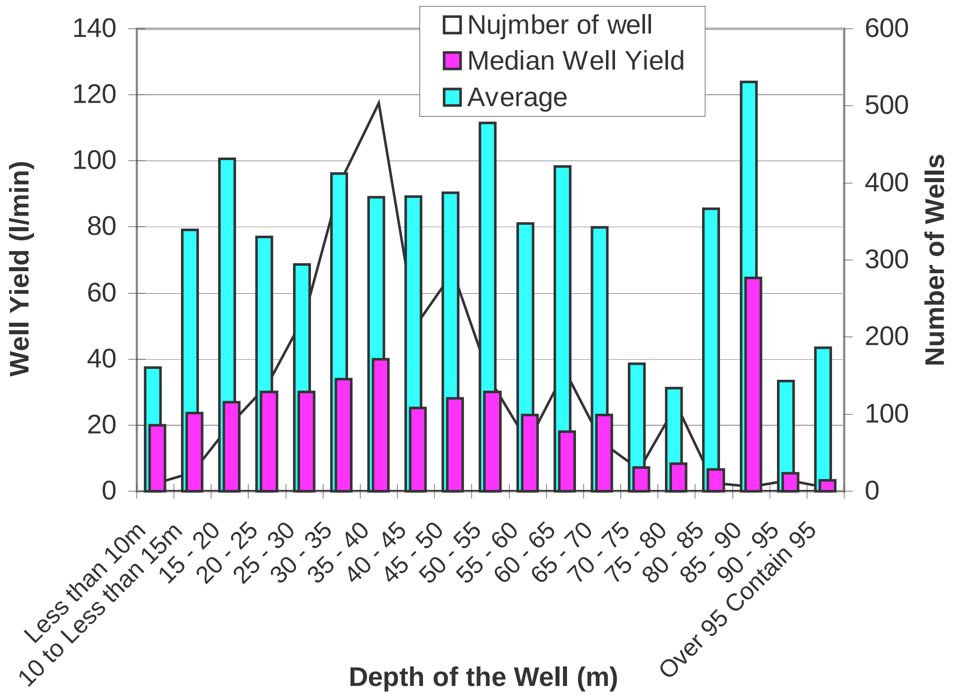


Figure 4.2 Relationship between Average of Well Yield and Well Depth

Figure 4.3 shows the locations of fractures recorded during the drilling of test wells. The figure indicates that many fractures are developed above the depth of about 50 m. Thus, a non-fracture zone with a thickness of 20-40 meters occurs below around the depth of 50 m. The calliper logging shows that this was the hard rock zone. Some fractures were observed between the depth of around 70 and 100 m in some test wells. Some of them had further fractures below the depth of 100 m.

The above results show the aquifers can be practically classified into three categories to consider a future groundwater development in the area, though a network of fractures in the basement rock, or a fractured aquifer system, is not clear yet. These categories are;

Upper fractured aquifer	A fractured aquifer already exploited in the depth to about 70 m
Lower fractured aquifer	A deep fractured aquifer in the depth from 70 to 100 m
Deeper fractured aquifer	A deeper aquifer in the depth from 100 to 200 m

The following sections describe the aquifers categorized above.

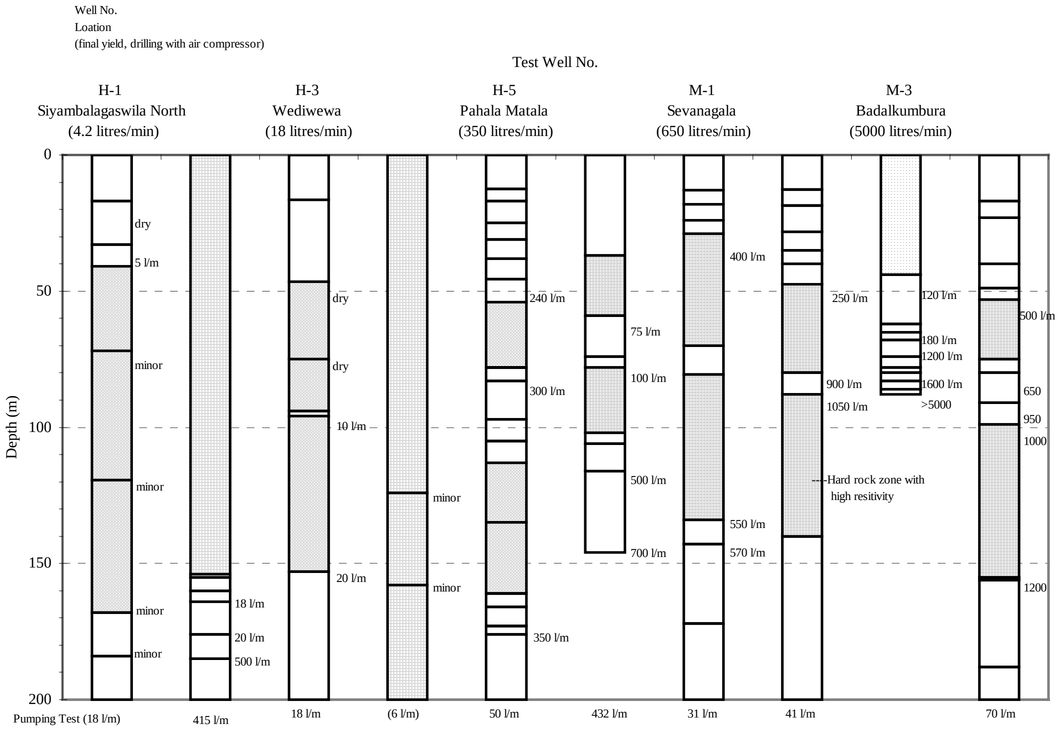
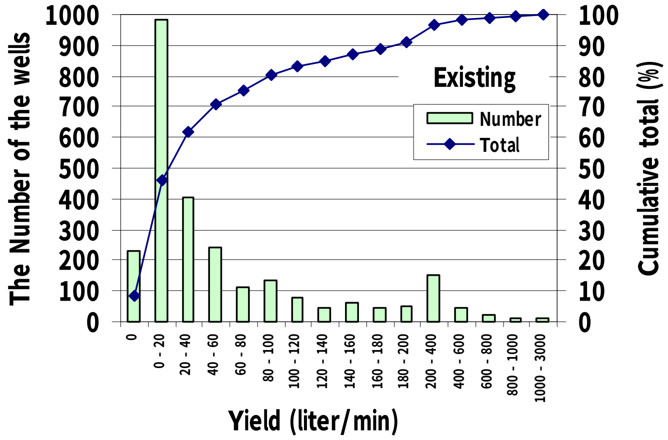


Figure 4.3 Fractures Recorded in Test Wells

4.2.2 UPPER FRACTURED AQUIFER (0 TO 70 M. IN DEPTH)

A total of 2625 wells, which is 92.3 % of the total number of existing wells, are 70 meters or less in depth. *Figure 4.4* shows the number of wells classified by yield. A total of 981 wells yielded 20 litres/min or less, and 239 wells yielded between 20 to 40 litres/min. Consequently 61.6 % of existing wells with a depth of less than 70 m yielded 40 litres/min or less including non yielding wells. On the other hand, there are 519 wells (19.8 %) yielding more than 100 litres/min, which can be extracted by a submersible pump if necessary.



Yield (liter/min)	Number of Wells	Accumulating Total	
		No.	%
0	228	228	8.7
0 - 20	981	1209	46.1
20 - 40	407	1616	61.6
40 - 60	239	1855	70.7
60 - 80	115	1970	75.0
80 - 100	136	2106	80.2
100 - 120	79	2185	83.2
120 - 140	47	2232	85.0
140 - 160	60	2292	87.3
160 - 180	43	2335	89.0
180 - 200	51	2386	90.9
200 - 400	151	2537	96.6
400 - 600	45	2582	98.4
600 - 800	20	2602	99.1
800 - 1000	9	2611	99.5
1000 - 3000	14	2625	100.0

Figure 4.4 Number of Wells Classified by Yield

(Upper Fractured Aquifer of 0 to 70 m in Depth)

The yield map, *Figure 4.5(1)*, shows that the areas where wells are expected to yield more than 100 litres/min are located in the western end of Hambantota, and the south end, middle, and eastern area of Monaragala.

Three test wells, No.H-5 (Pahala Mattala), M-1 (Sevanagala) and M-2 (Bodagama), encountered productive fractures above the depth of 50 m. The fractures yielded from 240 to 400 litres/min during drilling. No.M-4 test well (Yalabowa) encountered fractures at the depth of 56 m, which yielded 500 litres/min.

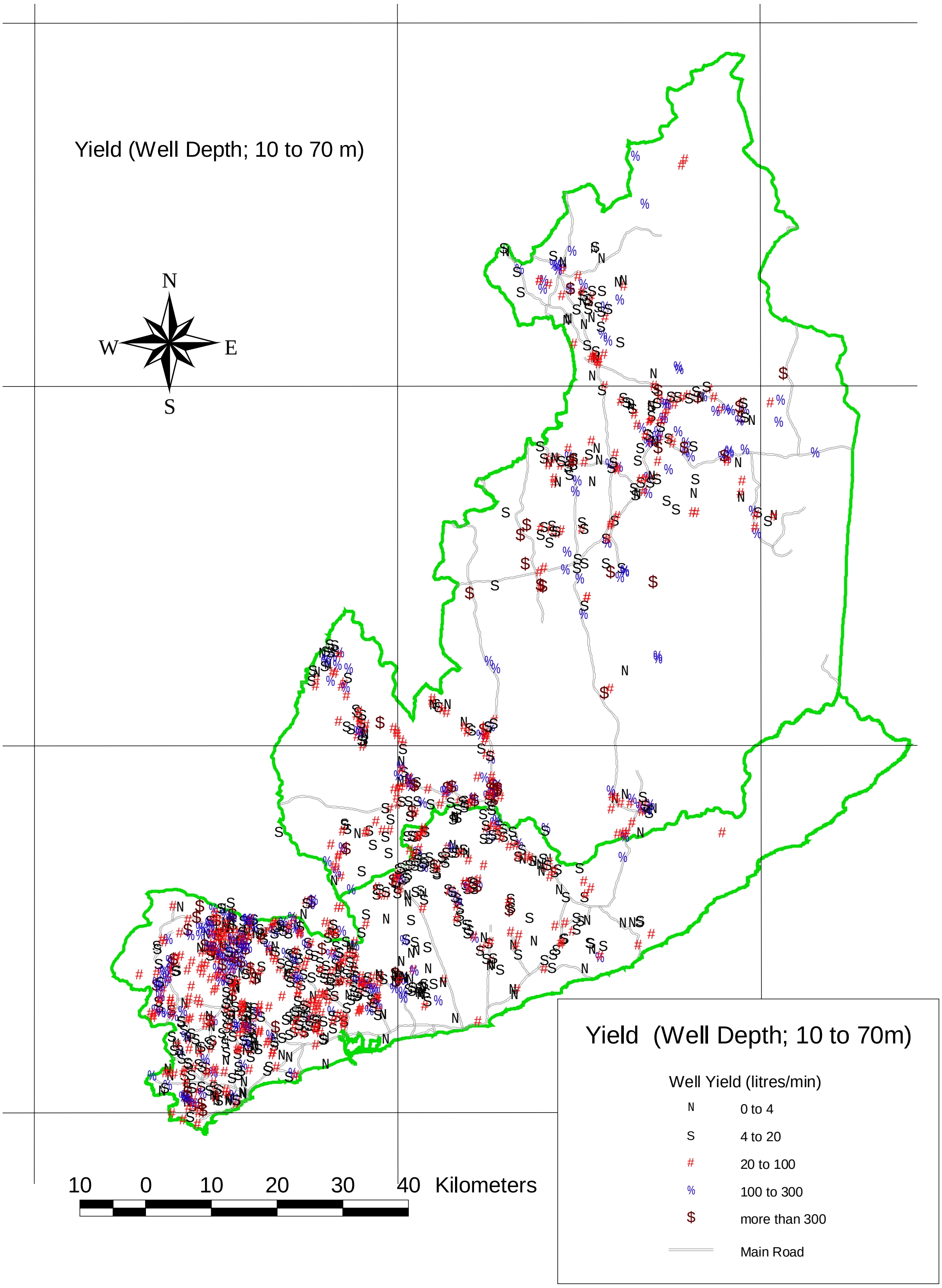


FIGURE 4.5(1) WELL YIELD (WELL DEPTH; 10 TO 70 M)

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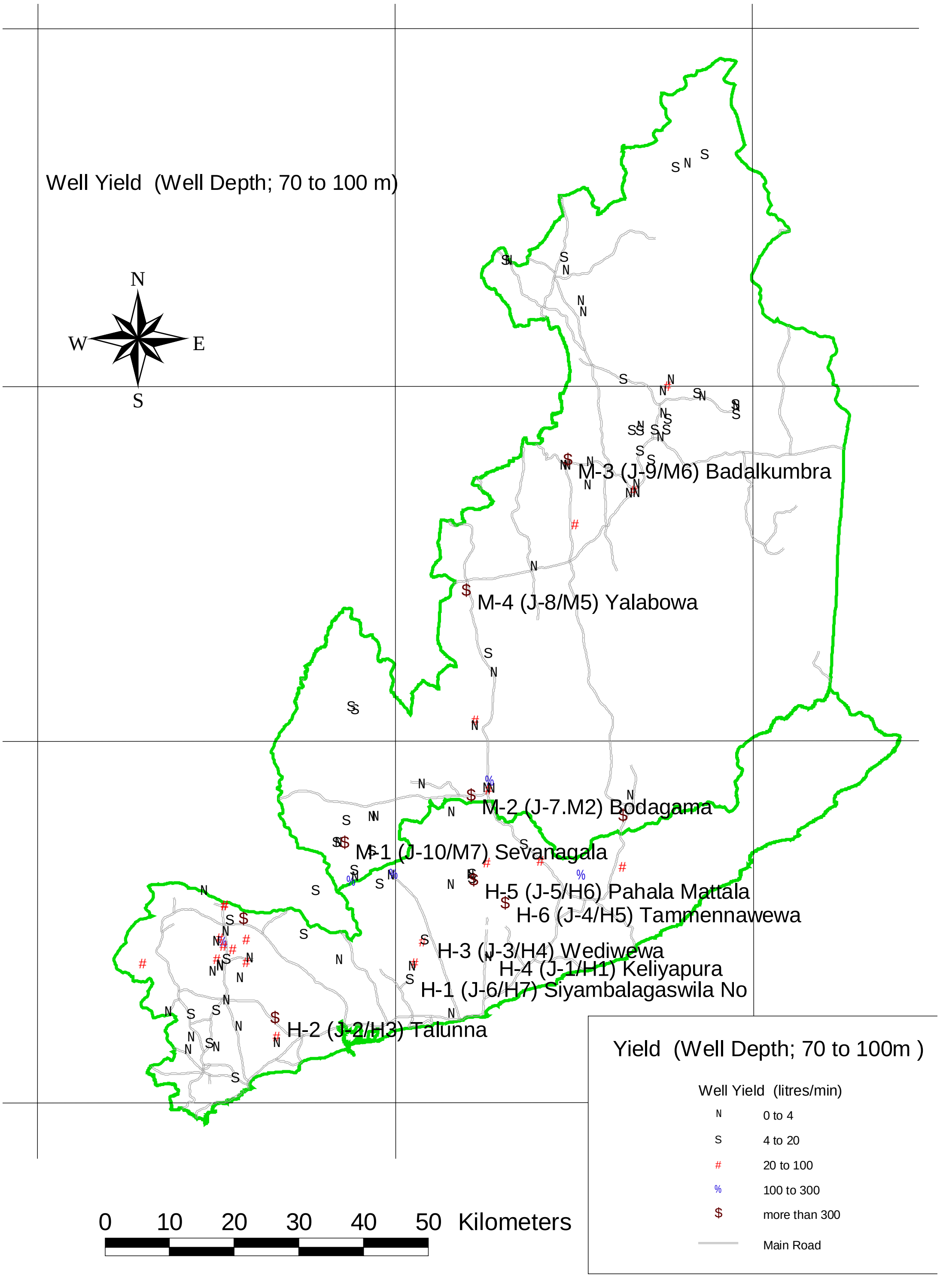

FIGURE 4.5(2) WELL YIELD (WELL DEPTH; 70 TO 100 M)

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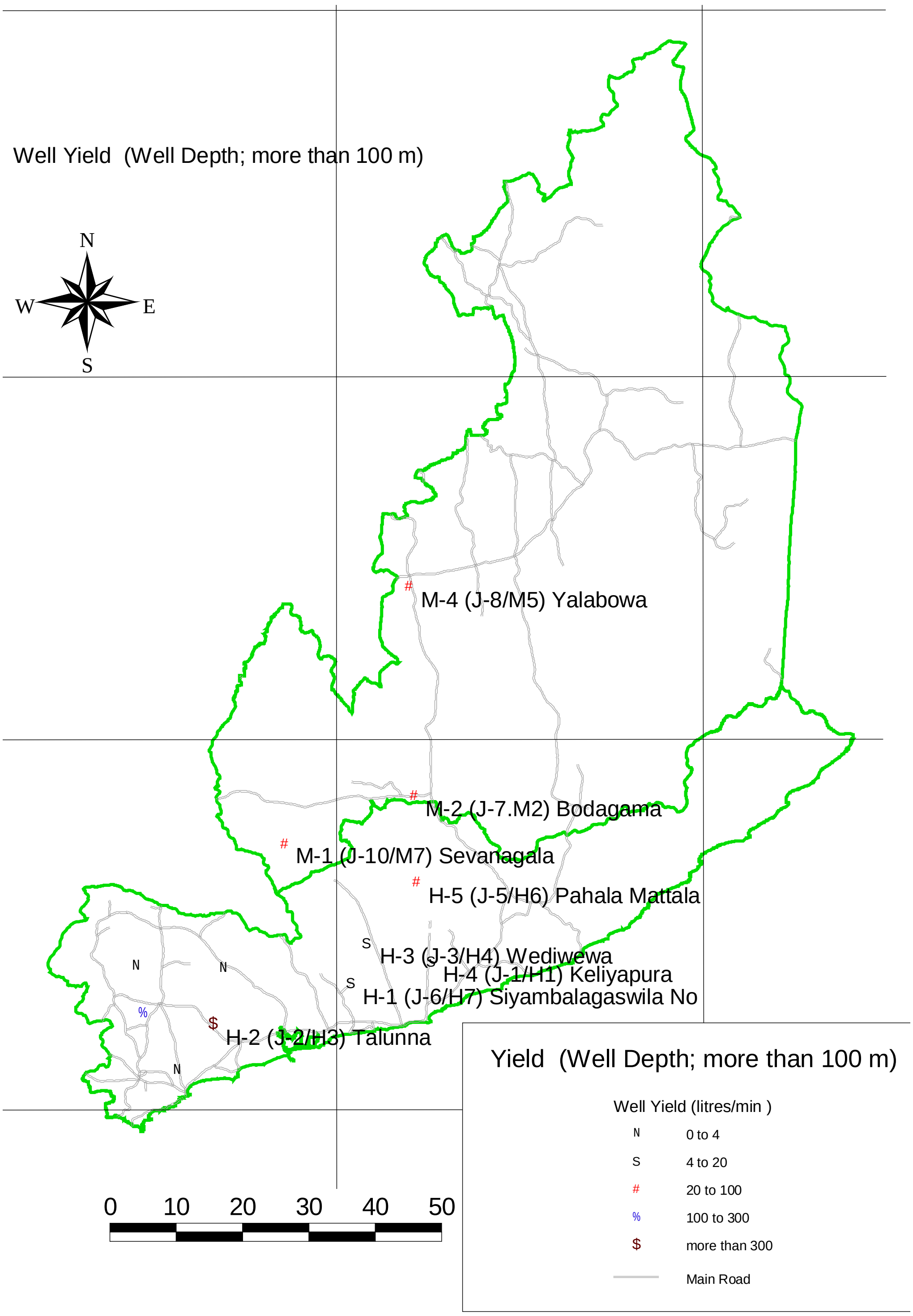

FIGURE 4.5(3) WELL YIELD (WELL DEPTH; MORE THAN 100 M)

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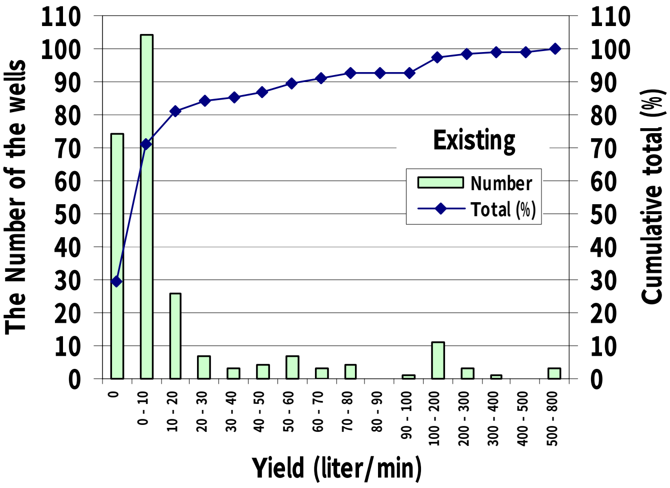
4.2.3 LOWER FRACTURED AQUIFER (70 TO 100 M. IN DEPTH)

Figure 4.5(2) shows the distribution of yield from a well with the depth between 70 and 100 m. *Figure 4.6* shows the number of wells classified by yield. The 130 wells (51.8 %) yielded 20 litres/min or less. The 18 wells (7.2 %) yielded more than 100 litres/min. The bar chart shows that the range of the yield from 100 to 200 litres/min was prominent. This is typical expected yield when a borehole encounters a productive fracture zone.



Yield (liter/min)	Number	Accumulating Total No.	Accumulating Total %
0	74	74	29.5
0 - 10	104	178	70.9
10 - 20	26	204	81.3
20 - 30	7	211	84.1
30 - 40	3	214	85.3
40 - 50	4	218	86.9
50 - 60	7	225	89.6
60 - 70	3	228	90.8
70 - 80	4	232	92.4
80 - 90	0	232	92.4
90 - 100	1	233	92.8
100 - 200	11	244	97.2
200 - 300	3	247	98.4
300 - 400	1	248	98.8
400 - 500	0	248	98.8
500 - 800	3	251	100.0

Figure 4.6 Number of Wells Classified by Yield

(Lower Fractured Aquifer of 70 to 100 m in Depth)

Two test wells, No.M-2(2) (Bodagama) and No.M-4(2) (Yalabowa), were drilled to 100 m to confirm the productivity of the fractured zone. As a result, the pumping tests of No.M-2(2) and No.M-4(2) were conducted for 72 hours with the pumping rate of 440 and 610 litres/min respectively. No.H-6 (Tammennawewa) was cased to 102 m and the pumping test was conducted for 72 hours with the pumping rate of 432 litres/min. No.M-3 (Badalkumbura) also encountered a large productive zone from 63 to 84 m depth. The borehole yielded more than 5,000 litres/min during the drilling from 83 to 88 m depth. Consequently the drilling was stopped at the depth of 88 m.

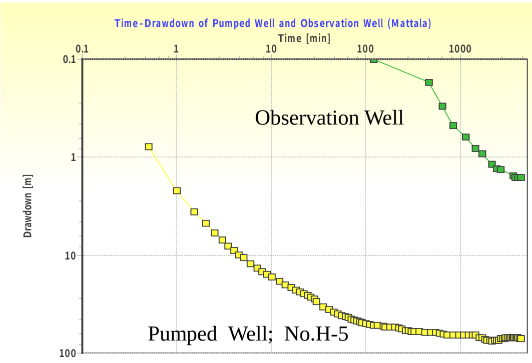
4.2.4 DEEPER FRACTURED AQUIFER (100 TO 200 M DEPTH)

The test well construction for the Study was the first drilling to 200 m in the area. The productive fractures below 100 m occurred in the test wells except No.H-1 and No.H-4. Particularly the fracture that occurred in the borehole No.H-2, Talunna, was most productive. Screen pipes were installed from 172.9 to 188.9 m in borehole No.H-2. The pumping test was conducted for 4 days with the pumping rate of 415 litres/min. There was a large fractured zone from the depth of 105 to 116 m in borehole No.H-6 (Tammennawewa). However, the formation was too loose to penetrate. It is low Possibility to drill the well into such loose formation.

The fractures observed in No.H-3, H-5, M-1, M-2, and M-4 yielded from 20 to 50 litres/min. Even this yield amount, on average, for these test wells was more productive than the existing tube wells drilled to 70 m or more. The geophysical logs show that some fractures occur in and around the boundary between granitic gneiss and hornblende-biotite gneiss.

4.2.5 INTERCONNECTION OF AQUIFERS

Each fractured aquifer described in the previous section is separated by hard rock. In certain areas, however, the pumping from a test well influenced the water level in a shallow well located near the pumped well: namely, No.H-5 (Pahala Mattala) and No.H-6 (Tammennawewa) as shown in *Figure 4.7*.



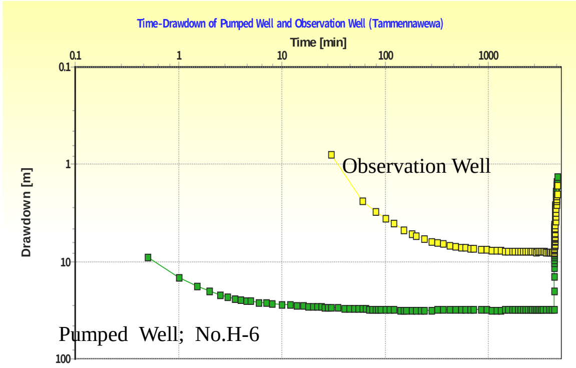


Figure 4.7 Influence of Pumping Well

Screen pipes of No.H-5 have been installed from 163 to 195 m. The upper part of the annular space between the casing pipes and drilled hole was grouted up to the packer just above the screen. The observation well was located about 180 m away from No.H-5 and its depth was 38 meters. The geophysical log shows that the hard rock formation occurs between the depth of 55 to 85 m, which is a zone with high resistivity and low gamma. This zone is most likely impermeable. Even so, the fact that the water level of the observation well was affected by the pumping from the test well indicates that there is an interconnected fracture network between the upper fractured aquifer and the deeper fractured aquifer.

Test well No.H-6 was cased up to 102 m and the positions of screen pipes is 52.5-60.5 and 72.5-84.5 m in depth. The upper part of annular space was grouted up to the packer just above the screen as in other test wells. A well located 77 meters away from the test well was influenced by the pumping from the test well. The observation well was 35 m in depth. The geophysical log shows that the hard rock formation occurs in the depth from 37 to 53 m. The influence of the pumping suggests also that the deeper fracture is connected with the upper fracture in the area.

As described in the following section, the seasonal water level fluctuation also seems to show the existence of the interconnection of fractures in the basement rock.

4.2.6 MAJOR FINDINGS

- The fractured aquifer in the area is classified into three categories: namely, upper fractured aquifer located in the depth of 70 meters or above, lower fractured aquifer located in the depth from 70 to 100 m, and deeper fractured aquifer occurring in the depth from 100 to 200 m.

- The test well drilling confirmed the occurrence of the productive lower fractured aquifer in three test wells: No.M-2 (Bodagama), No.M-3 (Badalkumbura) and No.N-4 (Yalabowa).

- The drilling of the test well No.H-2 (Talunna) confirmed the occurrence of a productive deeper fractured aquifer.

- The influenced water level of the observation well by the pumping from a test well indicates that there is an interconnected fracture network between the upper fractured aquifer and the deeper fractured aquifer.

4.3 GEOLOGICAL STRUCTURE AND GROUNDWATER

4.3.1 GENERAL

The forming of water bearing fractured zone in hard rock is considered to be highly dependent on the geological structure in the area. Analyses were conducted to confirm the relation between geological structure and groundwater occurrence using GIS with the database.

The results of the analysis were tabulated below.

No.	Analysis Item	Relation
1	Relation between Well Yield [a] and Fault and thrust/shear zone [b]	A well nearer to fault or thrust/shear zone yields a little more than a distant well.
2	Relation between Well yield [a] and Lineament [c]	A well located near the lineament with the direction of NNW-SSE yields more than other wells on average.
3	Relation between Well yield [a] and Geology [b]	Not clear
4	Relation between Well yield [a] and Surface water (river) [d]	A well nearer to a river yields a little more than a distant well.
5	Relation between Well yield [a] and Lineament density [c]	Not clear
6	Relation between Electric conductivity [a] and Geology [b]	Not clear
7	Relation between Fluoride [a] and Geology [b]	Not clear
8	Relation between Total iron [a] and Geology [b]	Not clear

Sources; a) Well database (WRB, NWSDB, JICA test well)
b) Geological Map with a scale of 1:100,000 by GSMB
c) Landsat imagery analysis in Chapter 3
d) Digital Map with a scale of 1:250,000 by Survey Department

4.3.2 ANALYSIS AND RESULTS

(1) Yield and Geological Structure

<Fault and thrust/shear zone>

- The distance between an existing well and the nearby fault or thrust/shear zone shown in the 1:100,000 geological map issued by GSMB was calculated using GIS. *Figure 4.8* seems to indicate that a well nearer to the fault or thrust/shear zone yields a little more than a distant well.

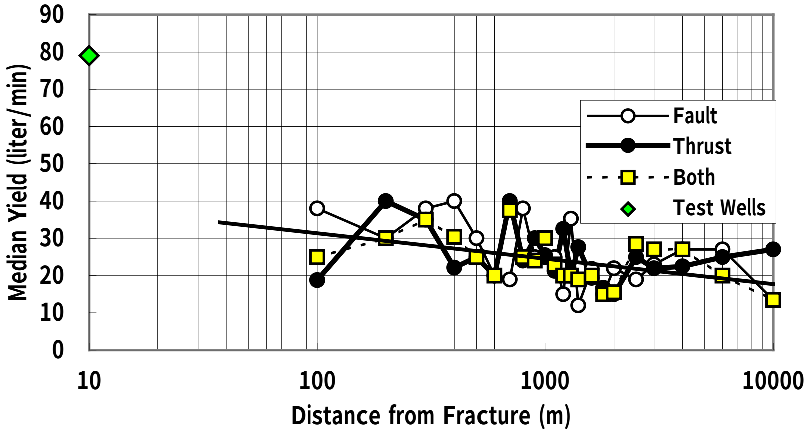


Figure 4.8 Relation between Yield and Distance from the Fracture

<Lineament>

- The relation between yield and the direction of lineament was examined using GIS. *Figure 4.9* shows the result. The figure indicates that a well located near the lineament with the direction of NNW-SSE yields more than other wells on average.

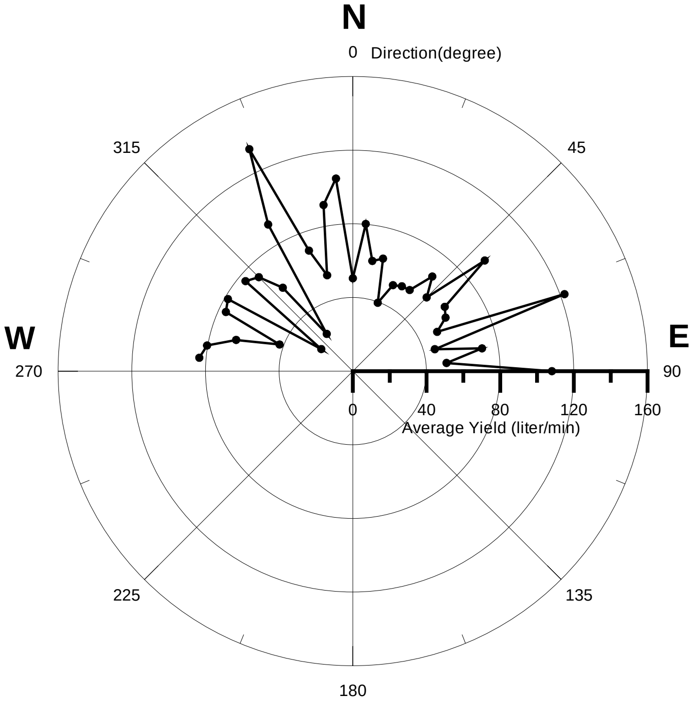


Figure 4.9 Relation between Yield and Direction of Lineament

<River, geology, lineament density>

- The distance between an existing well and the nearby river was calculated with GIS. A well nearer to a river yields a little more than a distant well.

- The relation between yield and geology classified in the 1:100,000 geological map was not confirmed.

- Also the relation between yield and lineament density was not confirmed.

(2) Groundwater Quality and Geology

Although the relation between groundwater quality, namely EC, Fluoride, and Total Iron, and geology was analysed with GIS, the significant relation was not found.

4.3.3 Major Findings

- The existence of fault and thrust/shear zone affects the productivity of aquifer.

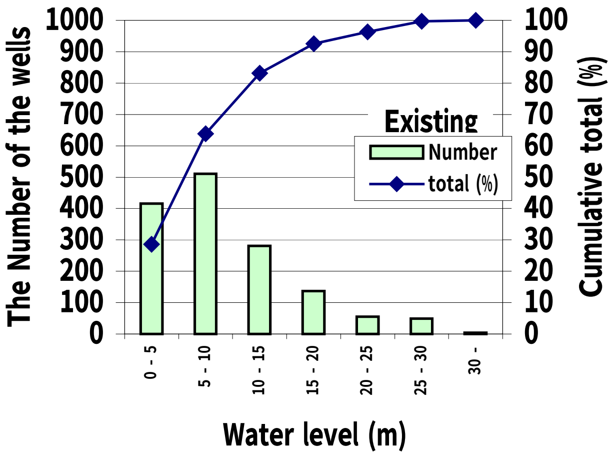
- The lineament with the direction of NNW-SSE also affects the productivity of the aquifer.

4.4 GROUNDWATER LEVEL

4.4.1 GENERAL FEATURE OF THE STUDY AREA

(1) Upper Fractured Aquifer (GL - 70 m)

The number of wells and the depth to water surface of the upper fractured aquifer are graphed below. 63.8 % of the water levels are 10 m or above in depth and 28.8 % between 10 and 20 m in depth. Consequently 92.6 % of the water level is 20 m or above in depth.



SWL (mBGL)	Number	Accumulating Total	
		No.	(%)
0 - 5	416	416	28.6
5 - 10	511	927	63.8
10 - 15	281	1208	83.1
15 - 20	137	1345	92.6
20 - 25	55	1400	96.4
25 - 30	49	1449	99.7
30 -	4	1453	100.0

Figure 4.10 Number of wells and water level; Upper fractured aquifer

Figure 4.11(1) shows the depth to groundwater surface in a well. The wells with relatively deeper water level are mostly located in the western Hambantota where the low level planation surface with the altitude of 100 m or more is distributed. And also the central western part in Monaragala has a relatively deeper water level area that is in a southern part of the hills with inselberg.

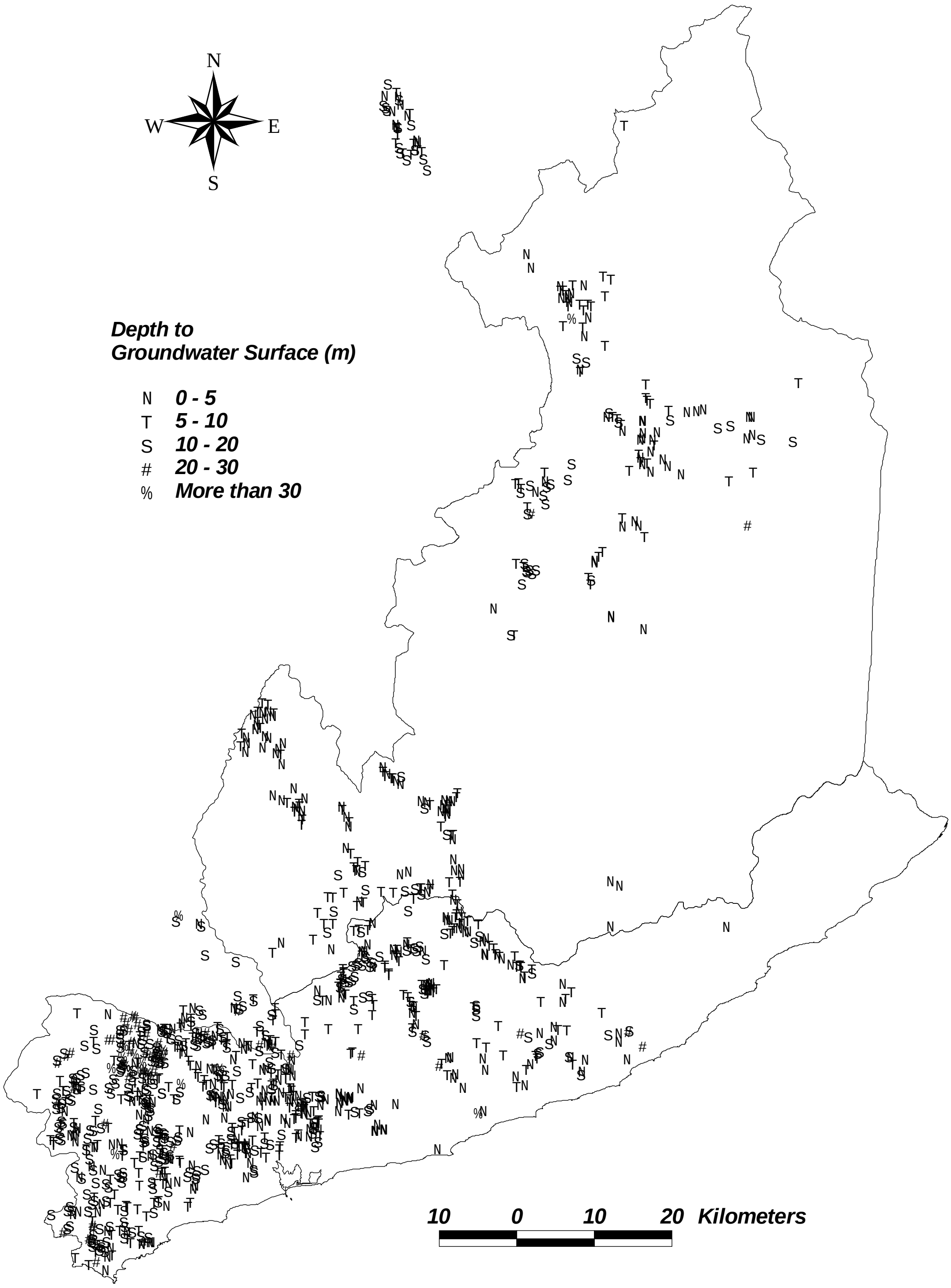


FIGURE 4.11(1) DEPTH TO WATER SURFACE (UPPER FRACTURED AQUIFER)

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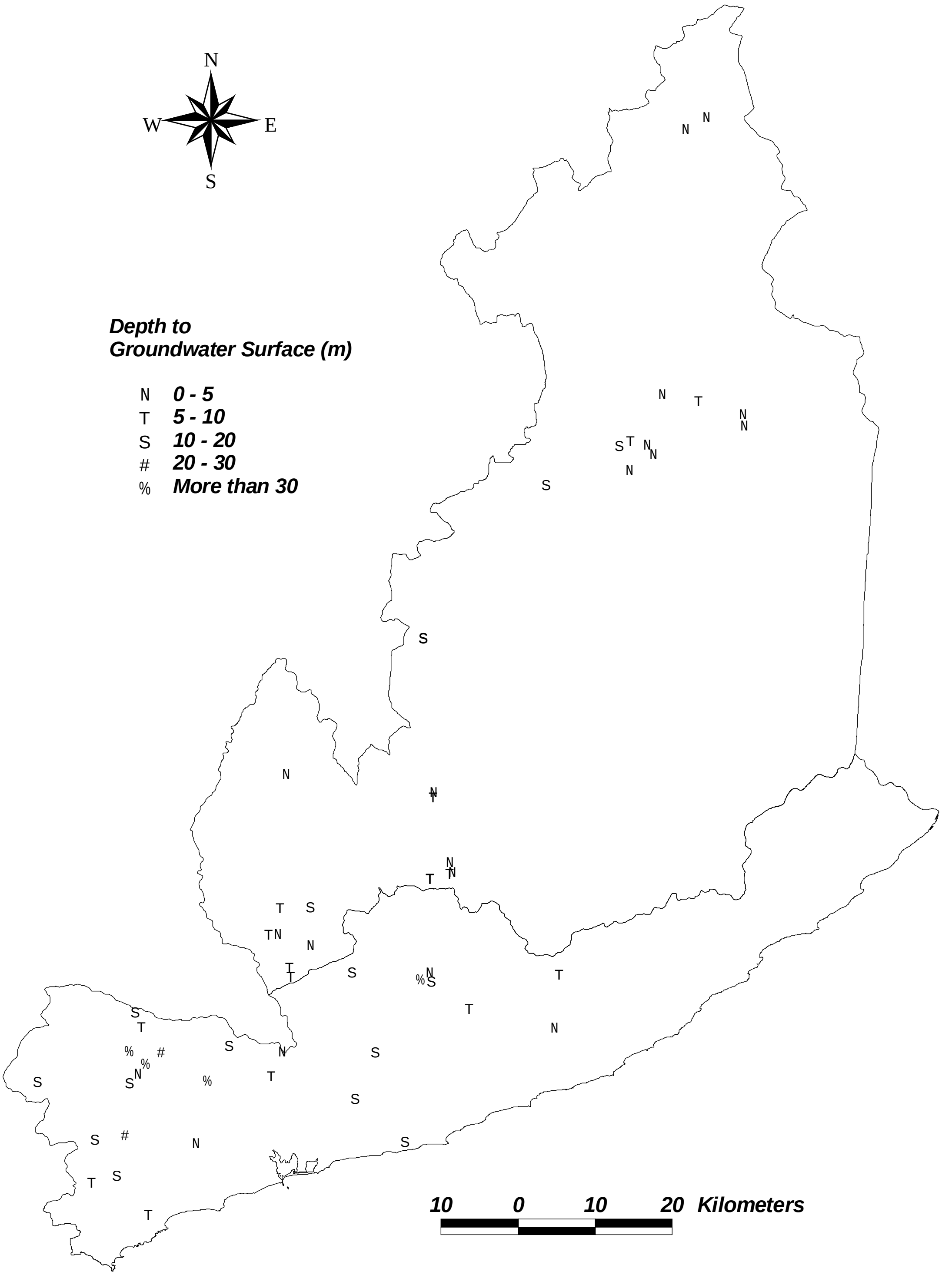

FIGURE 4.11(2) DEPTH TO WATER SURFACE (LOWER FRACTURED AQUIFER)

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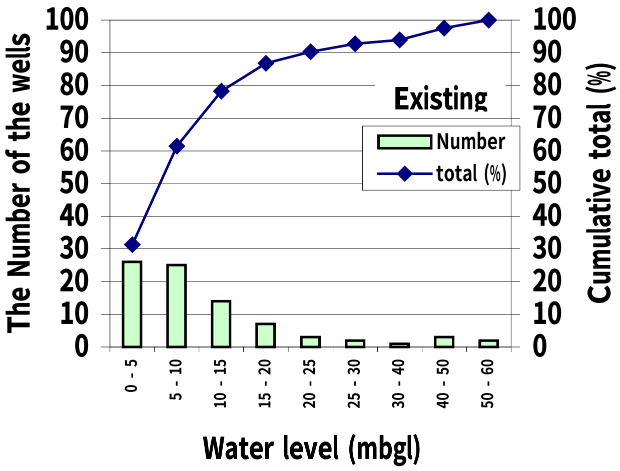
(2) Lower Fractured Aquifer (70 – 100 m)

The number of wells and the depth to water surface of the lower fractured aquifer are graphed below, *Figure 4.12*. 86.7 % of the water level is 20 m or above in depth. The number of wells with the water level 40 m or below is 6.0 %.



SWL (mbgl)	Number	Accumulating Total	
		Total	total (%)
0 - 5	26	26	31.3
5 - 10	25	51	61.4
10 - 15	14	65	78.3
15 - 20	7	72	86.7
20 - 25	3	75	90.4
25 - 30	2	77	92.8
30 - 40	1	78	94.0
40 - 50	3	81	97.6
50 - 60	2	83	100.0

Figure 4.12 Number of wells and water level; Lower fractured aquifer

Figure 4.11(2) shows the depth to groundwater surface in a well with the depth from 70 to 100 m. Similarly to the upper fractured aquifer, the western area of Hambantota seems to be the relatively deeper water level area. In general, the water level becomes deeper to the south eastern coastal side.

(3) Deeper Fractured Aquifer (100 – 200 m)

The water level records of the test wells constructed in the Study are all of data of the deeper fractured aquifer.

In Hambantota, the water level ranges from 8.5 to 13 mbgl with two exceptions. One exception is the water level of 3.55 mbgl in No.H-2 (Talunna) and the other exception is No.H-4 (Keliyapura) that is actually dry. In Monaragala, the water levels were 1.73 mbgl in Sevanagala, 7.9 mbgl in Bodagama, and 12.7 mbgl in Yalabowa. Even for the aquifer occurring below 100 m or more in depth, its pizometric head is about 10 mbgl or above.

4.4.2 WATER LEVEL FLUCTUATION

The Study Team conducted periodic measuring of water levels of 30 selected existing wells and installed automatic water level recorders provided by JICA at 10 test wells constructed for the Study to observe continuous water level fluctuations.

(1) Results of Periodic Measurement of Existing Wells

In general, the groundwater level decreased from September to November 2001, and then increased in December. The level slightly fell in January 2002 and rose from March to May. Although the rainfall increased from September to November, the groundwater level was not affected yet as of November. The effect of rainfall seems to appear in December. Rainfall decreased in December and the water level fell a little in January. As rainfall increased over the period from January to April, the groundwater level rose slightly from March to May. The correlation between water level fluctuations and monthly rainfall variation shows that the rainy season from September to January and also the rain in April have recharged the upper fractured aquifer.

(2) Results of Continuous Water Level Record

In Hambantota, the water levels of most test wells (excluding No.H-6) were recorded since late March; the level of No.H-6 was recorded since mid April. The records of water levels in the test wells in Monaragala started from September '02. The data is graphed in *Figure 4.13*. Some observations were made as follows:

1) Artificial Effects

<Influence of water extraction from a nearby borehole>

Momentary drop and recovery of water level was recorded on 8 and 9 April in Well No.H-5. This was due to the influence of the drilling of the additional borehole located about 40 meters away from Well No.H-5 (Pahala Mattala). The recorded water level change in Well No.H-5 was in agreement with the drilling progress of the additional borehole.

The same kind of water level drop was recorded on 5 June. This time, a pumping test of the above additional Mattala well was being carried out on 5 June. After that, in the middle of the water level recovery, it is suspected that the float of the recorder might have been stuck in the well.

<Influences of the wells own water extraction>

Well No.H-3 was a poor productive well. The pumping test conducted on 22 February caused a drawdown of 46 m. The curve of the water level change seems to show that the water level has recovered recently.

Well No.H-1 was also poorly productive. Three times sharp drops and recovery curves happened at the date when a bottle of water was sampled

2) Natural Effects

<Daily changes>

Daily fluctuations were recorded in Well No.H-2, Talunna, Well No.H-5, Pahala Mattala, and Well No.H-6, Tammennawewa. The width of daily fluctuations varied with a half-month cycle. The largest daily fluctuation occurred in the day of a new moon and a full moon. This daily fluctuation is the effect of Earth tide.

<Seasonal variation and rainfall>

For long-term variation, the water level in Well No.H-5 had been rather stable from the middle of March to the middle of April, and then the level slowly rose to early June.

The water level in Well No.H-6 began to increase gently after the record started and reached the highest level around 7 May. Then the level fell and continues to fall so far.

Although the screen pipes of Well No.H-2 were installed below 160 m (the same as in Well No.H-1 and Well No.H-5), the water level in Well No.H-2 displayed a different tendency. The penetrated rocks in No.H-2 showed no fractured formation at all up to about 150 mbgl. On the other hand, some fractures occurred in the upper part of the penetrated rocks in the other boreholes. The fracturing conditions in a basement rock probably have an effect on the above difference of the water level fluctuation in these wells.

The bar chart in *Figure 4.13* indicates the mean daily rainfall of 23 stations in the Study area. The figure shows that the recharge by rainfall during from March to May probably caused the rising of the water level from late April.

The rising of the water level in Well No.H-6 started earlier than the other two wells, No.H-1 and H-5, and the level became stable a few days after daily rainfall turned out to be small. The observed aquifer is a fractured zone from 52 to 84 m in Well No.H-6. This means that the rainfall affected the upper part of the fractured zone earlier than the deeper fractured zone.

Generally, the recorded water level fluctuation correlates with rainfall in the area; even the aquifer occurs below the depth of 150 m. Seasonal rain also recharges a deeper fractured aquifer.

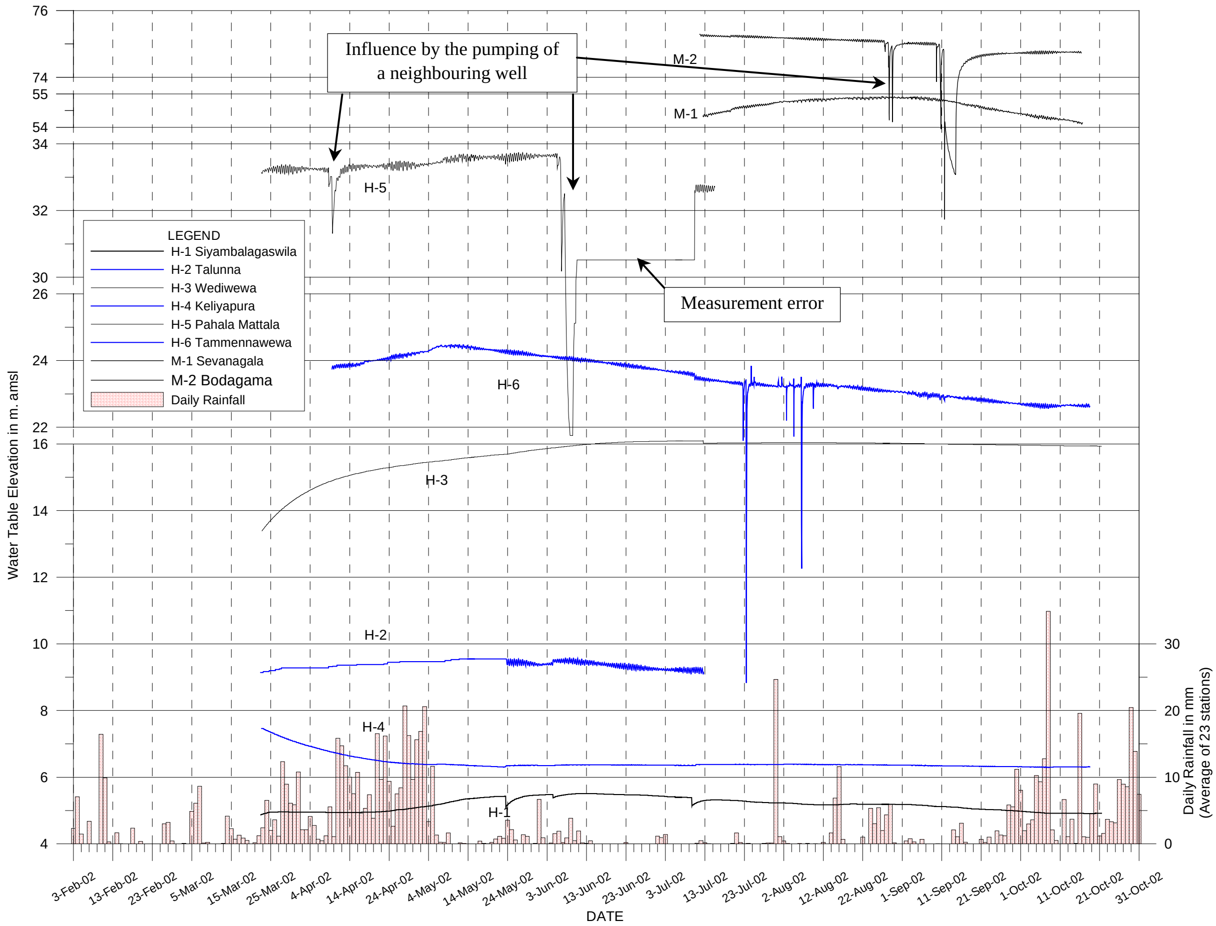


Figure 4.13 Hydrograph of Test Wells

4.4.3 MAJOR FINDINGS

- Influences of water extraction from a nearby borehole were observed. They indicate the occurrence of interconnections of fractures in the basement rock.

- The effect of Earth tide was observed in some test wells.

- Generally, the recorded water level fluctuation correlates with rainfall in the area, even when the aquifer occurs below the depth of 150 m. Seasonal rain also recharges a deeper fractured aquifer.

4.5 WATER QUALITY

Based on the results of water quality analysis and the groundwater quality data of the existing tube wells from the database, this section describes the groundwater quality characteristics of the existing tube wells and the test wells in the Study area.

4.5.1 WATER QUALITY OF THE EXISTING TUBE WELLS (UPPER FRACTURED AQUIFER)

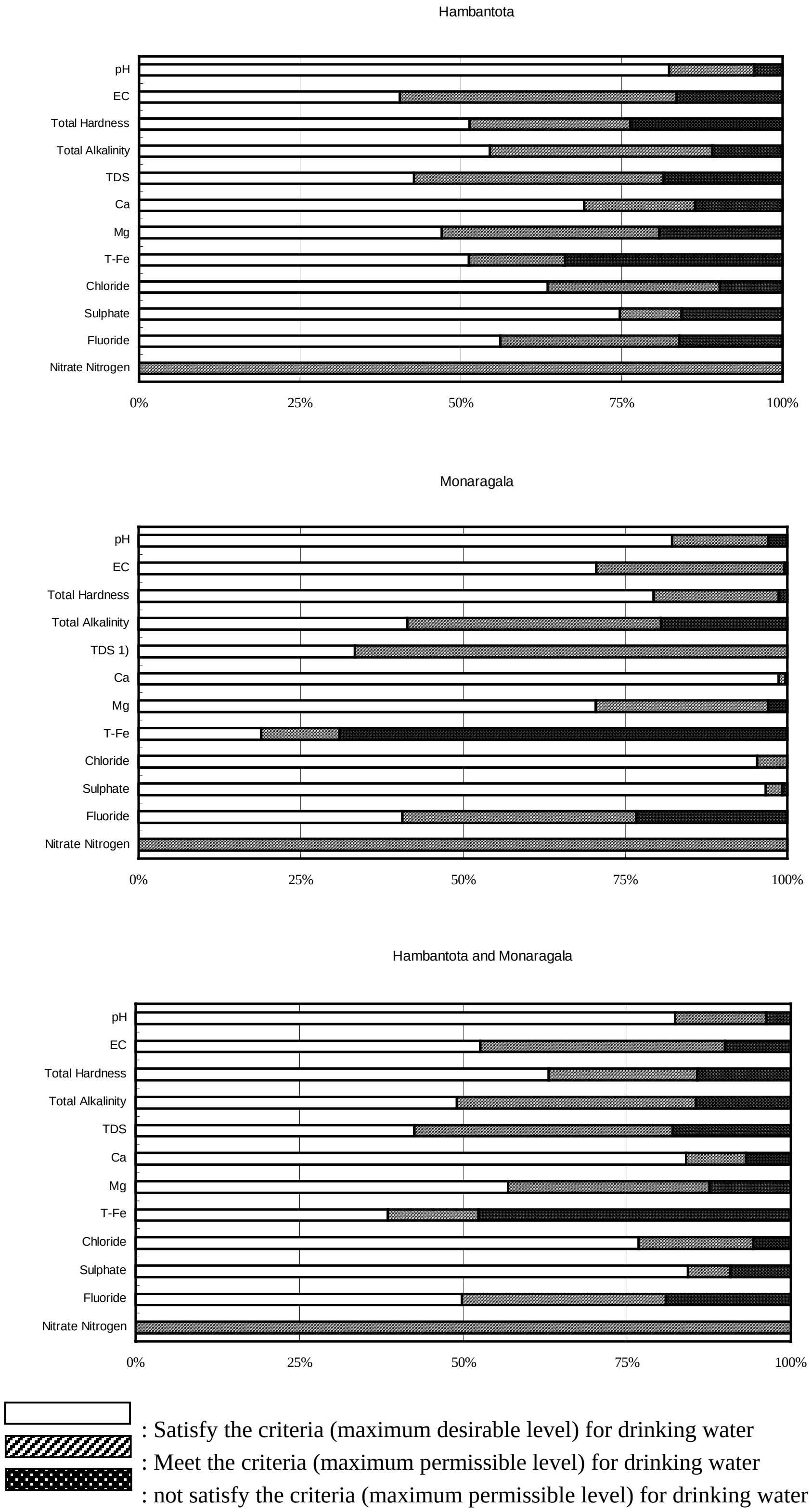
(1) Satisfaction of the Criteria for Drinking Water

For the evaluation of the groundwater quality conditions, the groundwater quality data of the existing tube wells in Hambantota and Monaragala are classified into three categories according to the water quality standards for drinking water in Sri Lanka.

- I: Satisfy the criteria (maximum desirable level) for drinking water.
- II: Meets the criteria (maximum permissible level) for drinking water.
- III: Not satisfy the required criteria for drinking water.

According to the results of the above classifications, outline of present groundwater quality conditions is summarized as follows (see *Figure 4.14*).

- In general, parameters representing inorganic substances namely, electrical conductivity (EC), total hardness, total alkalinity, magnesium, total iron and fluoride are at a high level.
- Approximately from 10 % to 20 % of tube wells in the Study area do not satisfy the criteria of EC, total hardness, total alkalinity, total dissolved solids (TDS), magnesium and fluoride for drinking water.
- Especially for total iron, as high as approximately 50 % of tube wells exceed the criteria of total iron for drinking water.
- To compare Hambantota and Monaragala, concentrations of major inorganic substances of groundwater in Hambantota tend to be higher than in Monaragala, while concentration of total iron and fluoride in Monaragala are higher than in Hambantota.



: Satisfy the criteria (maximum desirable level) for drinking water
: Meet the criteria (maximum permissible level) for drinking water
: not satisfy the criteria (maximum permissible level) for drinking water

1): the available data of TDS in Monaragala is shortage.

FIGURE 4.14 UPPER FRACTURED AQUIFER CONDITION OF GROUNDWATER QUALITY (EXISTING WELLS)

(2) Regional Distribution of Groundwater Quality

Regional distributions of groundwater quality of the existing tube wells in the Study area are shown in *Figures 7.15 to 7.17 in the Supporting report and Appendix G*. Based on these figures, the regional distributions of groundwater quality can be classified into two patterns. One is high concentration of values centering in the central to the western part of Hambantota (Pattern I). The other is high concentration of values distributed in the western part of Monaragala to the western part of Hambantota (Pattern II).

The Characteristics of two regional distribution patterns are described below.

1) Regional Distribution Pattern I

The distribution of EC is a distinctive feature for this pattern, and high concentration of EC is observed from central to the western part of Hambantota (see *Figure 7.15 in the Supporting report*). Water quality items of TDS, total hardness, calcium, magnesium, chloride and sulphate also shows similar trend.

As for the reasons, EC depends on the total concentration of dissolved inorganic substances. Similarly, TDS is a term used to describe the inorganic salts, which are usually calcium, magnesium, sodium, and potassium cations and carbonate, hydrogencarbonate, chloride, sulphate, and nitrate anions. Hardness is caused predominantly by calcium and magnesium cations.

The regional distribution of Pattern I concerning EC, TDS, total hardness, may be affected by geological factors. In addition, groundwater quality items are accelerated and rise by the strong influence of climatic factors in this area.

2) Regional Distribution Pattern II

High concentration of total iron was observed in the whole Study area. However, the highest concentration area of total iron covers the northern part of Monaragala, and from the western part of Hambantota to the western part of Monaragala. The regional distribution of fluoride is similar to the one of total iron (see *Figure 7.16* and *Figure 7.17 in the Supporting report).*

4.5.2 Deep Aquifer Groundwater (as Water Quality Data of Test Well)

Water quality analysis of the test well for deep aquifer groundwater is carried out in this Study. There were six test wells in Hambantota and six wells in Monaragala. Based on the results of water quality analysis, possibility of utilization for drinking water and its characteristics are described below.

(1) Satisfaction of the Criteria for Drinking Water

Based on the results of water quality analysis of 12 test wells, water quality requirements are described from the point of view of drinking water criteria.

Comparison between the requirements of drinking water criteria and the above results of water quality analysis, including problems of water use for drinking, are summarised below (see *Table 4.1*).

- Pahala Mattala in Hambantota and Yalabowa in Monaragala satisfy all the criteria (Maximum Permissible Level) for drinking water. However, 10 test wells among 12 test wells do not have appropriate quality for drinking purpose without purification.
- From the results of analysis of 12 test wells, it is found that 12 items of the requirements for drinking water criteria are not satisfied, namely, pH, EC, total hardness, total alkalinity, TDS, calcium, magnesium, total iron, chloride, fluoride, lead and chromium.

- Six test wells have especially high concentration of salt content, which is expressed by electrical conductivity, total hardness, total dissolved solids and other dissolved substances. It is difficult to purify by an ordinary purification method for water supply system such as coagulation-filtration method.
- The above six test wells are Siyambalagaswila North, Wediwewa, Keliyapura, Talunna and Tammennawewa in Hambantota and Bodagama in Monaragala.
- Furthermore, Wediwewa and Keliyapura have chromium, which exceeds the criteria for drinking water. Also high concentration of lead was detected at Sevanagala. These heavy metals are health-related drinking water contaminants.

Table 4.1(1) Satisfaction of the Criteria for Drinking Water (Hambantota)

Location	Siyambalagaswila North	Talunna	Wediwewa	Keliyapura	Pahala Mattala	Tammennawewa	Standards for Drinking Water	
Sample No. Labeled	H-1(J-6/H7)	H-2(J-2/H3)	H-3(J-3/H4)	H-4(J-1/H1)	H-5(J-5/H6)	H-6(J-4/H5)	Maximum Desirable Level	Maximum Permissible Level
Date of Collection	16.03.2002	10.03.2002	22.02.2002	23.02.2002	14.03.2002	06.02.2002		
Appearance	turbid	turbid	Clear	turbid	turbid	Turbid	-	-
Temperature (^oC)	33.5	32.7	33.2	32	33.9	32.6	-	-
Colour (Hazen Units)	5	5	10	10	5	5	-	-
Odour	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	Unobjectionable	Unobjectionable
Taste	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	Unobjectionable	Unobjectionable
pH	7.9	6.8	12.1	12.1	8.7	7.8	7.0 to 8.5	6.5 to 9.0
Electrical Conductivity (mS/cm)	9.1	2.8	9.4	5.9	1.2	4.4	0.75 mS/cm	3.5 mS/cm
Total Hardness as $CaCO_3$ (mg/l)	4,060	1,200	980	1,200	500	1,700	250 mg/l	600 mg/l
Total Alkalinity as $CaCO_3$ (mg/l)	150	50	1,900	1,400	325	200	200 mg/l	400 mg/l
Total Dissolved Solids (mg/l)	4,970	1,380	5,130	3,150	1,060	2,270	500 mg/l	2,000 mg/l
Sodium (Na^+)	750	208	900	130	450	500	-	-
Potassium (K^+) mg/l	130	70	600	90	50	60	-	-
Calcium (Ca^{2+}) mg/l	724	328	164	400	96	360	100 mg/l	240 mg/l
Magnesium (Mg^{2+}) mg/l	1,082	92	138	48	63	194	30 mg/l if SO4 >=250mg/l 150 mg/l if SO4 <250mg/l	140 mg/l
Total Iron (Fe^{3+}) mg/l	0.6	0.1	0.1	1.4	0.6	0.4	0.3 mg/l	1.0 mg/l
Chloride (Cl^-) mg/l	2,800	780	520	100	430	1,200	200 mg/l	1,200 mg/l
Sulphate (SO_4^{2-}) mg/l	880	292	660	350	300	735	200 mg/l	400 mg/l
Fluoride (F^-) mg/l	0.7	0.3	0.6	0.6	0.9	0.6	0.6 mg/l	1.5 mg/l
Bicarbonate (HCO_{3-}) mg/l	150	50	160	120	325	200	-	-
Nitrate (NO_3) mg/l	<0.01	0.40	0.07	0.50	<0.01	0.02	-	10 mg/l
Lead (as Pb) mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	0.05 mg/l *
Cadmium (as Cd) mg/l	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	0.005 mg/l *
Arsenic (as As) mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	0.05 mg/l *
Chromium (as Cr) mg/l	<0.005	<0.005	0.100	0.080	<0.005	<0.005	-	0.05 mg/l *

Note * : the criteria are required as upper limit of concentration.

[shaded box] : This value exceeds the criteria (maximum permissible level) for drinking water.

Table 4.1(2) Satisfaction of the Criteria for Drinking Water (Monaragala)

Location	Sevanagala	Bodagama	Badalkumbra	Yalabowa	Bodagama	Yalabowa	Standards for Drinking Water	
Sample No. Labeled	M-1(J-10/M7)	M-2(J-7/M2)	M-3(J-9/M6)	M-4(J-8/M5)	Additional[1)]	Additional[1)]	Maximum Desirable Level	Maximum Permissible Level
Date of Collection	02.07.2002	02.07.2002	10.08.2002	19.07.2002	21.10.02	26.09.2002		
Appearance	turbid	Turbid	Clear	Clear	Clear	Clear	-	-
Temperature (^oC)	31.0	31.0	-	31.0	26.5	28.2	-	-
Colour (Hazen Units)	5	5	20	5	Colourless	Colourless	-	-
Odor	Unobjectionable	Unobjectionable	None	None	-	-	Unobjectionable	Unobjectionable
Taste	None	Salty	good	Normal	-	-	Unobjectionable	Unobjectionable
pH	10.4	7.9	7.4	7.6	6.8	6.9	7.0 to 8.5	6.5 to 9.0
Electrical Conductivity (mS/cm)	2.1	6.0	0.41	0.71	2.4	0.78	0.75 mS/cm	3.5 mS/cm
Total Hardness as $CaCO_3$ (mg/l)	14	1,220	310	360	361	314	250 mg/l	600 mg/l
Total Alkalinity as $CaCO_3$ (mg/l)	230	355	255	324	995	476	200 mg/l	400 mg/l
Total Dissolved Solids (mg/l)	1,060	3,140	194	835	1,603	515	500 mg/l	2,000 mg/l
Sodium (Na^+)	290	590	12	31	-	-	-	-
Potassium (K^+) mg/l	36	60	5	8	-	-	-	-
Calcium (Ca^{2+}) mg/l	4.8	115	56	90	51	57	100 mg/l	240 mg/l
Magnesium (Mg^{2+}) mg/l	0.6	270	40	33	57	42	30 mg/l if SO4 >=250mg/l 150 mg/l if SO4 <250mg/l	140 mg/l
Total Iron (Fe^{3+}) mg/l	0.6	0.4	1.2	0.5	0.3	0.3	0.3 mg/l	1.0 mg/l
Chloride (Cl^-) mg/l	96	860	7	30	244	25	200 mg/l	1,200 mg/l
Sulphate (SO_4^{2-}) mg/l	232	430	4	56	78	95	200 mg/l	400 mg/l
Fluoride (F^-) mg/l	1.3	0.9	0.6	0.6	1.7	0.5	0.6 mg/l	1.5 mg/l
Bicarbonate (HCO_3^-) mg/l	10	354	255	248	-	-	-	-
Nitrate (NO_3-N) mg/l	<0.05	<0.05	0.3	ND	-	-	-	10 mg/l
Lead (as Pb) mg/l	0.062	0.027	<0.01	<0.01	<0.01	<0.01	-	0.05 mg/l *
Cadmium (as Cd) mg/l	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	0.005 mg/l *
Arsenic (as As) mg/l	<0.001	<0.001	-	<0.001	-	-	-	0.05 mg/l *
Chromium (as Cr) mg/l	0.027	0.01	<0.005	<0.005	<0.005	<0.005	-	0.05 mg/l *

Note * : the criteria are required as upper limit of concentration. [shaded box] : This value exceeds the criteria (maximum permissible level) for drinking water.

ND : Not detected. It means that the concentration is under the limits of detection. Additional [1)] : Well depth is about 100 m.

(2) Stiff Diagrams and its Distribution

Based on the results of the test well and its neighboring existing tube wells, stiff diagrams of groundwater are illustrated as shown in *Figure 7.29 in the Supporting report.*

According to the comparison between the existing tube wells and the test wells, the stiff diagrams of the existing tube well and the test well in Hambantota have mostly the same shapes, except for Keliyapura H-4(J-1/H1). The depth of the test wells are approximately 200 m, except Tammennawewa which is approximately 100 m, while the depth of the existing wells are less than 40 m. The results suggest that the groundwater of five test wells in Hambantota have the hydrogeological interaction with the shallow aquifer.

In contrast, no likeness of stiff diagrams between the existing tube well and the test well in Monaragala are found. It can be said that the groundwater quality in these test wells have a higher concentration of major ionized substances (namely, Na^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, HCO_3^{2-} and SO_4^{2-}) than the existing tube well, except for Yalabowa M-4(J-8/M5).

(3) Consideration of Purification Method

Based on the results of water quality analysis of the test wells, it is found that groundwater quality of some test wells do not satisfy the water quality standards for drinking water in Sri Lanka. It is necessary to purify the groundwater if it is to be utilized for drinking purpose. In this section, the required purification methods are described.

According to the results of water quality analysis of the test well (refer to *Table 6.5 in the Supporting Report*), required purification methods and its major purified items are summarized as below.

Purification method	Major purified item
- Desalination:	salinity as EC, total hardness, TDS, total iron and other dissolved substances.
- Softening:	calcium and magnesium
- Defluoride:	fluoride
- Deferrization:	total iron
- pH control	pH and total alkalinity
- Coagulation-sedimentation and filtration for removal of heavy metals:	lead and chromium

The groundwater development plan in this Study aims for establishment of the rural water supply system. Therefore, the groundwater development plan should be planned paying attention to small-scale facilities, simplified operation/maintenance and low costs. Generally, in a groundwater development plan, it is common for other water resources to be selected as alternatives, if groundwater quality does not satisfy the drinking water standards. However, it is difficult to find other water resources for water supply system in the Study area.

From the above background, it is suggested to introduce the following purification methods as the rural water supply system.

- Removal of total alkalinity by pH control process.
- Softening by crystallization process.

- Defluoride by ion exchange process using activated alumina.
- Deferrization by oxidation and filtration process.

From the viewpoint of costly, high-consumption energy and requirement of an accurate operation/maintenance, desalination process and coagulation-filtration process for heavy metals are not feasible methods for the rural water supply system.

4.5.3 MAJOR FINDINGS

According to the study of groundwater quality in the Study area, the following observations were obtained.

i) In the existing wells, high values of EC, total hardness and ionized substances, which do not satisfy the criteria for drinking water, were observed in the central part to the western part of Hambantota.

ii) In the existing wells, high concentrations of fluoride and total iron are distributed in the western part of Hambantota to the western part of Monaragala and the northern part of Monaragala. In the two test wells, Keliyapura and Badalkumbra, the concentration of total iron exceeded the criteria for drinking water, and also the concentration of fluoride was higher than the criteria in another test wells in Bodagama. Further monitoring of water quality and accumulation of the additional data will be recommended for the lower and deeper aquifer.

iii) As groundwater moves along flow systems in the underlying rock, the quality is altered by the effects of geochemical processes such as mineral dissolution and ion-exchange reactions with the rock. In other words, high values of EC and high concentrations of solute such as fluoride and iron as described above can be caused geochemically during the time of groundwater movement from recharge to discharge area. Longer flowing time makes solutes in groundwater higher concentration, while actual geochemical processes in the groundwater are complex. The central and coastal area of Hambantota has low precipitation and a landform of micro-relief. The movement of groundwater in the area is naturally slow. In consequently the concentration of dissolved inorganic substance, which is indicated as the value of EC, becomes higher in the area.

iv) According to the results of groundwater analysis of 12 test wells in the Study area, it became clear that Pahala Mattala in Hambantota and Yalabowa in Monaragala satisfy the criteria (Maximum permissible level) for drinking water.

v) However, six test wells contain high salt content, which is expressed by EC, total hardness and TDS. Moreover, high concentration of chromium was detected at two test wells (Keliyapura and Wediwewa in Hambantota), and one test well (Bodagama in Monaragala) contaminated with lead. This was the first analysing of heavy metals in the area. Therefore, it is recommended to continue monitoring and analysing of heavy metals to reveal its distribution in the area, especially for the lower and deeper aquifer

vi) From the comparison between stiff diagrams of the test wells and its neighbouring the existing tube well, it seems that the groundwater of the five test wells in Hambantota have the same cultivation source as the shallow well. In contrast, no similarity of stiff diagrams between the existing tube well and the test well in Monaragala was found.

vii) Although the following purification processes is applied for the rural water supply systems, from the viewpoint of costs, energy consumption and operation/maintenance, introduction of these purification methods for desalination and removal of heavy metals in Hambantota and Monaragala is not feasible.

- Removal of total alkalinity by pH control process.
- Softening by crystallization process.
- Defluoride by ion exchange process using activated alumina.
- Deferrization by oxidation and filtration process.

viii) It is recommended to consider alternative water sources or study making a comprehensive of water resources development plan.

4.6 AQUIFER PROPERTIES

4.6.1 GENERAL

The obtained aquifer properties of each borehole are summarized in *Table 4.2*.

Table 4.2 Aquifer Properties (Transmissivity; *T*, Hydraulic Conductivity; *k*, Storativity; *S*)

Location	Well	Well Depth	Open Hole/ Screen Length	***Q/s***	***T***	***K***	***S***
		(m)	(m)	(l/min/m)	(m^2/day)	(m/day)	
Siyambalagaswila	H-1	200.4	20	(0.75)	0.14	7.00E-03	---
	JM07	33.53	23.17	2.04	2.02	8.72E-02	---
Talunna (Vitalandeniya)	H-2	194.4	16	15.34	25.29	1.58E+00	---
	JM02	36	25	1.81	4.09	1.64E-01	---
Wediwewa	H-3	200.4	20	(0.65)	0.18	9.00E-03	---
	JM04	44	(35)	0.07	0.17	4.86E-03	---
Keliyapura	H-4	200.2	32	(0.21)	0.14	4.38E-03	---
	JM01	33	(28)	1.72	1.30	4.64E-02	---
Mattala	H-5	200.4	32	0.72	0.85	2.66E-02	
				---	6.77	2.12E-01	2.72E-04
	H-5(2)	52.5	45.7	6.98	9.45	2.07E-01	
				---	4.74	1.04E-01	5.74E-04
	JM06	38	30.5	0.09	0.03	1.08E-03	---
Tammennawewa	H-6	102	20	13.98	31.93	1.60E+00	---
				---	18.83	9.42E-01	1.23E-04
	JM05	35.97	21.34	1.03	1.14	5.34E-02	---
Sevanagala	M-1	200.4	48	0.23	0.06	1.27E-03	---
	M-1(2)	40.8	35	3.05	1.10	3.14E-02	---
	JM14	45	(34)	2.24	1.55	4.56E-02	---
Bodagama	M-2	200.2	32	0.31	0.10	3.13E-03	---
	M-2(2)	100	60	15.40	53.20	8.87E-01	---
				---	81.90	1.37E+00	3.23E-04
	JM09	25.17	21.12	3.09	1.89	8.95E-02	---
Badalkumbra	M-3	88.3	20	215.91	741.00	3.70E+01	---
	JM13b	24.7	(18.7)	3.50	(2.56)	1.37E-01	---
Yalabowa	M-4	195	36	0.73	0.58	1.61E-02	---
	M-4(2)	100	64	46.92	53.70	8.39E-01	---
				---	89.40	1.40E+00	1.87E-03
	JM12	34.69	(22.69)	2.49	1.73	7.62E-02	---

*; Estimated figures **; Test conducted with an observation well. (o.h); Open Hole

The distribution of transmissivity is shown in *Figure 4.15*.

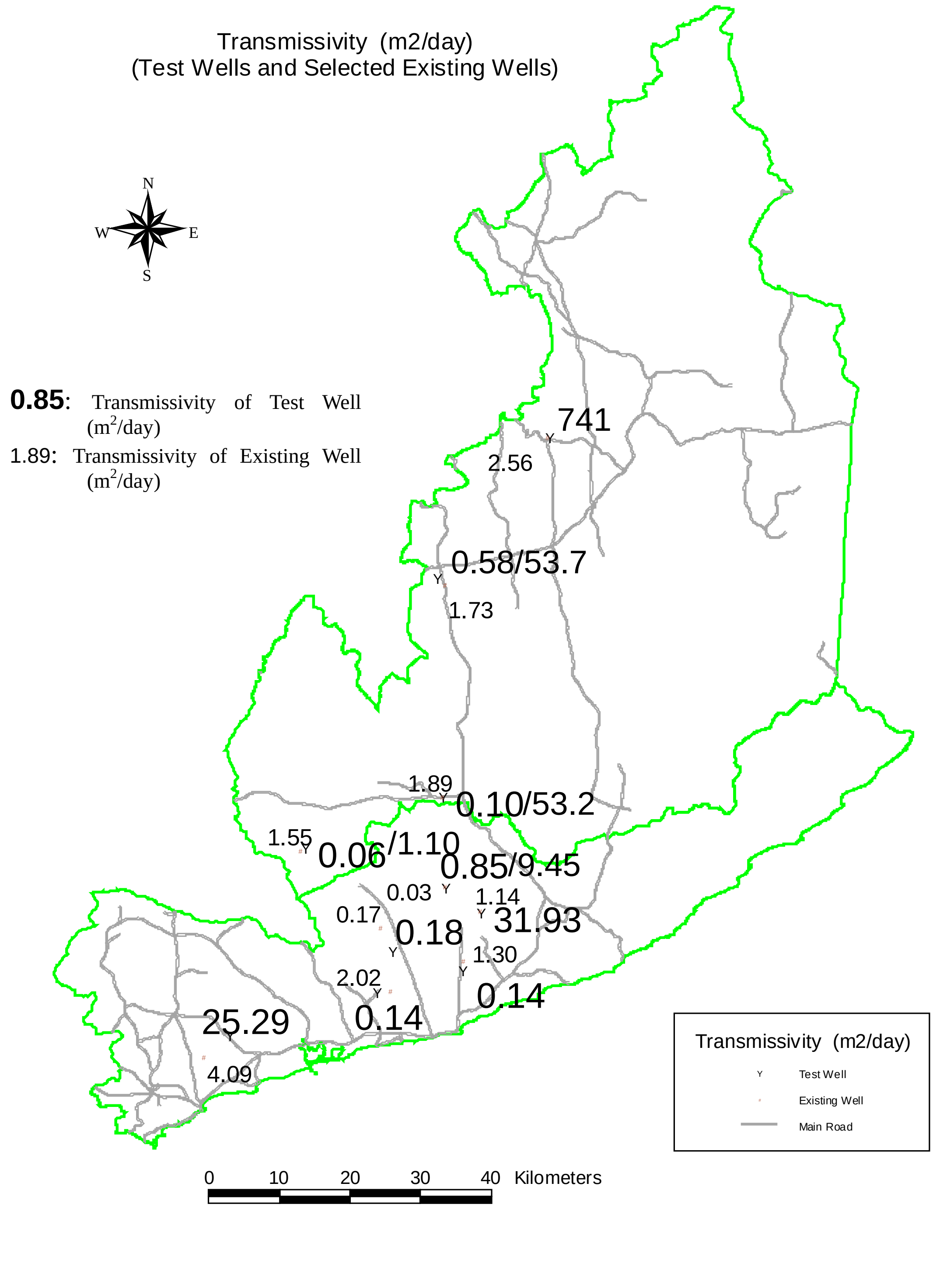


FIGURE 4.15 TRANSMISSIVITY

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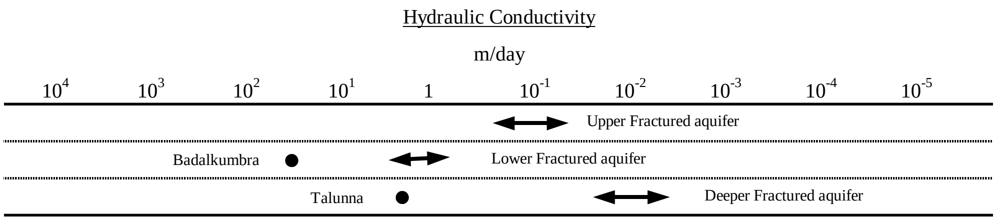
The table below shows the general ranges of hydraulic conductivity for soils and rocks. The values of massive to fractured metamorphic rocks vary from 10^{-5} to 10^{1} m/day. The range of the obtained values in the Study area is also shown in the table.



Relative permeability

Very high	High	Moderate	Low	Very low
Clean gravel	Clean sand and sand and gravel	Fine sand	Silt, clay, and mixtures of sand, silt, and clay	Massive clay
Vesicular and scorioceous basalt and covernous limestone and dolomite	Clean sandstone and fractured igneous and metamorphic rocks		Laminated sandstone, shale, and mudstone	Massive igneous and metamorphic rocks

after Kashef, A.I, GROUNDWATER ENGINEERING, 1987,
(U. S. Bureau of Reclamation, Ground Water Manual, U.S. Department of Interior, Washington, 1977.)

4.6.2 Upper Fractured Aquifer (GL - 70 m)

The lowest transmissivity was 0.03 m^2/day in Pahala Mattala (JM06); the second lowest was 0.17 m^2/day in Wediwewa (JM04). In other areas, transmissivity ranges from 1.14 to 4.09 m^2/day. In Pahala Mattala, another pumping test was carried out for the additional well drilled by WRB. The estimated transmissivity was 9.45 m^2/day. In addition, an analysis using the data of water level change in the test well No.H-5 was performed. The transmissivity was estimated at 4.74 m^2/day. Both values were very high compared with the result derived from the existing well test (JM06). The additional test well was only 180 m from the JM06. This means that the potential development level of fractured aquifer varies from place to place. Storativity, or storage coefficient, was obtained as 5.74 x 10^{-4} based on this analysis.

The estimated, or apparent, hydraulic conductivity ranges from 4.64 x 10^{-2} m/day (Keliyapura) to 1.64 x 10^{-1} m/day (Vitalandeniya) except at Mattala, where the estimated value was 1.08 x 10^{-3} m/day.

4.6.3 Lower Fractured Aquifer (70 – 100 m)

There are four test wells installed screen pipes in lower fractured aquifers: namely, No.H-6 Tammennawewa, No.M-2(2) Bodagama, No.M-3 Badalkumbura, and No.M-4(2) Yalabowa.

The highest transmissivity was 741 m^2/day in Badalkumbra (No.M-3). In the three other areas, the values of transmissivity were 31.9 (Tammennawewa), 53.2 (Bodagama) and 53.7 (Yalabowa) m^2/day. In Tammennawewa, transmissivity of 18.8 m^2/day was another estimated result based on the analysis using the data of an observation well that was 77 m away from the pumped test well. Additional estimation of the transmissivity was conducted using the drilled test well as an observation borehole for Bodagama and Yalabowa. The results were 81.9 m^2/day in Bodagama and 89.4 m^2/day in Yalabowa. S (storativity) was obtained as 1.23 x 10^{-4}

from the pumping test of Well No.H-6 Tammennawewa, 3.23 x 10-4 from the test of No.M-2(2) Bodagama, and 1.87 x 10-3 from the test of No.M-4(4) Yalabowa.

The estimated, or apparent, hydraulic conductivity ranges from 8.39 x 10^{-1} m/day (Yalabowa) to 1.6 m/day (Tammennawewa), except at Badalkumbra where the estimated value of 3.70 x 10^{1} m/day was outstanding.

4.6.4 DEEPER FRACTURED AQUIFER (100 – 200 M)

The pumping tests of eight test wells have been completed for the deeper fractured aquifer. The highest value of the estimated transmissivity was 25.3 m^2/day in Talunna. The other estimated values range from 0.06 to 0.85 m^2/day. Generally the obtained values were rather low except at Talunna. The presumed, or apparent, hydraulic conductivity varies mostly from 1.27 x 10^{-3} to 2.66 x 10^{-2} m/day and it suggests that the fractures in deeper zone develop poorly in general. Well No.H-2, Talunna, however, showed a presumed hydraulic conductivity of 1.58 m/day,. S (storativity) was estimated at 1.23 x 10^{-4} from the pumping test of Well No.H-5.

The estimated storativity by the Study varies from 1.23 x 10^{-4} to 5.74 x 10^{-4}. The fractured aquifer in the study area may be considered to have this range of storativity values.

CHAPTER 5 GROUNDWATER EVALUATION

5.1 GENERAL

The fractured aquifer in the area was categorised into three parts: namely, the upper fractured aquifer, the lower fractured aquifer, and the deeper fractured aquifer. The deeper fractured aquifer below 100 m in depth was first confirmed by the Study; therefore, there is still little information about the aquifer at present. Two sheets of the hydrogeological map have been prepared: namely, the hydrogeological map for the upper fractured aquifer, *Figure 4.1(1)*, and the hydrogeological map for the lower and deeper fractured aquifer, *Figure 4.1(2)*. These maps will be revised with the further accumulation of hydrogeological data. The maps contain the information on groundwater yield, quality (EC), depth to groundwater, existing well location, geological structure and physiographic information such as surface water and contour lines. Naturally, groundwater yield, or productivity, is one of the most important factors for groundwater exploitation. The quality of groundwater is another essential factor. Pumping and maintenance costs depend on the depth to water. The analyses using GIS show the regional characteristics in the area. Finally, the groundwater resources evaluation maps, *Figure 5.1(1),(2)*, were provided based on the hydrogeological map to contribute to the groundwater development plan. Outline of the preparing procedure of these maps were shown below (*Figure 5.2*).

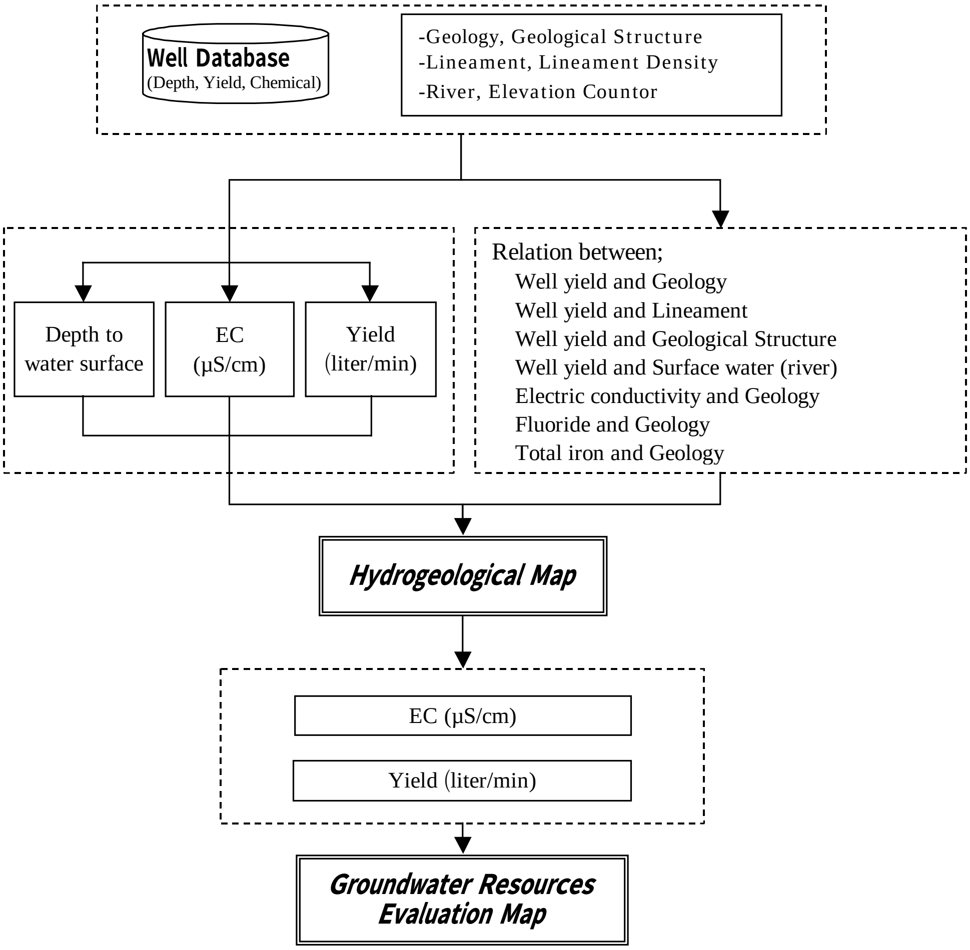


Figure 5.2 Outline of the Preparing Procedure of Hydrogeological Map and Groundwater Evaluation Map

Classification Matrix for Groundwater Resources Evaluation

			Estimated Yield (liters/min)		
			100 <	50 - 100	< 50
EC (μS/cm)		Allotment Points	Good	Fair	Poor
			3	2	1
< 750	Good	2	6	4	2
750 - 3500	Fair	1	3	2	1
3500 <	Poor	0	0	0	0
			Weighting		

Evaluation of Groundwater Resources

- 6 *Very Good*
- 4 *Good*
- 3 *Good*
- 2 *Fair*
- 1 *Moderately Fair*
- 0 *Poor*

Explanation of Hydrogeological Symbols

JICA Test Wells

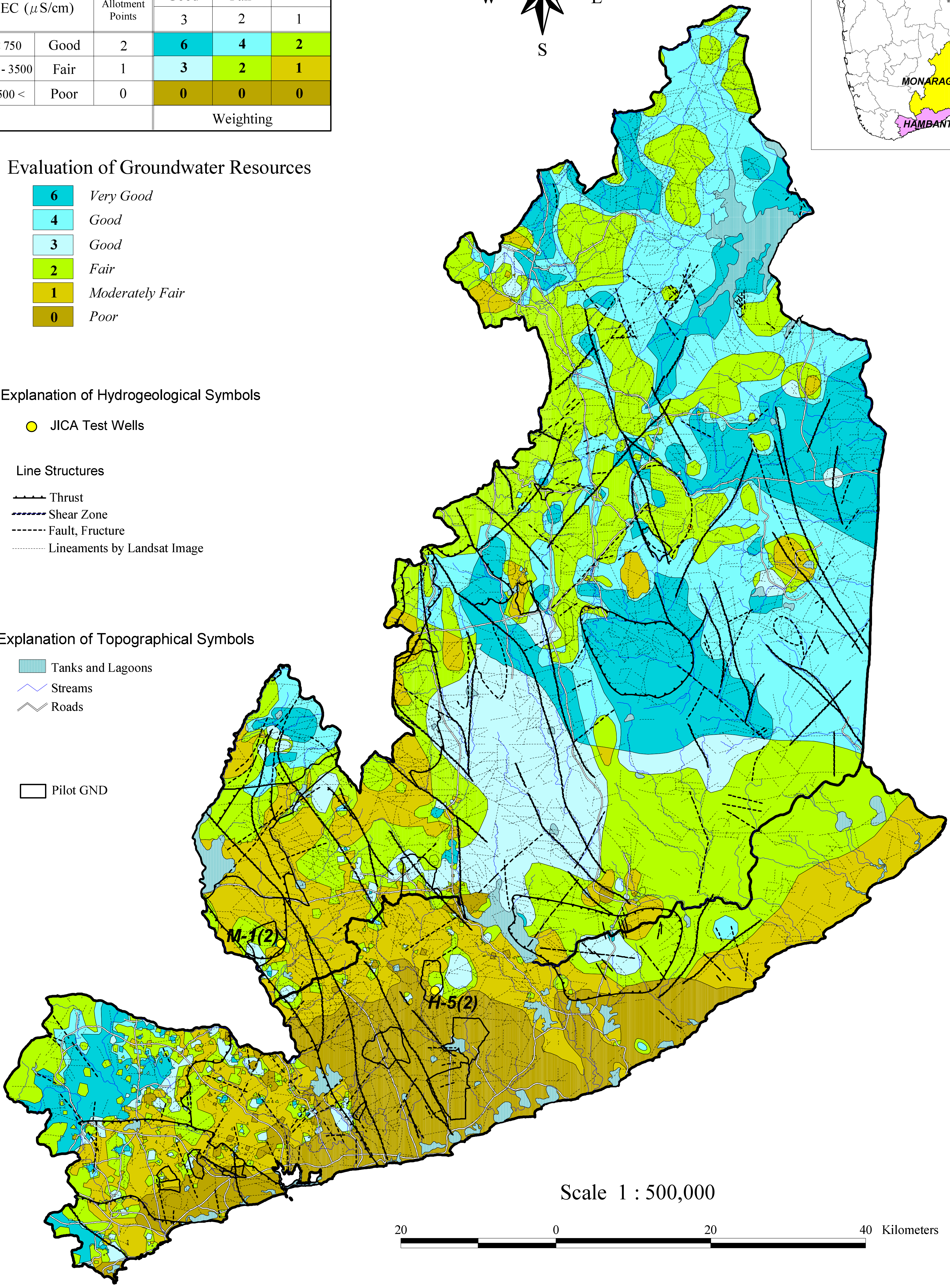
Line Structures

- Thrust
- Shear Zone
- Fault, Fructure
- Lineaments by Landsat Image

Explanation of Topographical Symbols

- Tanks and Lagoons
- Streams
- Roads

Pilot GND



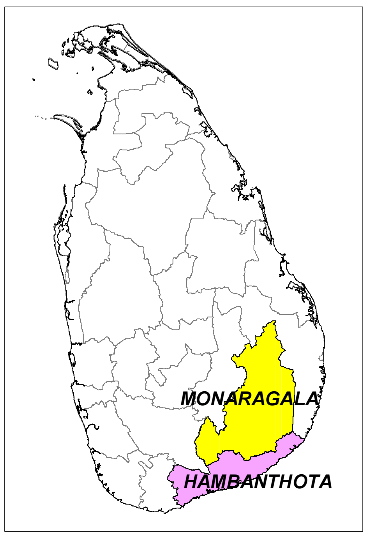


Figure 5.1(1) Groundwater Resources Evaluation Map

Upper Farctured Aquifer (Shallower than 70)