WORKING PAPER 122

Characterization and Monitoring of the Regolith Aquifer within Four Selected Cascades (Sub-watersheds) of the Malala Oya Basin

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International
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Contents

Summary

It is now clearly recognized that the groundwater present in the hard rock region of the dry zone of Sri Lanka is made up of the shallow 'Regolith Aquifer' and the deeper fracture zone aquifer. However, up to now no study had been carried out or reported in this country on the dynamic nature of this shallow regolith aquifer. This is the very first study carried out and reported in this regard.

The Malala Oya Basin is located within IWMI's study area of the Ruhuna Basin, and it is made up of 17 individual sub-watersheds or cascades. The study area included four of these cascades which are located within the upper segment of the Malala Oya Basin. The recently constructed trans-basin feeder canal cuts across two of these cascades as shown in Figure 6 of this report.

The chief objectives of this study were to a) characterize the mode of occurrence of the regolith aquifer within the study area, b) monitor and quantify the pattern of depletion as well as the pattern of replenishment of the aquifer through the wet and dry seasons, and c) understand the nature of changes in the chemical quality in the aquifer through the dry and wet seasons. As part of the study, it also evaluated the present impact of the Mau Ara trans-basin canal on the groundwater conditions below the area of influence of this trans-basin feeder canal.

The presently functioning open dug wells that are present within the study area were chosen for monitoring the water table of the regolith aquifer. A total of 25 such dug wells were selected for this study and their location is shown in figures 9 and 21. As seen in figures 9 and 21, these dug wells are located within the area bordering the main axis of the natural drainage of landscape and are situated just below the seepage zone of the small village tank. As explained in Figure 5, the regolith aquifer is situated within the low-lying aspect of these inland valleys that drain this landscape.

The field studies included (a) weekly monitoring of the depth of the water table of the 25 dug wells, and (b) monthly sampling of the 25 dug wells for measurement of electrical conductivity (EC), and chemical analysis was carried out in the laboratory for Na, K, Ca, Mg, F, Cl, SO_4 and hardness. Water releases to the trans-basin canal were also monitored from June to December 2004.

Results show that the main depletion of groundwater levels takes place from May onwards, as shown in Annex 1. The depletion of the groundwater ranges between 3.0 and 6.0 meters below ground level (m.b.g.l.) and takes place over a 23-week period up to October. The depth to depletion increases with the macro-elevation of the landscape, with the wells located in the higher aspects having a depth to depletion of between 6 to 8 meters (m) as compared with 3 to 4 m in the lower aspects. The groundwater levels in the dug wells located below the trans-basin feeder canal were maintained at an acceptable level because of the intermittent flows that took place in the trans-basin feeder canal during July to September. The important implication of this latter result has been discussed.

With reference to the mode of replenishment, it was shown that by the end of November a majority of the dug wells had reached their maximum groundwater level except for four wells which showed a slower rate of replenishment and reached this maximum level only by the last week of December. These latter four wells are situated further away from the main drainage valley, and are located in the upper aspects of the landscape. It is also observed that a cumulative rainfall of 170 millimeters (mm) is needed to saturate the soil profile, and that a response from groundwater commences only after this amount of rainfall has been received. In sum, it is observed that the mode of replenishment is very similar in relation to the macro-topography and relief, but that slight variations can be observed in relation to differences in the micro-topography of the relief.

Three broad categories of electrical conductivity (EC) of low, medium and high were recognized on the basis of the monitored values for EC. A very small rise in the value of EC is observed following the initial Maha rains, which is attributed to the leaching of salts accumulated within the soil profile during the dry season. Despite a decline in groundwater levels through the dry season (May to September) no corresponding change in EC could be observed. It is therefore argued that the underlying regolith aquifer which feeds these wells has adequate capacity to recover and this would enable the maintenance of the quality of water in dug wells over the six-month dry period. It is also clearly evident that all wells located along the natural drainage ways have a low EC value because there is sufficient flushing out of soluble salts which drain into these free-draining situations. Wells that show a high EC value are located at the break of a slope in the landscape, and also where there is an underlying sub-surface obstruction.

Wells that have a low fluoride content are found to be located in positions of the landscape where drainage, and also the flushing out of groundwater under natural conditions, is very good. Wells that have a moderate fluoride content are found to be located in positions that are close to the axis of the main drainage system where there is moderate sufficiency of drainage and flushing out. Wells that have a high fluoride content are all located at inter-flow sites in the landscape where there is insufficient flushing out of the water table.

Both the chloride contents as well as the seasonal trends in chloride contents follow the same pattern as the fluoride values described above.

Based on the results of the variation in sulphate content over the study period, it is suggested that the sulphate content in well water could be used as a reliable indicator of the quality of well water. Matching the World Health Organization (WHO) guidelines for the sodium content of drinking water, all wells except the well numbers 3, 21, 27, 37 and 39 could be considered to fall within the suitable category.

With reference to the impact of the trans-basin feeder canal on the groundwater conditions below the canal, it is clearly shown that the intermittent flows in the trans-basin feeder canal have helped to sustain a minimal water table of between 4 to 5 m.b.g.l. during most of the dry period up to September-October. This condition of a reliable availability of groundwater during the very dry months of July-September in locations below the trans-basin feeder canal would ensure a more productive settlement activity in this area of influence.

INTRODUCTION AND GENERAL BACKGROUND

For several years the British Geological Survey had been investigating the nature of the aquifer that occurs within the regolith of the hard rock regions in tropical Africa and South Asia, a larger part of which is underlain by crystalline basement rocks such as granites, gneisses, schists and quartzites. These investigations have shown that the groundwater in these areas, which are underlain by crystalline basement rocks, normally occur in two main forms: (1) the shallow regolith aquifer, and (2) the deeper fracture zone aquifer. The term ‘regolith aquifer’ has come into use mainly over the last 15 years.

In the course of the studies carried out on aspects of the hydrogeology of the shallow – weathered zone of the hard rock areas in Sri Lanka over the five year period from1983–1988 by the British Geological Survey in collaboration with the Water Resources Board of Sri Lanka, the key findings as reported by Herbert et al. (1988) are that (a) there is a water table at the regolith-hard rock interface over most of the dry zone, and (b) the more permeable zone of the regolith is in the top of the interface, namely in the Sap Rock.

In general, the uppermost section of the basement rocks have been altered by the tropical weathering processes to form a distinct horizon of varying depth termed the regolith. This regolith is made up of the upper ‘saprolite’ or highly weathered rock, and the underlying ‘saprock’, which is a slightly weathered rock. Most dug wells penetrate only to the top of the saprock horizon as digging becomes more difficult once this saprock is reached. The water table is mostly found within the saprolite, which provides a substantial storage for extraction. The thickness of the saprolite and saprock zones can vary greatly in proportion and scale from site to site.

Based on the experience of the British Geological Survey in the basement hard rock regions of tropical Africa, Wright and Burgess (1992) conclude that “Basement aquifers are of particular importance in the tropical regions because of their widespread extent and accessibility, and also because there is often no readily available alternative source of water supply for the widely scattered rural communities.” This holds true for most of the dry and semi-arid parts of the dry zone of Sri Lanka where there are many scattered village settlements.

In these regions the traditional hand-dug wells have been abstracting water from this basement regolith aquifer for their village domestic requirements over a period of at least two millennia. Despite their relatively low yields and seasonal water level fluctuations, these hand-dug wells have provided the basic domestic water needs that make human settlement possible in these dry environments.

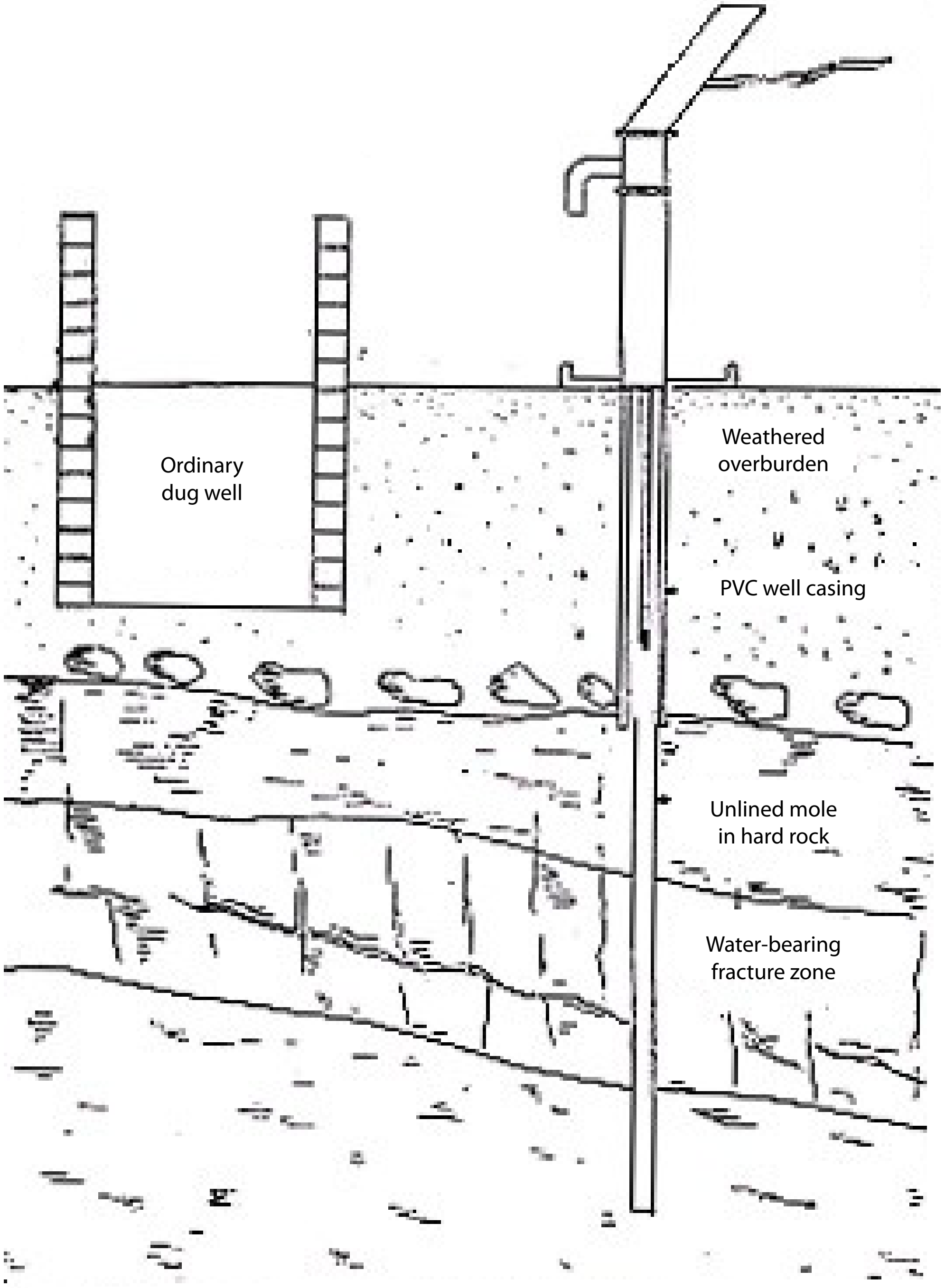
Development of the regolith aquifer component is normally carried out by digging wells (dug wells), whereas development of the fractured bedrock component is typically carried out by drilling deeper boreholes as shown on Figure 1.

EVOLUTION OF OUR UNDERSTANDING OF THE REGOLITH AQUIFER IN SRI LANKA

The earliest studies of groundwater in the hard rock region of this country were by Sirimanne (1952), in which he had pointed out that the un-weathered crystalline rocks, by their very nature, are relatively impervious and non-porous, and what circulation takes place is mainly along joints and fissures and also along planes of foliation and cleavage. As summarized by Cooray (1988), “there is, therefore, no continuous body of groundwater with a single water-table in crystalline rocks, but rather separate pockets of groundwater, each with a distinct water table.” A sketch diagram showing the occurrence of groundwater in such pockets in crystalline rocks according to

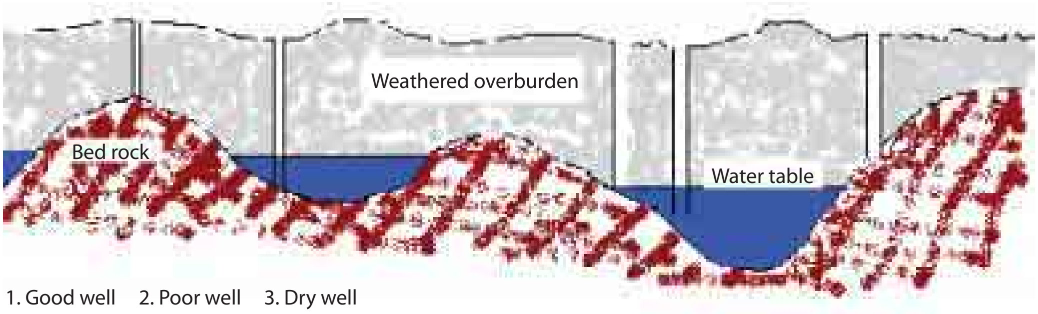
Sirimanne (1952) is shown in Figure 2. This figure shows that the utilization of such water pockets depends on their exact location in the underlying weathered rock topography, and therefore haphazard well sinking in areas of crystalline rock often leads to failure.

Figure 1. Shallow dug well and deep bore well.



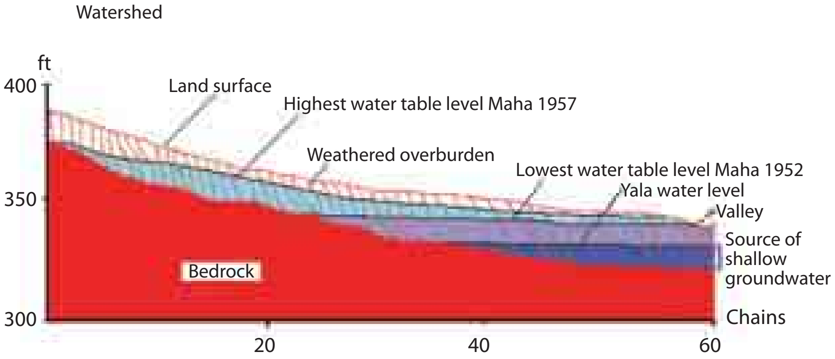
A schematic representation of the geochemical environments of dug wells and the deep wells

Figure 2. Sketch showing occurrence of groundwater in pockets of crystalline rock.



The first systematic study of groundwater table behavior in the dry zone was reported by Panabokke (1959). Based on this study, the highest and the lowest positions of the wet season water table recorded over a period of 8 years, as well as typical dry season positions of the water table, is shown in Figure 3. As shown in Figure 3, the landscape position within which groundwater could be tapped during the dry season is that lower depth in the valley, within which the Yala season water table is present.

Figure 3. Groundwater behavior Maha Illuppallama (1950-1960).



Source: Soil science vol. 87-1959.

With the rapid increase in agro-well development that had taken place in the late eighties, a very large number of both successful and unsuccessful agro-wells had been constructed all over the Anuradhapura District. It was initially observed that most of these agro-wells were distributed around the small tanks and also in close proximity to the village settlements along the tanks. Instead of using any scientific means of groundwater exploration, the indigenous knowledge of the villagers was used in the siting of these early agro-wells.

It was only around the mid-1990s when the International Irrigation Management Institute (IIMI) had completed a study of the small tank cascade systems in the Anuradhapura District under the International Fund for Agricultural Development (IFAD) supported Participatory Rural Development Project (PRDP) investigations, that a clear picture began to emerge on the relationships between the location of the small tank cascade systems and the underlying regolith aquifer. It is in that study that the hydrology of the small tank cascade systems were subjected to a critical analysis, which brought out the position and dynamics of the groundwater regime within these small tank cascade systems as reported by Sakthivadivel and Panabokke (1996) and Senaratne (1996).

It is now clearly recognized that the large number (more than 15,000) of small tanks that are distributed across the hard rock undulating landscape of the dry zone are not randomly located and distributed as commonly perceived; rather, they are found to occur in the form of distinct cascades that are positioned within well-defined small watersheds or meso-catchment basins.

The shallow regolith groundwater within these cascades is mainly confined to a narrow belt along the main valley of each cascade, and to a smaller extent along the side valleys which are shown in Figure 4. It could thus be seen that this shallow groundwater is restricted to a definite landscape position within a cascade of small tanks and is not ubiquitous as commonly perceived. The depth of this shallow groundwater is usually between 5 to 10 m, and as shown in Figure 5, it is this shallow groundwater in the lower part of the valley that is being tapped by the agro-wells.

Figure 4. Schematic representation of groundwater area within a cascade.

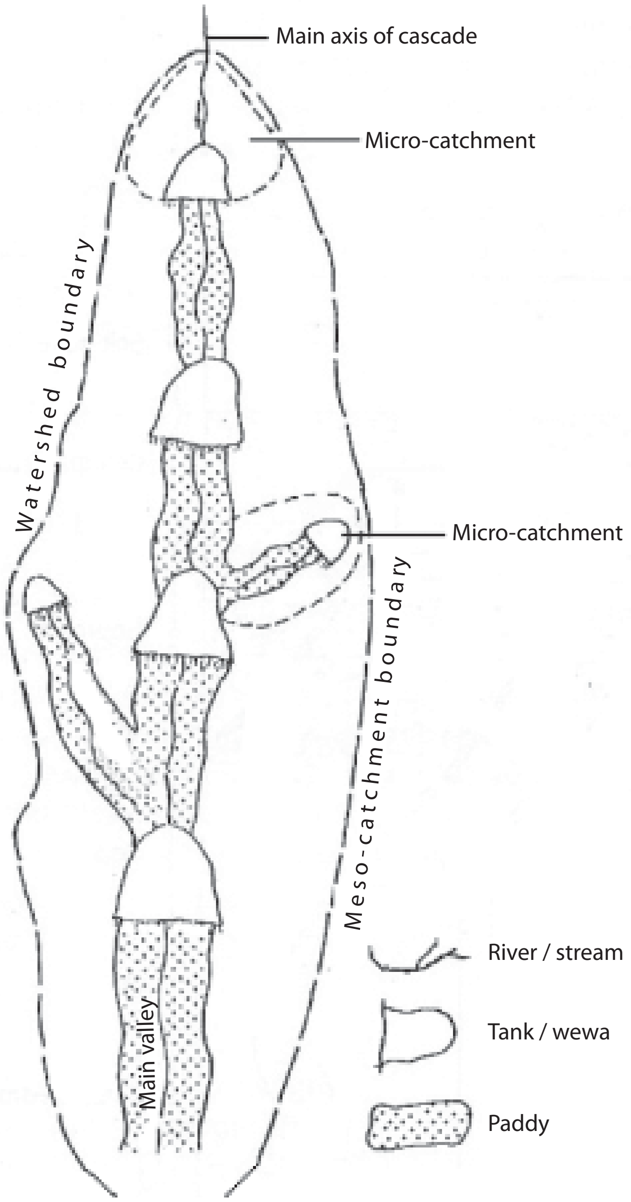
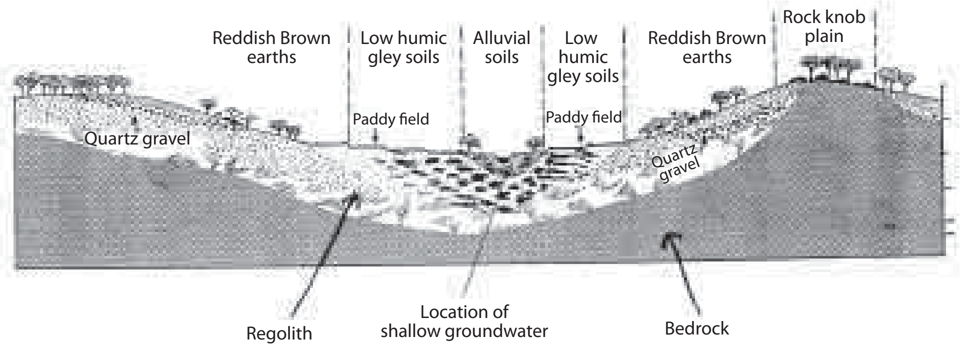


Figure 5. Shallow regolith aquifer in lower part of valley in the landscape.



OBJECTIVES OF THE STUDY

The five main objectives of this study were as follows:

1. Characterize the mode of occurrence of the regolith aquifer within the respective cascades (sub-watersheds) that were selected for this study.
2. Monitor and study the physical nature of seasonal changes that take place in the regolith aquifer, namely,
    a. the pattern of depletion of the regolith aquifer through the dry season, and
    b. the pattern of replenishment of the regolith aquifer through the wet season.
3. Establish the relationships of the above pattern of recharge and replenishment of the regolith aquifer with reference to both the macro- and micro-topographical aspects of the landscape.
4. Monitor and study the chemical nature of the seasonal changes that take place in the regolith aquifer, namely the pattern of variation in the chemical quality of the groundwater of the dug wells through the dry and wet seasons, respectively.
5. Examine the possible causes for the variation in chemical quality of the groundwater over the wet and dry seasons, especially the changes that take place immediately after commencement of the wet season.

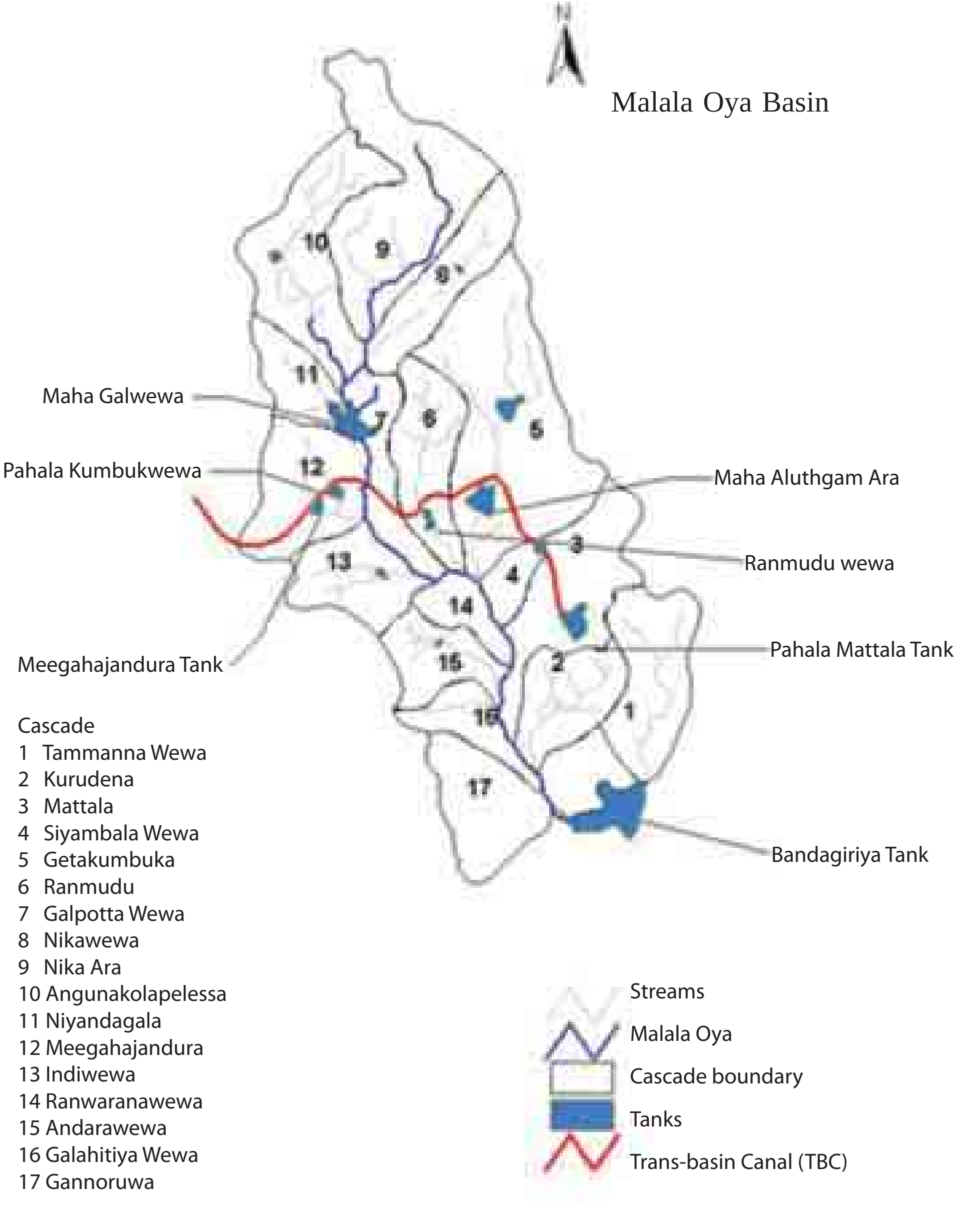
In addition, the following two sub-objectives were also to be addressed:

1. Evaluate the impact of the Mau Ara trans-basin canal on the groundwater conditions below the area of influence of the trans-basin feeder canals.
2. When conditions permit, conduct pumping tests in selected locations in order to establish the transmissivity of the regolith aquifer at strategic locations.

STUDY AREA AND STUDIES CARRIED OUT

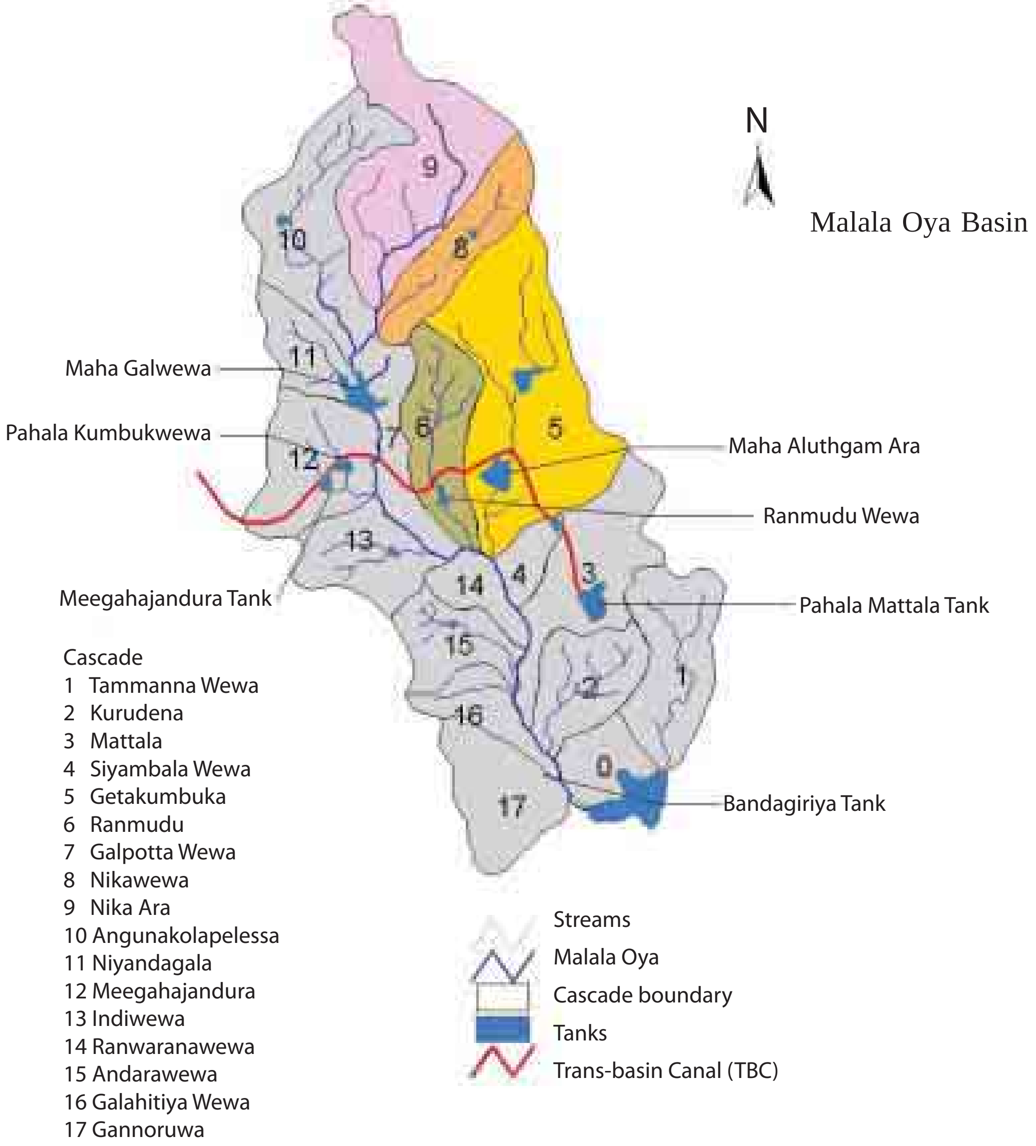
The study area was the upper segment of the Malala Oya Basin, across which the recently constructed trans-basin canal traverses. A map of the whole Malala Oya Basin together with the location of the trans-basin canal is shown in Figure 6. As also shown in Figure 6, the Malala Oya Basin, which is 405 square kilometers (km^2) in extent, is made up of 17 individual cascades or sub-watersheds. The proper study area included the four cascade numbers 5, 6, 8 and 9 as shown in Figure 6. The trans-basin canal crosses cascade number 12 on the right bank, and cascade numbers 6 and 5 on the left bank of the Malala Oya Basin.

Figure 6. The Malala Oya Basin and location of trans-basin feedìs/cmer canal.



The areal extent of each of the sub-watersheds and the locations of the dug wells that were included in this study are shown in Figure 7.

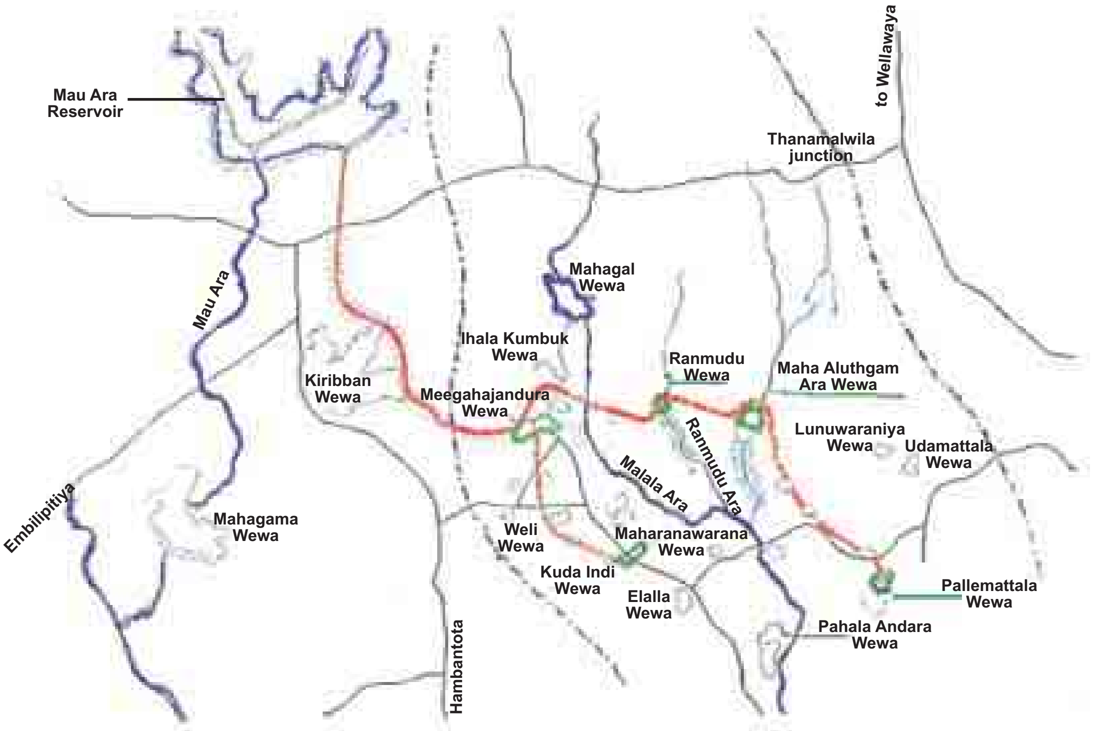
Figure 7. *The areal extent of each of the sub-watersheds and the locations of the dug wells.*



The Malala Oya Basin is a highly water-short basin as reflected in the overall water balance for this agroecological region where the mean annual rainfall is around 1,000 mm while the mean annual evaporation is around 1,550 mm. At present there are a total of 371 small tanks within this basin, of which only 29 tanks are currently functioning, and that too only during a single wet season Maha crop of paddy in a good season. This gives a measure of the hydrological stress that occurs within this basin.

In order to ameliorate this adverse water deficit, the Department of Irrigation (DI) had constructed a trans-basin or feeder canal, 15 kilometers (km) in length and 150 cubic meters per second (cumec) capacity, which commences from the Mau Ara Reservoir (41 million cubic meters (MCM)) and proceeds along the landscape contour, as shown in Figure 8, into the Malala Oya Basin in its upper reaches. As shown in Figure 6 it traverses cascade number 12, Meegahajandura, on the right bank of the main Malala Oya, and after having crossed the main Malala Oya River by an underpass it traverses the two cascades numbered 6, Ranmudu Ara, and 5, Gatakubuka Ara, which are located in the left bank of Malala Oya and formed the area of this study. As shown in this figure, this trans-basin feeder canal presently augments the minor tanks of Meegahajandura and Indiwewa on the right bank; and the Ranmudu Wewa and Maha Aluthgam Ara Wewa on the left bank before ending up at the Pallemattala Wewa.

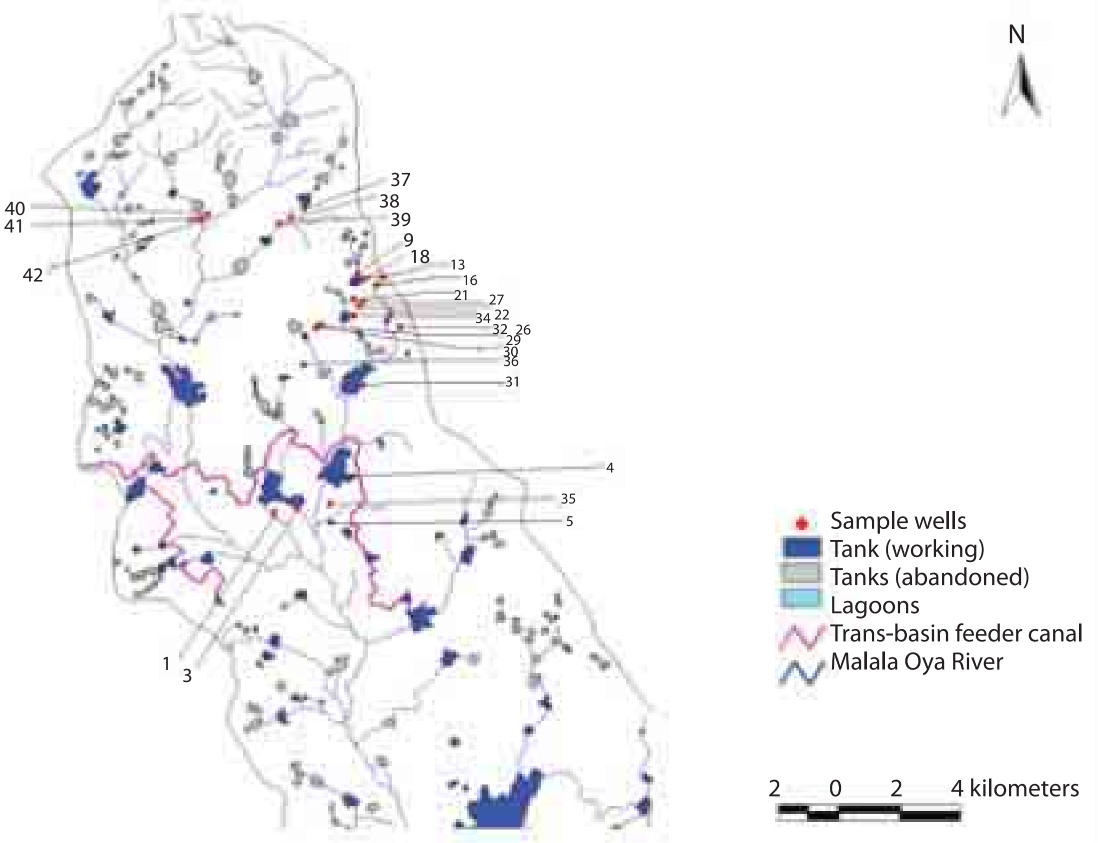
Figure 8. Traverse pathway of the trans-basin feeder canal.



The presently existing and functioning open dug wells within the study area were chosen for monitoring of the water table of the regolith aquifer. These open dug wells range in size from 0.9 m to 2.7 m in diameter and from 3.9 m to 9.0 m in depth, and have been in continuous use by the village settlers in this region for more than 75 years. A total of 25 dug wells were selected for this study, and their location and number is shown in Figure 9. As shown in Figure 9, 20 dug wells numbered 9, 13, 16, 18, 21, 22, 26, 27, 29, 30, 31, 32, 34, 36, 37, 38, 39, 40, 41 and 42 are located above the trans-basin feeder canal, and five dug wells numbered 1, 3, 4, 5 and 35 are located below the trans-basin feeder canal.

From this figure it is also to be noted that all these domestic dug wells are located within the area bordering the main axis of the natural drainage of the landscape, or is just below the seepage zone of the small village tank. As previously shown and explained in Figure 5 the regolith aquifer is situated within this lower-lying aspect of this undulating landscape.

Figure 9. Well locations and trans-basin feeder canal.

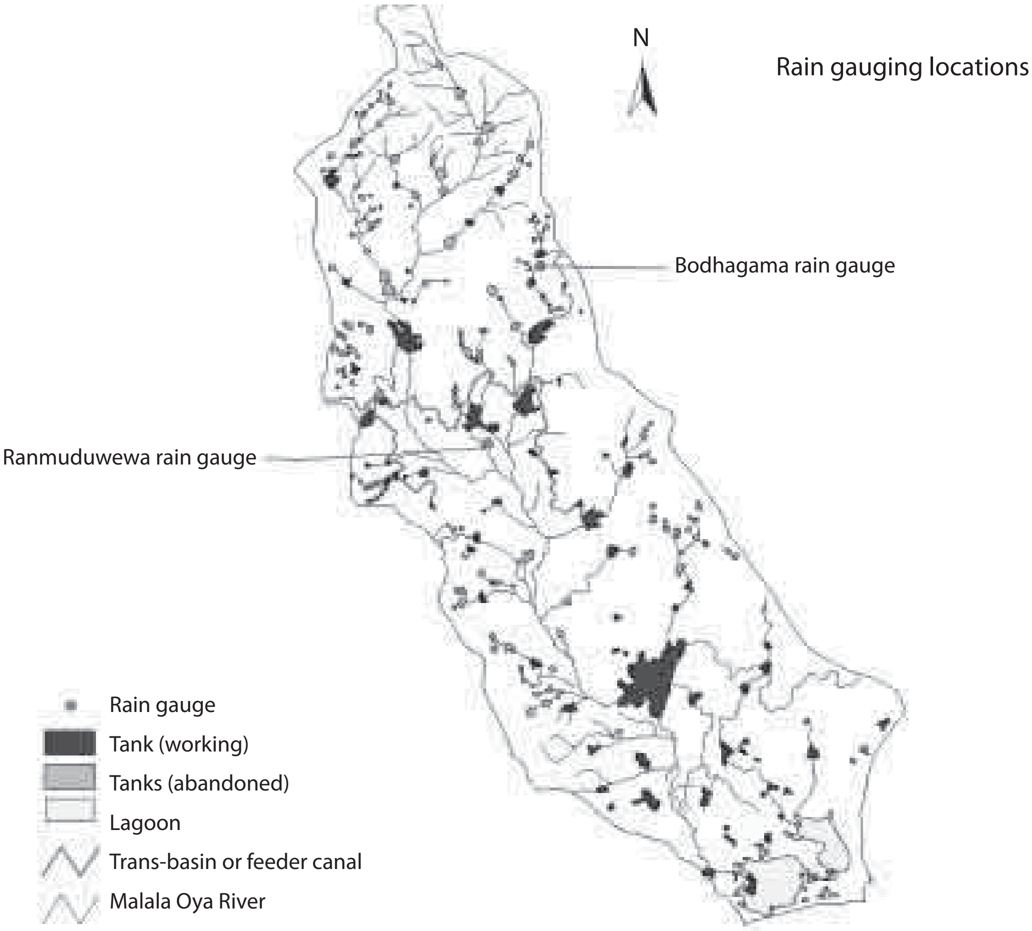


With reference to the studies that took place over the 12-month period from January to December 2004, the main field studies and laboratory studies carried out were as follows:

- Measurement of daily rainfall at two locations within the study area as shown in Figure 10.
- Weekly monitoring and measuring the depth of the water table of the 20 dug wells located above the trans-basin feeder canal, as well as the 5 dug wells located below the trans-basin feeder canal as shown in Figure 9.
- Computing and plotting the change in depth of the water level below ground level (b.g.l.) on a weekly basis.
- Monthly sampling of all 25 dug wells for measurement of Electrical Conductivity (EC), and for chemical analysis of nine chemical properties (EC, TH, F, Cl, SO_4, Na, Ca, Mg and K).
- Laboratory analysis of foregoing water samples, and computing and plotting of results.

In addition, the tank storage of Gal Amuna Reservoir and releases to the trans-basin feeder canal were also monitored from June to December 2004.

Figure 10. Rain gauging locations within study area.



RESULTS

Physical Change – Nature of Seasonal Changes in Groundwater Levels of the Regolith Aquifer

Patterns of Depletion of Groundwater Levels through the Dry Season

The locations of the 25 dug wells that were monitored in this study are shown in figure 9. As shown in this location map, six wells, numbered 37, 38, 39, 40, 41 and 42, are situated in the upper aspects of the Malala Oya Basin, and 14 wells, numbered 9, 13, 16, 18, 21, 22, 26, 27, 29, 30, 31, 32, 34 and 36, are situated in the middle aspects of the basin. The five wells, numbered 1, 3, 4, 5 and 35, are all situated below the trans-basin diversion canal.

It can also be observed from this same figure that these dug wells are mostly located within the drainage axis of the second or third order drainage ways that make up the natural drainage network of the respective cascades.

The weekly rainfall data for the period January to December 2004 for the two rain guage stations, Bodagama in the upper part of the basin and Ranmudu Wewa in the middle aspect of the basin, are shown in Figure 11. The monthly rainfall data for the period January to December 2004 for these same two stations are shown in Figure 12. The trans-basin feeder canal flow for the period 24 June to end December 2004 is shown in Figure 13.

Figure 11. Weekly rainfall pattern for January to December 2004.

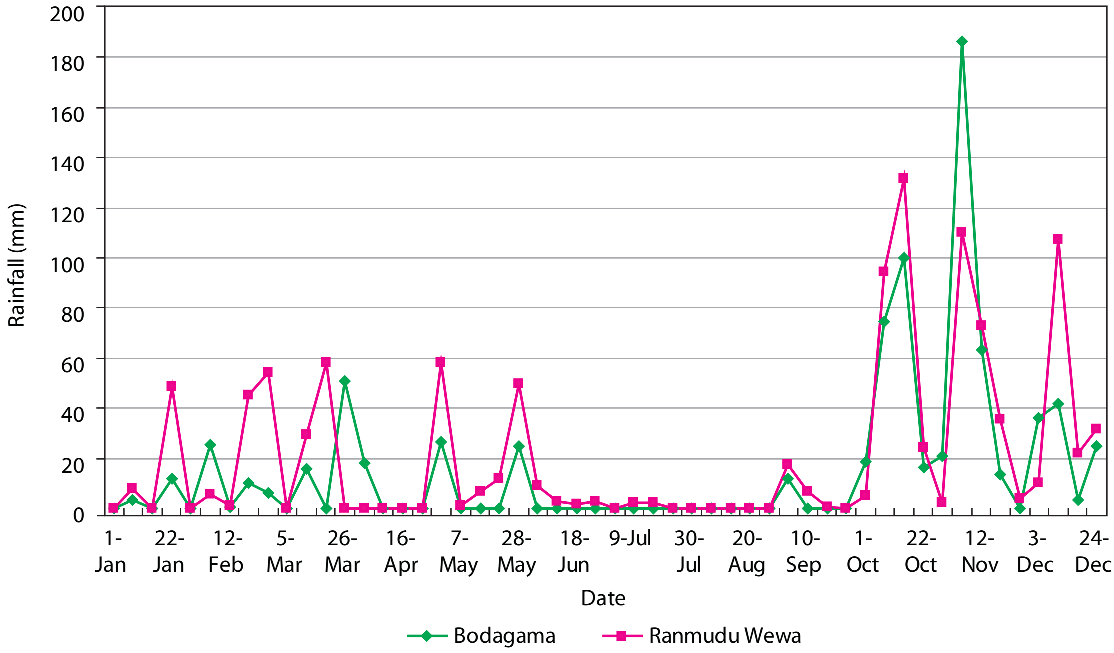


Figure 12. Monthly rainfall for Bodagama and Ranmudu Wewa - January to December 2004.

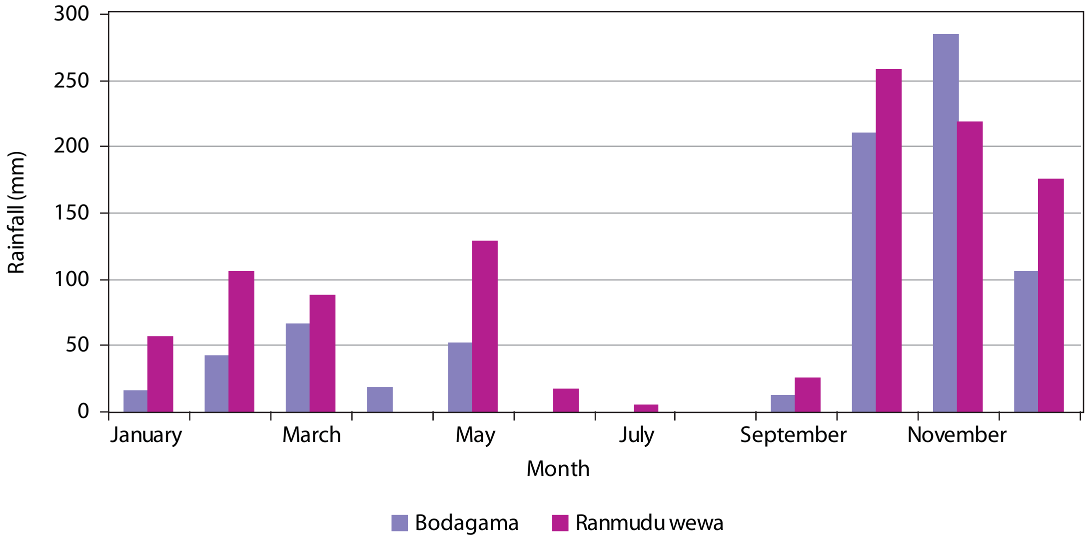
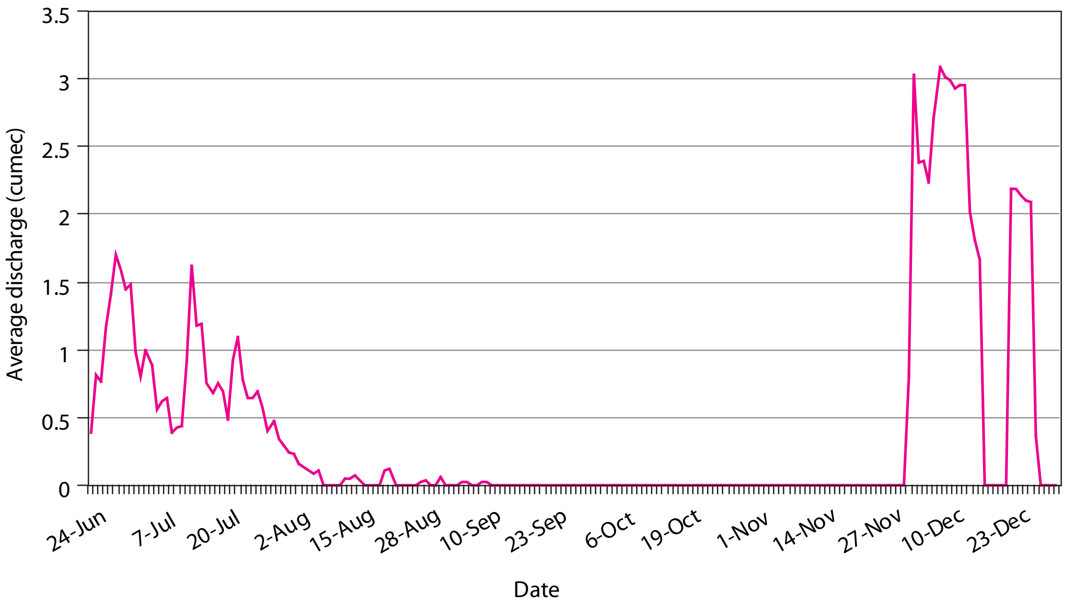


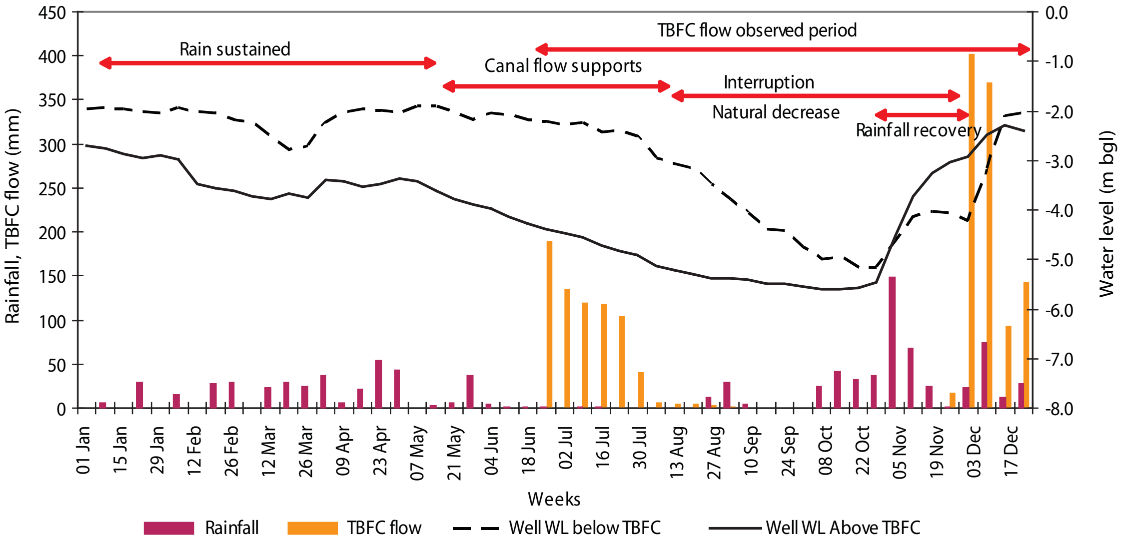
Figure 13. Trans-basin feeder canal flow - June to end December.



The pattern of change in the groundwater levels in each of the 25 monitored dug wells over the period commencing the first week of January through to the last week of December in 2004 is shown in Annex 1. These figures show the weekly measured values of the water table below ground level (b.g.l.) for each of the 25 dug wells that were monitored.

The foregoing data for the 20 dug wells located above the trans-basin feeder canal was then pooled into a single trend curve, and compared with the pooled trend curve for the five dug wells located below the trans-basin feeder canal. The two curves are shown in Figure 14.

Figure 14. Seasonal trends of changes in groundwater level – January to December 2004.



This figure gives an overall generalized picture of the seasonal trends of changes in the groundwater level throughout the study period of twelve months from January to December 2004. As shown in Figure 14, the main decline in the groundwater level takes place from mid-May onwards. With reference to the dug wells located above the trans-basin feeder canal, a real decline in the groundwater level from a value of 3.3 to 5.5 m.b.g.l. takes place over a period of 23 weeks from the second week of May to the second week of October.

With reference to the dug wells located below the trans-basin feeder canal, the main decline in the groundwater level from 3.0 to 5.0 m.b.g.l. takes place from the first week of August, which coincides with the curtailing of flows in the trans-basin feeder canal as shown in Figure 13.

It can also be observed from the depletion pattern shown in Annex 1, in all of the 25 dug wells, that all the wells have reached their lowest groundwater level by the first week of October, namely the end of the dry season. Taken together with Figure 14 it can also be observed that the rate of decline or depletion of the groundwater level in all of the 20 dug wells, located above the trans-basin feeder canal during the period from the first week of July to the first week of October, is higher when compared with the five dug wells located below the trans-basin feeder canal.

The foregoing observation would indicate that the intermittent flows that have taken place in the trans-basin feeder canal, as shown in Figure 13, have helped to sustain a minimal level in the water table between 4 to 5 m.b.g.l. during the most stressful dry period of September to October when most dug wells in this environment face serious problems of depletion of water supply to their domestic wells.

This observation would also imply that the trans-basin feeder canal flows, although small and intermittent, have helped to augment and hold up a minimum depth of the water table, below the trans-basin feeder canal, that could be exploited for domestic use during this most stressful dry period of September to October.

It can also be observed in Annex 1 that the sequential pattern of depletion over the period April to October is not uniform in all the 20 dug wells located above the trans-basin feeder canal. Well numbers 9, 18, 22, 30, 32 and 34 show a more rapid rate of decline than well numbers 21, 26, 27, 29, 37, 39, 40, 41 and 42, which show a more gradual rate of decline.

A grouping based on the depth of depletion shows that well numbers 40, 41 and 42 show a depth of depletion value of 8.0 m.b.g.l.

Well numbers 37, 38 and 39 show a depth of depletion value of 5.5 m.b.g.l.

Well numbers 9, 16, and 18 show a depth of depletion value of 5.0 m.b.g.l.

Well numbers 22, 34, 36, 21, 26, 27, 13, 29 and 31 show a depth of depletion value of 4.0 m.b.g.l.

At this stage, it would be too premature to attempt to assign any reasons for this difference in sequential behavior between the groupings made for the wells monitored. However, it is very evident that the six wells numbered 37, 38, 39, 40, 41 and 42 are located in the higher aspects of the study area and should, therefore, show a higher depth of depletion, namely 8.0 m.b.g.l. by the end of the dry season.

Patterns of Replenishment of the Groundwater Level in the Regolith Aquifer over the Rainy Season

It can be observed from both Figure 14 and Annex 1 that it is only after a cumulative rainfall of around 100 mm has been received by the third week of October that the groundwater levels begin to show a significant difference. It is further clearly brought out in all 25 wells shown in Annex 1 that a rise in the levels of the water table begins to take place in all wells only by the first week of November, when a cumulative rainfall of around 170 mm has been received. This implies that a rainfall of around 170 mm is needed to saturate the soil overburden before any groundwater recharge takes place.

From the figures shown for all 25 monitored wells (as shown in Annex 1), it can be observed that by the end of November, or by the first week of December, a majority of the wells have reached their maximum groundwater level.

Understandably, it can be seen that the maximum groundwater level is reached two weeks later by mid-December in all of the six wells numbered 37, 38, 39, 40, 41 and 42, which are located in the upper aspects of the Malala Oya Basin.

It can also be observed from Annex 1 that the rate of replenishment or recharge is very similar in all the wells except in that of well numbers 13, 21, 29 and 36, which all show a slower rate of replenishment levels than the other wells. While the other wells have reached their maximum replenishment levels by the first week of December, these four wells reach their maximum water level only by the last week of December. As shown in Figure 9, all these four wells are located away from the main central drainage systems and would, therefore, take a longer time to get completely replenished.

CHEMICAL CHANGES

Seasonal Changes in Electrical Conductivity (EC)

Based on the values of Electrical Conductivity (EC), obtained from all 25 wells over the twelve-month monitoring period (Annex 2, Table B1), the following groupings were made:

Group 1. Wells with low EC; 0-750 micro-Siemens per centimeter (μs/cm)

Group 2. Wells with moderate EC; 751-1,500 (μs/cm)

Group 3. Wells with high EC; 1,501-3,000 (μs/cm)

The seasonal change in EC values over the twelve-month period January to December 2004 for all three groupings is shown in Figures 15, 16 and 17.

As shown in these three figures, the wells in Group 1 show very little variation in EC values up to September. A slight rise in EC values can be observed following the initial Maha rains in October followed by a slight decline in December.

In Groups 2 and 3, a significant decline is observed up to September/October, followed by a rise in EC values between November and December.

Surprisingly, no clear relationship can be observed between the general trend in the decline of groundwater levels in the dug wells through the dry season and the changes in the EC values of groundwater over the same period. Although one would have expected some degree of increase in the EC values to take place as a consequence of the decline in water tables, no such trend could be picked up from the foregoing figures 15, 16 and 17.

Figure 15. Seasonal changes in electrical conductivity from January to December 2004 – wells with low electrical conductivity.

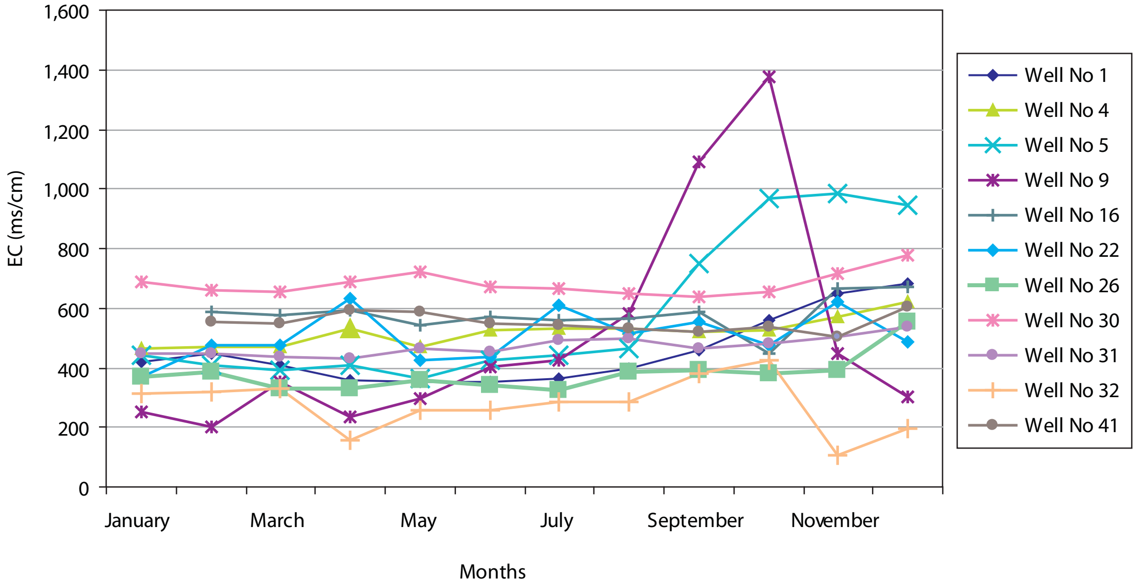


Figure 16. Seasonal changes in electrical conductivity from January to December 2004 – wells with moderate electrical conductivity.

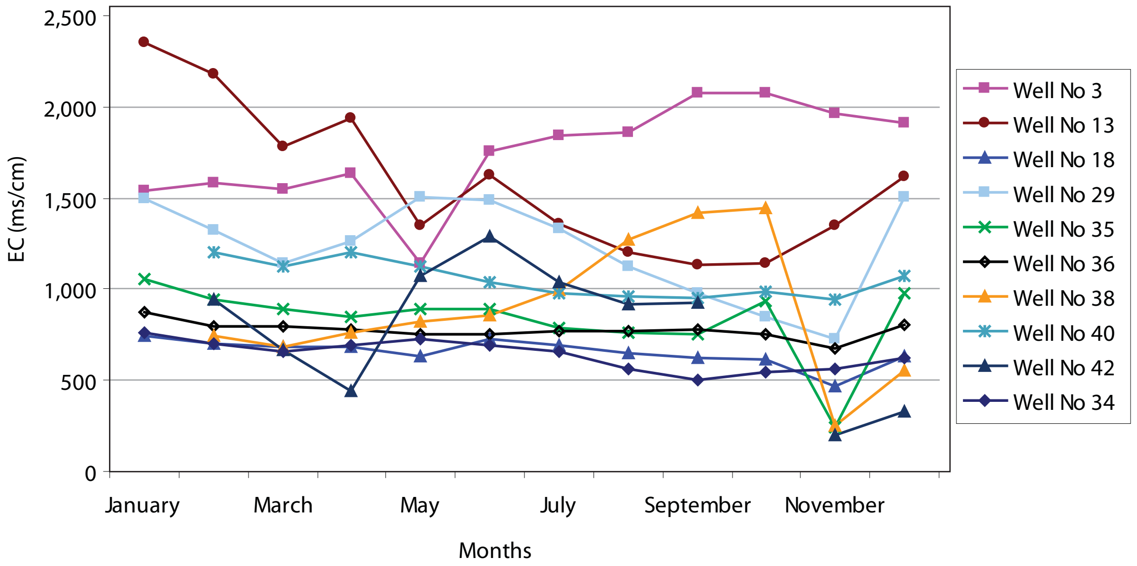
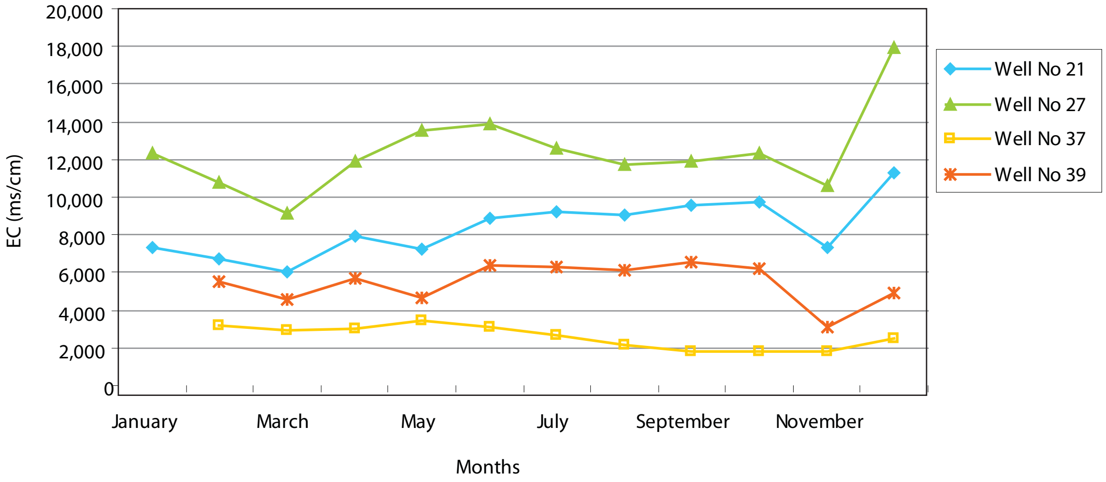


Figure 17. Seasonal changes in electrical conductivity from January to December 2004 – wells with high electrical conductivity.



For the wells located below the trans-basin feeder canal, namely wells numbered 1 and 5 as shown in Figure 15, a significant increase in the EC values could be observed after August as a consequence of the stopping of water issues from the trans-basin feeder canal. This could be considered normal, because the dilution effects caused by seepage from the trans-basin feeder canal would have ceased, following the stoppage of water issues in the trans-basin feeder canal.

Well number 21 as shown in Figure 17, which had a high value of EC 9,760 µs/cm in October dropped to a value of 7,320 µs/cm by November, but then recovered to a value of 11,320 µs/cm by December.

Similarly, well number 27, which had a high value of 12,370 µs/cm in October dropped to a value of 10,580 µs/cm in November, but then recovered to a value of 17,920 µs/cm by December as shown in Figure 17.

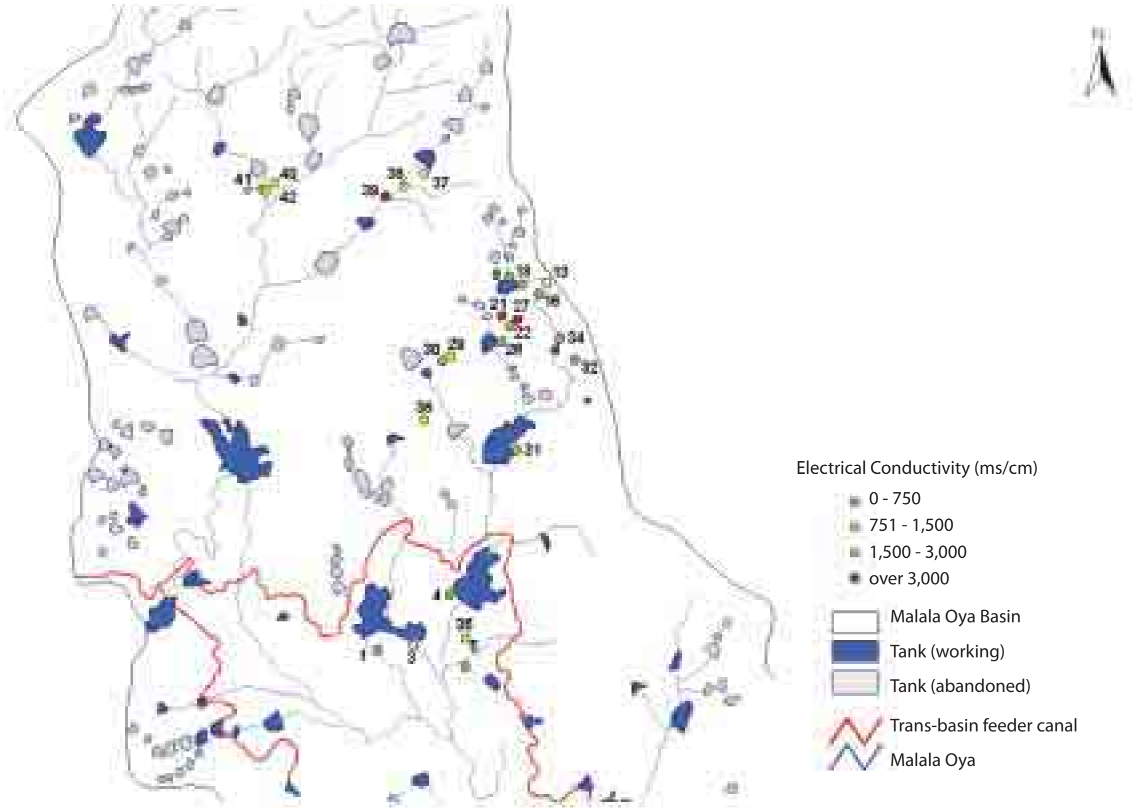
This behavior can be explained by the fact that both these wells numbered 21 and 27 are located very much above the natural drainage system in this landscape, and they also have an inherently high EC value. With the 145 mm of rainfall that was received in early November, a temporary dilution of soluble salts would have taken place, after which the water in the wells recovered to their original high EC status.

A similar phenomenon is also be observed in well number 39 which had an initial EC value of 6,200 µs/cm in October, which declined to a value of 3,070 µs/cm in November and recovered in December.

The moderate rise in the EC values of well number 9 during the period August to December could be attributed to the decline and drying up of the water level in the Bodagama tank, which provides the seepage to this well.

The overall picture of the range in EC values of the 25 monitored dug wells is shown in Figure 18.

Figure 18. Range of EC values of the 25 monitored wells.



As shown in Figure 18, the wells which have a low EC value less than 750 µs/cm are all located in the lower aspects of the landscape almost bordering the natural drainage way. In this location there is sufficient flushing and draining out of any soluble salts.

Similarly, wells which have a moderate EC value between 751 and 1,500 µs/cm are also located in positions where there is good landscape drainage.

In the case of the wells which have a high EC value, these are located in positions where there is either interflow from the adjacent upland, as is the case with wells numbered 21 and 27; while well number 39 is located at the confluence of two drainage valleys where soluble salts tend to accumulate.

Seasonal Change in Total Hardness of Well Waters

Detailed results are shown in Annex 2, Table B2.

The results of the analysis of the total hardness (TH) show that 15 wells numbered 1, 4, 5, 9, 16, 22, 26, 29, 30, 31, 32, 34, 35, 38 and 41 have an average value of total hardness of less than 250 milligrams per liter (mg/l) and a maximum value of less than 400 milligrams per liter in the studied period. These wells showed a slight decline in the values of hardness following the October-November rainfall.

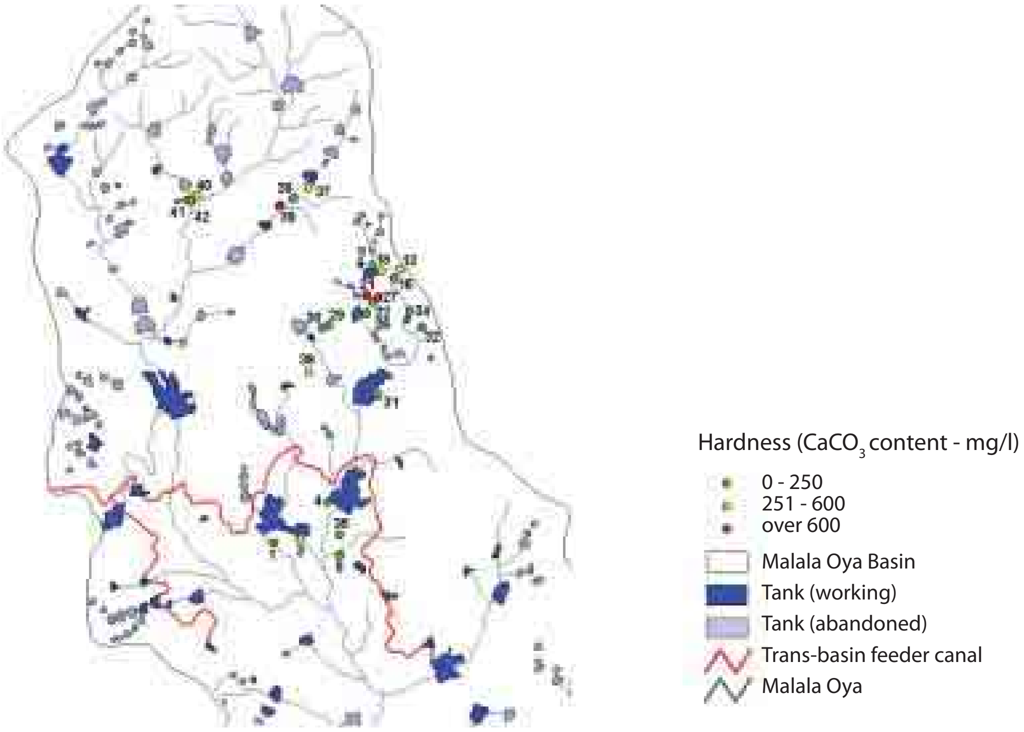
Well number 3, located below the trans-basin feeder canal showed a rise in the value of hardness value after August as a consequence of the interruption of flows in the trans-basin feeder canal, but a decline in the value of hardness was evident following the November rainfall.

The three wells numbered 21, 27 and 39, which had a value of hardness of more than 1,500 mg/l, showed a significant decline in values following the October-November rainfall.

Well numbers 21 and 27 showed only a temporary decline and reverted to their higher values by December, whereas well number 39 showed a continuing decline up to December. This difference in behavior between these wells could again be explained by their relative positions in the landscape.

Figure 19 shows the range of average values in hardness for the 25 monitored wells.

Figure 19. Range in hardness values of the 25 monitored wells.



Seasonal Change in Fluoride and Chloride Contents of Well Waters

Details of the seasonal changes in fluoride content in the well water are given in Annex 2, Table B3.

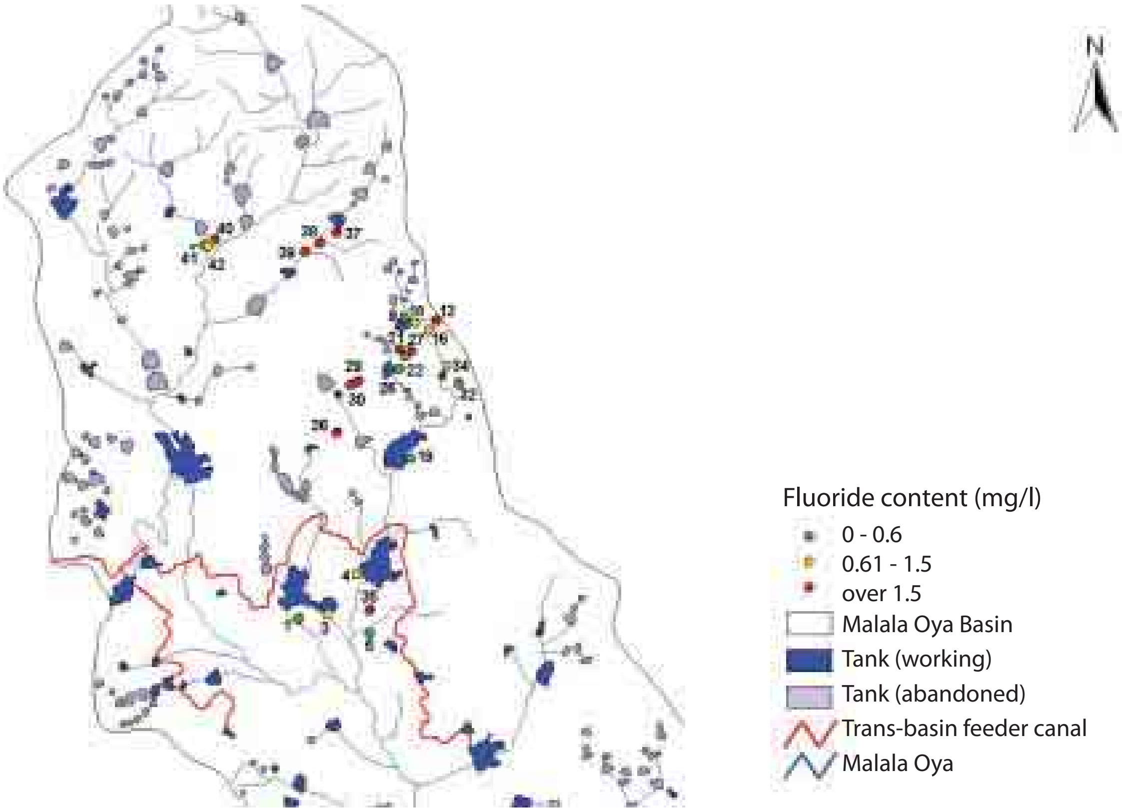
Out of the 25 wells that were sampled every month and analyzed for fluoride content, eight wells numbered 1, 5, 9, 22, 26, 31, 32 and 41 had an average fluoride content less than 0.6 mg/l, which is considered a low level.

Six wells numbered 3, 4, 16, 18, 34 and 42 had an average fluoride content between 0.6 and 1.8 mg/l, which is considered a moderate level.

Eleven wells numbered 13, 21, 27, 29, 30, 35, 36, 37, 38, 39 and 40 had an average fluoride content higher than 1.8 mg/l, which is considered a high level.

The distribution pattern of the location of these three categories of well water is shown in Figure 20. As shown in this figure, wells numbered 13, 21 and 27 are located at interflow sites in the landscape where there is inadequate flushing out of the water table; and hence the high value of fluoride content. It is surprising that well number 35, though located below the trans-basin feeder canal, shows a high value of fluoride content. This, together with wells numbered 37 and 39 appear to have a high fluoride content that is related to the underlying parent rock material of the regolith, namely the biotite gneisse, which are known to cause high fluoride levels in groundwater.

Figure 20. Good, average and bad wells ranked according to the average fluoride content.



Due to the seasonal variation in fluoride content of the 25 wells that were monitored, a very distinctive pattern was observed. Between 26 March and 14 May 2004, over an eight-week period, a total of 203 mm of rainfall was received at Bodagama, and 184 mm at Ranmudu Wewa.

Wells that had a low fluoride content showed a marked decline in fluoride values during this eight-week period; while wells with a medium fluoride content showed a moderate decline in fluoride values.

In sharp contrast, wells that had a high fluoride content showed a marked rise rather than a decline during this same period. This differential behavior between wells of low fluoride and high fluoride content needs further study.

At this stage of the study, it would not be possible to adduce acceptable reasons for the low fluoride content of the eight wells, as well as the moderate level of the six wells; and also the differential behavior between low fluoride and high fluoride wells.

With reference to the chloride content of the 25 wells that were monitored (Annex 2, Table B4) and the monthly analysis of the well water that was carried out, the results are as follows.

Eighteen wells numbered 1, 4, 5, 9, 16, 18, 22, 26, 29, 30, 31, 32, 34, 35, 36, 38, 41 and 42 had a chloride content of less than 200 mg/l, which is considered a low level.

Four wells numbered 3, 13, 37 and 40 had a chloride content between 200 and 1,200 mg/l, which is considered a moderate level.

Three wells numbered 21, 27 and 39 had a chloride content higher than 2,000 mg/l, which is considered a high level.

With reference to the seasonal variation in chloride content, all categories of wells showed a similar pattern to those wells of low and medium fluoride categories.

Seasonal Change in Sulphate (SO_4^{--}) Content of Well Waters

Results of the analysis of the sulphate content in the sampled well waters were available for the period March to December 2004 (detailed results are shown in Annex 2, Table B5).

There was only a very low variation in the sulphate content in all the wells during the period March to September. It was only after September that appreciable variations were observed.

Well numbers 21, 27 and 37 had their higher sulphate values in September; these were 566, 1401 and 281 mg/l, respectively. The same wells had their lowest SO_4 values in November; these values were 348, 1,100 and 189 mg/l, respectively.

Well numbers 3, 13 and 39 had their higher sulphate values in September; these values were 98, 141 and 158mg/l, respectively. These same wells had their lower SO_4 value in November; these were 76, 141 and 98 mg/l, respectively.

All other wells had an SO_4 value of less than 80 mg/l, and they showed very little seasonal variation.

Seasonal Variation in Cations (Na+, Ca++, Mg++ and K^+) Contents of Well Waters

Results of the analysis of all four cations were available for the period January to December 2004 (detailed results are shown in Annex 2, Tables B6, B7, B8 and B9).

Sodium (Na^+)

Adopting the WHO guideline limit of 200 mg/l for sodium in drinking water, all sampled wells, except wells numbered 3, 21, 27, 37 and 39 showed average values less than 200 mg/l. As a consequence of the October-November rainfall of around 189 mm, all these five wells showed a sharp decline in sodium values by November, but started recovering in December.

Well numbers 3 and 13 showed values between 180 and 200 mg/l between August and October.

Calcium (Ca^{++}) and Magnesium (Mg^{++})

All wells, except well numbers 21, 27 and 39 showed calcium and magnesium values that were within the acceptable limits of less than 150 mg/l; and they also showed little seasonal variation.

The above three wells showed values in excess of 150 mg/l for calcium, and values in excess of 250 mg/l for magnesium by the month of November.

The Sodium Absorption Rate (SAR) values were calculated for each of the well waters by making use of the mean values of Ca^{++}, Mg^{++} and Na^+. The results are shown in Table 1.

As shown in Table 1, only well number 37 has a high SAR value of 4.16. It also shows that well numbers 3, 27 and 39 have SAR values in excess of 1.75, which is within the acceptable level (SAR less than 9) of a very small hazard for irrigation quality of water. All other wells have water of a highly acceptable quality for irrigation purposes.

Table 1. *Sodium Absorption Ratio (SAR) values for selected wells.*

Well No.	SAR Value	Well No.	SAR Value
1	0.23	29	0.85
3	2.08	30	0.27
4	0.19	31	0.15
5	0.28	32	0.14
9	0.22	34	0.21
13	0.81	35	0.49
16	0.29	36	0.15
18	0.12	37	4.16
21	0.43	38	0.43
22	0.29	39	1.79
26	0.20	40	0.51
27	1.80	41	0.11
		42	0.42

RESULTS OF PUMPING TESTS

As a part of the study to understand the basic parameters of the aquifer, seven pumping tests were carried out within the study area. These are constant discharge tests. Although the pumping rate should be controlled depending on the properties of the well, the pump that was used in this field study could not be adjusted to the necessary rate. A summary of the results of the pumping tests is given below (Table 2):

Table 2. Results of pumping tests.

Well No.	Well diameter (m)	Water level before pumping (m)	Pumping rate (l/min)	Transmissivity m^3/day m
1	2.0	2.0	260	1.31
3	2.5	1.4	260	1.45
18	1.5	1.1	260	2.31
27	1.3	3.5	260	2.36
30	1.65	1.5	390	0.84
38	1.0	1.4	150	1.72
40	1.0	4.3	160	1.42

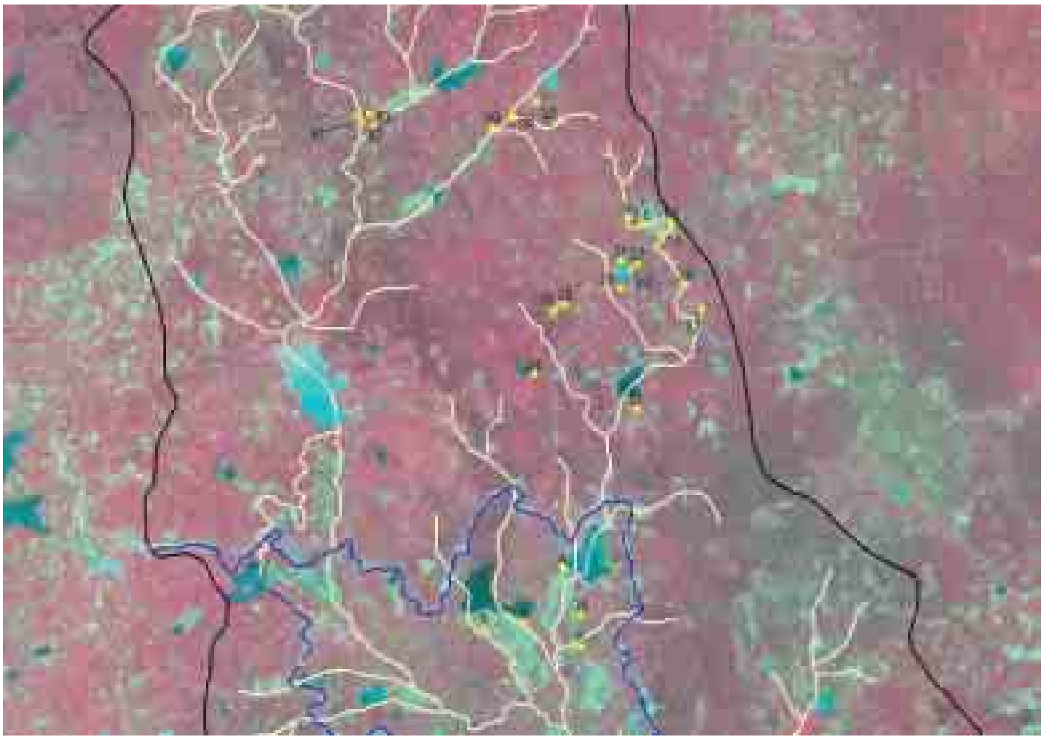
The wide range in the values obtained, reflects the non-uniformity of the regolith aquifer in this study area. It also shows that because of the low hydraulic conductivity of the underlying weathered rock material, it is not possible to abstract groundwater continuously at a higher rate of pumping.

ANALYSIS OF RESULTS AND CONCLUSIONS

Mode of Occurrence and Depletion of Regolith Aquifer

As shown in Figure 21 the dug wells were mostly located within the drainage axis of the second or third order drainage ways that made up the drainage network of each cascade or sub-watershed. A map that was prepared earlier in1993 (October-December, unpublished) by Stephan Pfister, while serving an internship with IWMI, shows all existing dug wells present within the study area. That map shows that all presently existing dug wells are located within the lower aspect of each drainage valley.

Figure 21. Location of dug wells along drainage map



The foregoing observations confirm the fact that the regolith aquifer in this hard rock terrain of the Malala Oya Basin is mainly situated within the narrow inland valleys that dissect this landscape. Its mode of occurrence is in the form of a shallow phreatic water table which gets steadily depleted to some degree during the dry season from May to September, and then gets quickly recharged with the ensuing rains of the wet Maha season. Its degree of depletion is related to the duration and intensity of dryness during the period May to September. A smaller decline can be observed during the intervening short dry season of February to March.

Long time settlers of this area report that in some years the dry season could be longer and more protracted, and in such years the regolith aquifer gets depleted to a greater depth than recorded during the year 2004, which according to them was a “better than normal” year, where more than 150 mm of rainfall was received during the March-April-May period.

As shown in the results, the main depletion in groundwater levels takes place from mid-May onwards, and a depletion of groundwater between a range of 3.0 m.b.g.l. to 6.0 m.b.g.l. takes place over a 23-week period up to October.

It was also shown that the groundwater levels in the dug wells located below the trans-basin feeder canal were maintained at an acceptable level because of the intermittent flows that take place in the trans-basin feeder canal during the dry months of July, August and September.

This observation has important implications with regard to the contribution of the trans-basin feeder canal in recharging the regolith aquifer over the normal dry season. Because of the trans-basin feeder canal flows, the groundwater in the seepage zone of the canal could be held at a minimum threshold level, which would enable a higher density of human settlement taking place in areas benefiting from this seepage zone. This is especially significant for this arid climatic environment, which has a very low human carrying capacity at present.

It was also shown that the sequential pattern of depletion was not uniform over the period April to October in the 20 dug wells located above the trans-basin feeder canal. This could be related to the nature of the underlying regolith which has a low but highly variable hydraulic conductivity.

It was also shown that the depth to depletion increases with the macro-elevation of the landscape. The six wells numbered 37, 38, 39, 40, 41 and 42, which were located in the higher elevations of this study area, on the upper portions of the main watershed of the Malala Oya, had a depth to depletion between 6 to 8 m as compared with 3 to 4 m in the lower elevation.

Mode of Replenishment of the Regolith Aquifer

It was observed that it was only after a cumulative rainfall of 100 mm had been received that the groundwater levels begin to show an initial response; and that it was only after a rainfall of 170 mm had been received that a rise in groundwater levels takes place.

The fact that a rainfall of around 170 mm is needed to saturate the soil overburden is in accord with the value of the available moisture holding capacity of the soil profile, which is around 100 mm per 1.0 meter depth of soil for the reddish brown earth soils of this area.

It was also observed that by the end of November, or by the first week of December, a majority of the wells had reached this maximum groundwater level, except well numbers 13, 21, 29 and 36, which show a slower rate of replenishment and reach their maximum level only by the last week of December. This is due to the fact that all these four wells are situated away from the main drainage way and are also closer to the upper aspect of the micro-catchment in which they are located; and it therefore takes a longer duration of time to complete their recharge.

In sum, it could be stated that the mode of replenishment is very similar in relation to the macrotopography and relief, but that slight variations can be observed in relation to the difference in the micro-topography of the relief.

Nature of Seasonal Changes in Electrical Conductivity

Three broad categories or groupings of electrical conductivity (EC) were identified, namely 0-750 µs/cm, 751-1,500 µs/cm, and 1,501-3,000 µs/cm; and two wells 21 and 27 which had an EC value in excess of 8,000 µs/cm.

The change in EC value is very small in the wells in the first group, but there is a trend for this to increase with the initial Maha rains. The reason seems to be that the salts concentrated in the soil profile during the dry season get dissolved with the early rains and lead down to the water table, and this causes the initial small rise in the EC value. With the subsequent heavy rainfall of November-December, dilution takes place and the EC values are reduced.

Surprisingly, despite a decline in groundwater levels through the dry season (May-September), no corresponding change in the EC value could be observed. Although one would have expected some degree of increase in EC values with the decline in the levels of the water table, no such trend was observed. It could, therefore, be inferred that the underlying regolith aquifer, which feeds these wells, has adequate capacity to recover in order to maintain the quality of the water in the dug well over the six-month dry period.

Although well number 3 is located below the trans-basin feeder canal, together with well numbers 1, 4 and 5, it has an average EC value of 1,745 (Annex 2, Table B1) compared with average values less than 600 for well numbers 1, 4 and 5. This well number 3 has an underlying pan under the surface and salts have got accumulated over the last hundreds of years. This is now getting gradually flushed out with the seepage coming from the trans-basin feeder canal.

The reason for the high average EC value of 8,362 ìs/cm for well number 21 is due to the fact that it is located along the break of slope in the landscape, which means that salt accumulation takes place slowly over the years.

Well number 27 has the highest average EC value of around 12,300 ìs/cm. It is located besides a rocky hill in this area and gets its groundwater from the weathered fresh rock which has a lot of soluble salts.

As mentioned earlier, all wells located along the natural drainage ways have a low EC value because there is sufficient flushing out taking place of any soluble salts draining into the lower aspects of the landscape.

Nature of Seasonal Changes in Fluoride and Chloride Content

All eight wells numbered 1, 5, 9, 22, 26, 31, 32 and 41, which have a low fluoride content of less than 0.6 mg/l, are found to be located in special positions in the landscape where the drainage is very good and also the flushing out of the groundwater is good.

Well numbers 13, 21 and 27, which have a very high fluoride content of more than 5.0 mg/l, are all located at interflow sites in the landscape where there is inadequate flushing out of the water table.

The six well numbers 3, 4, 16, 18, 34 and 42, which have a moderate fluoride content between 0.6 and 1.8 mg/l, are all located in positions which are close to the axis of the main drainage system, where there is a moderate sufficiency of drainage and flushing out.

During the eight-week period between 26 March and 14 May 2004 when a total of 200 mm of rainfall was experienced, the wells with a low to moderate content of fluoride showed a significant decline in response to the rainfall, whereas the wells with a high content of fluoride showed a rise rather than a decline. At this stage, it is not possible to explain this phenomenon.

Both the chloride content as well as the seasonal trends in the chloride content of the 25 wells follow the same pattern as that of the fluoride values. Three well numbers 21, 27 and 29 had a chloride content higher than 2,000 mg/l.

Nature of Seasonal Changes in Sulphate and Cation Content of Well Waters

Sulphate

As expected, well numbers 21, 27 and 37 showed the highest sulphate values, followed by well numbers 3, 13 and 39, which were slightly lower in value. As seen earlier, all these six wells are in locations where there is inadequate flushing out of the groundwater.

All other wells had a SO_4 value less than 80 mg/l and also a very low seasonal variation. It is therefore suggested that the sulphate value of well water be used as a robust and reliable indicator to characterize the quality of well water.

Cation Contents

Since the sodium content of water could be used as a comparatively sensitive index of water quality, and by adopting the WHO guidelines in this instance, all wells except well numbers 3, 21, 27, 37 and 39 could be considered to fall within the suitable category for drinking water.

With reference to the calcium and magnesium content, all wells except well numbers 21, 27 and 39 fall within the acceptable limits.

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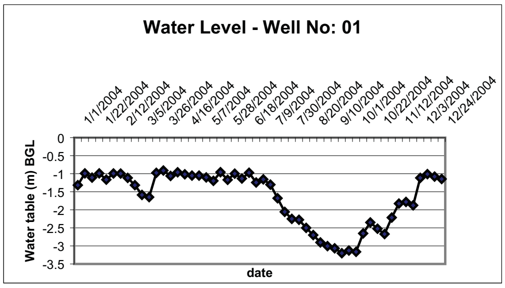
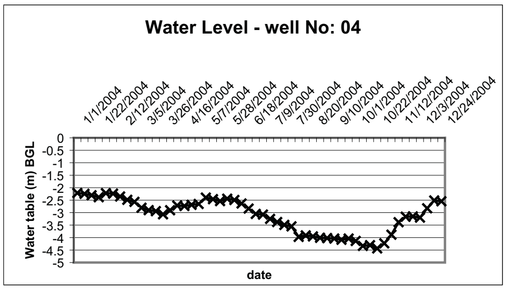
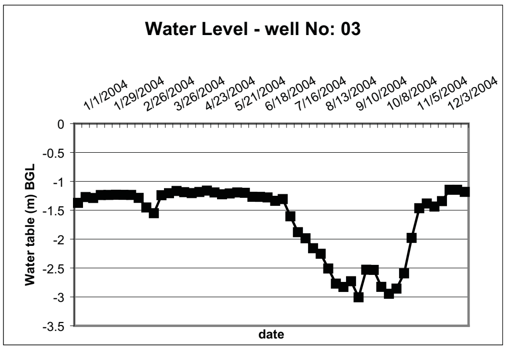
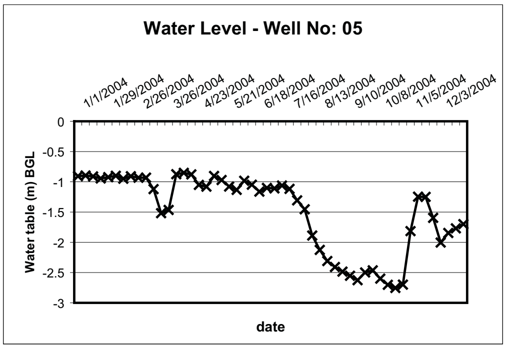
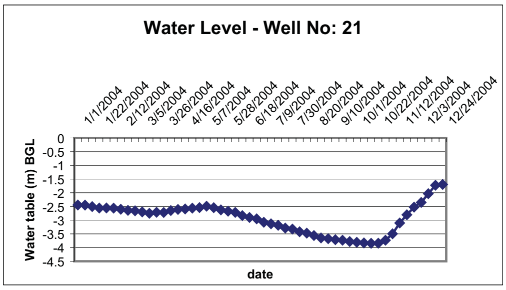
Annex 1. Water table behavior of sample wells.

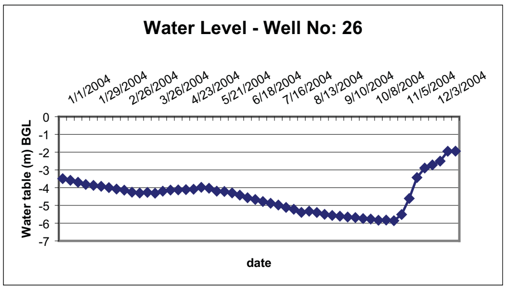


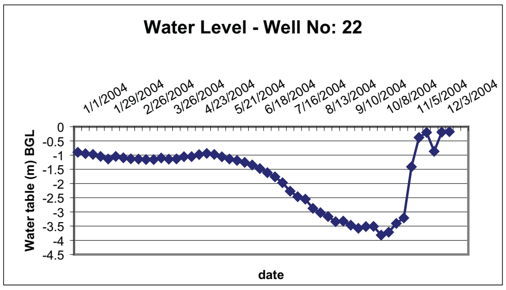


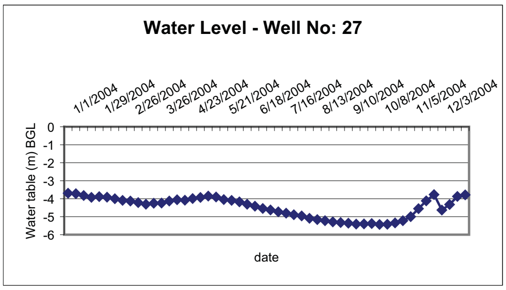


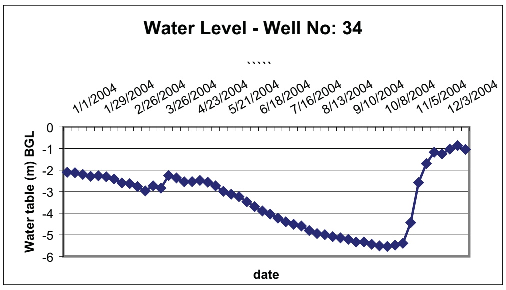


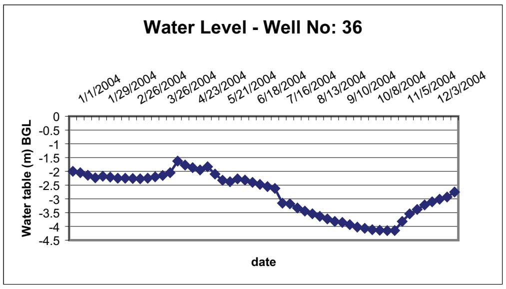












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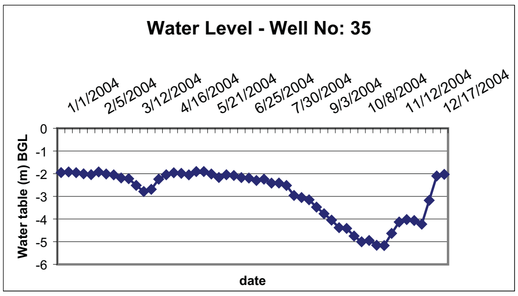
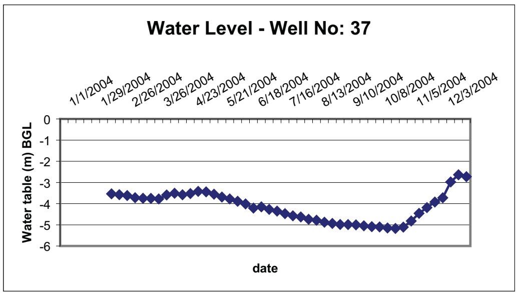
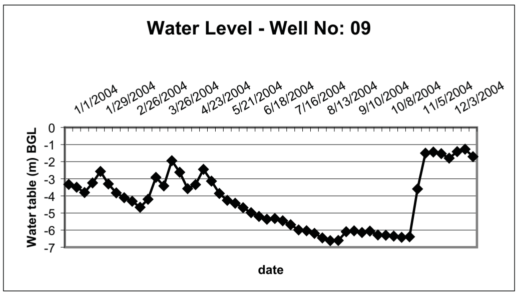
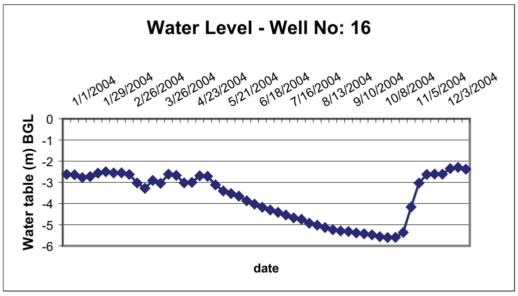
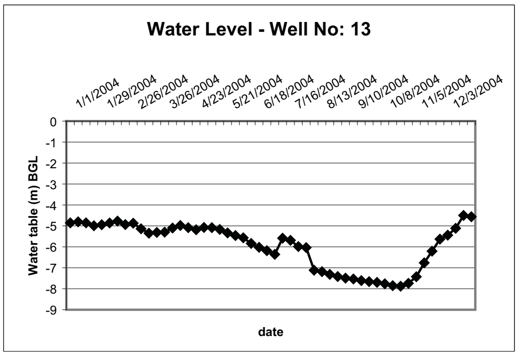
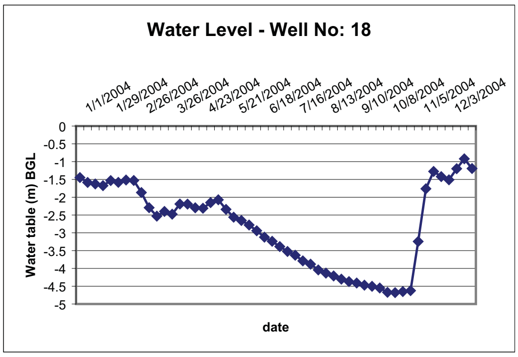


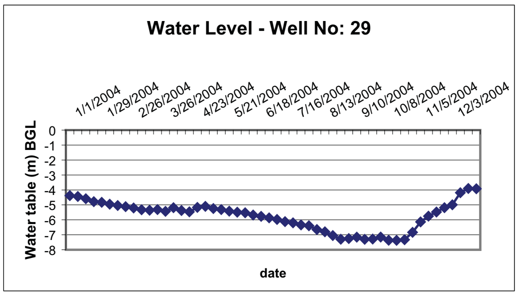


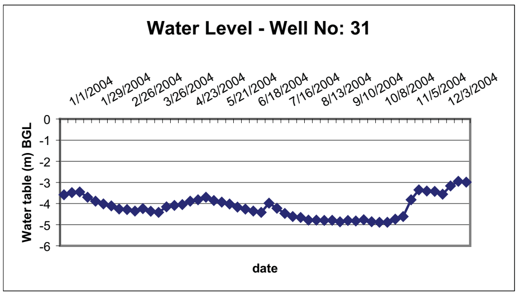


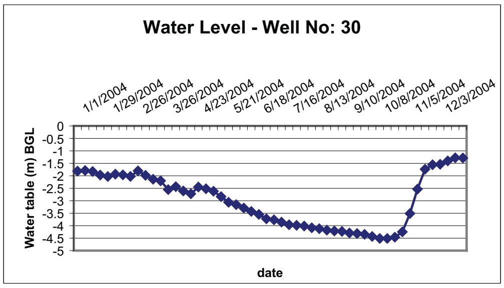


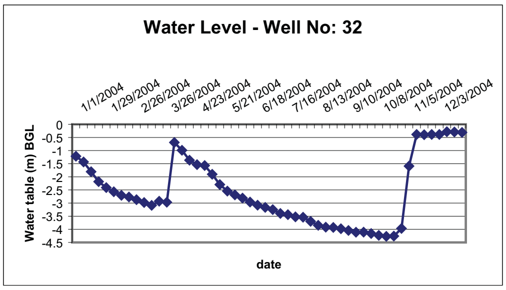




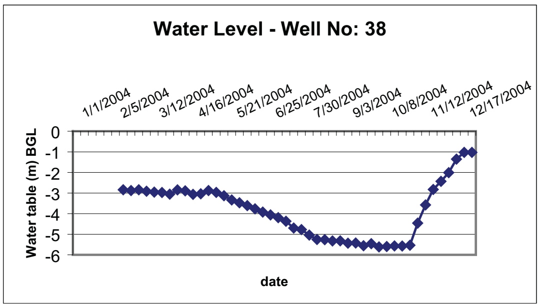


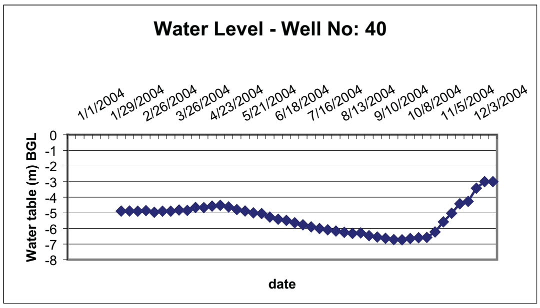


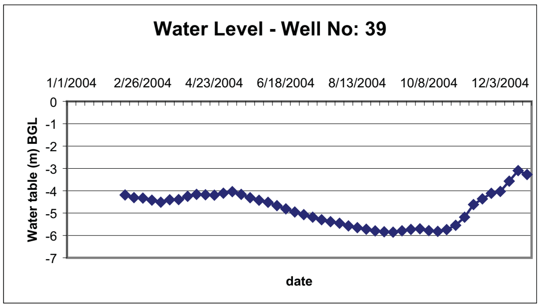


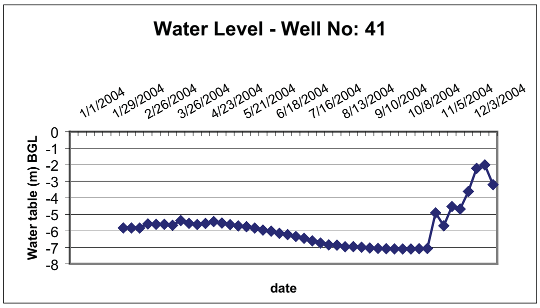


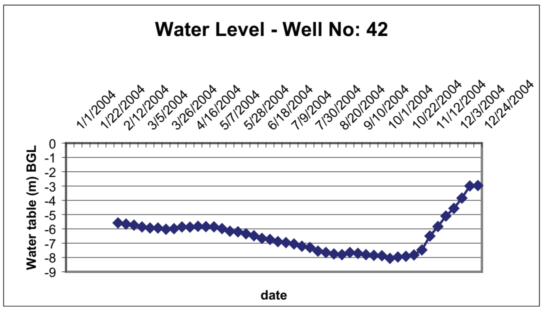
Annex 1. Continued.











Annex 2. Chemical properties of water in sample wells.

Table B1. Electrical Conductivity (μs).

Well number	January	February	March	April	May	June	July	August	September	October	November	December	Average
Well No 1	417	448	409	360	355	350	366	399	459	558	648	682	454
Well No 3	1,537	1,584	1,550	1,632	1,139	1,755	1,841	1,862	2,080	2,080	1,965	1,913	1,745
Well No 4	464	470	470	534	472	526	533	532	522	524	573	622	520
Well No 5	442	406	390	410	365	427	444	462	752	968	985	948	583
Well No 9	249	200	353	233	297	402	425	583	1,089	1,378	445	302	496
Well No 13	2,350	2,180	1,784	1,940	1,346	1,628	1,354	1,206	1,131	1,145	1,350	1,615	1,586
Well No 16	NA	587	574	592	541	570	562	563	589	445	667	669	578
Well No 18	746	705	684	687	632	725	692	645	626	615	470	633	655
Well No 21	7,350	6,710	6,000	7,900	7,280	8,870	9,240	9,040	9,560	9,760	7,320	11,310	8,362
Well No 22	367	475	478	630	424	436	608	515	553	476	622	484	506
Well No 26	370	387	330	330	359	344	325	387	389	379	390	556	379
Well No 27	12,370	10,810	9,100	11,920	13,530	13,870	12,570	11,720	11,870	12,370	10,580	17,920	12,386
Well No 29	1,497	1,322	1,146	1,266	1,509	1,488	1,329	1,123	981	850	725	1,502	1,228
Well No 30	688	660	656	687	720	674	666	649	636	652	715	778	682
Well No 31	448	446	435	433	466	455	491	497	464	479	505	538	471
Well No 32	316	319	332	156	258	256	283	286	383	425	108	195	276
Well No 34	764	705	658	691	724	691	658	566	504	545	563	622	641
Well No 35	1,056	943	895	850	888	892	787	759	754	932	238	979	831
Well No 36	873	799	797	776	754	753	771	769	780	750	672	803	775
Well No 37	NA	3,150	2,960	2,990	3,490	3,100	2,680	2,150	1,806	1,792	1,774	2,460	2,577
Well No 38	NA	747	683	762	823	860	998	1269	1423	1447	252	552	892
Well No 39	NA	5,510	4,600	5,720	4,660	6,400	6,310	6,100	6,580	6,200	3,070	4,930	5,462
Well No 40	NA	1,200	1,128	1,205	1,124	1,042	975	962	949	986	945	1,076	1,054
Well No 41	NA	555	551	593	585	548	540	533	520	538	506	606	552
Well No 42	NA	947	668	440	1,071	1,290	1,037	920	925	NA	195	325	782

Note: NA = Not Available

Annex 2. Continued.

Table B2. Total Hardness - mg/l as CaCO3.

Well number	January	February	March	April	May	June	July	August	September	October	November	December	Average
Well No 1	NA	NA	184	108	118.6	127	137	137.2	132	174	156	197	147
Well No 3	NA	NA	368	346	273.9	292	392	303.8	555	575	567	506	418
Well No 4	NA	NA	239	191	209.9	209	235	225.4	191	198	208	219	213
Well No 5	NA	NA	128	112	118.6	137	127	147	184	220	210	228	161
Well No 9	NA	NA	147	134	127.8	173	176	176.4	246	253	137	101	167
Well No 13	NA	NA	460	459	547	328	882	646.8	225	218	222	249	424
Well No 16	NA	NA	221	206	191.7	246	235	186.2	175	129	212	212	201
Well No 18	NA	NA	322	296	292	301	352	303.8	211	210	142	204	263
Well No 21	NA	NA	2,210	2,329	1,734	2,191	2,548	2,254	2,117	2,252	1,727	2,593	2196
Well No 22	NA	NA	174	234	136.9	146	186.2	196	187	168	182	168	178
Well No 26	NA	NA	147	147	120.3	155	137.2	147	133	122	130	159	140
Well No 27	NA	NA	1,101	2,142	2,142	2,191	2,548	2,450	2,566	2,757	2,382	2,745	2302
Well No 29	NA	NA	183.6	235	252	182	225	205.8	214	173	157	222	205
Well No 30	NA	NA	211	208	211	219	186	156.8	172	179	198	201	194
Well No 31	NA	NA	221	241	160	228	127	137.2	155	146	165	187	177
Well No 32	NA	NA	174	61	56.5	109	77.8	88.2	125	120	49	80.2	94
Well No 34	NA	NA	294	323	226	328	223	235.2	194	221	217	211	247
Well No 35	NA	NA	128	156	199	109	204	205.8	183	228	58	245	172
Well No 36	NA	NA	396	373	368	365	294	245	214	236	227	216	293
Well No 37	NA	NA	183.6	219	315	274	316	274	249	225	231	400	269
Well No 38	NA	NA	202	223	221	219	265.7	245	237	240	74	138	206
Well No 39	NA	NA	2,302	2,125	1,762	2,191	1,782	1,666	1,661	1,491	980	1,050	1701
Well No 40	NA	NA	460	576	510	255	395.8	343	344	343	327	333	389
Well No 41	NA	NA	239	333	276	264	264	254.8	182	204	172	201	239
Well No 42	NA	NA	147	107	448	273	391.8	349.2	314	NA	39	81	239

Note: NA = Not Available

Annex 2. Continued.

Table B3. Fluoride (F^-) Content (mg/l).

Well number	January	February	March	April	May	June	July	August	September	October	November	December	Average
Well No 1	0.5	0.5	0.5	0.5	0.1	0.9	0.5	0.6	0.5	0.5	0.6	0.4	0.5
Well No 3	1.3	1.5	1.2	1.1	1.2	1.7	1.8	1.4	1.4	1.2	1.1	1.3	1.3
Well No 4	1.3	1.5	1.5	1.4	1.2	1.3	1.4	1.8	1.5	1.8	1.6	1.7	1.5
Well No 5	0.3	0.5	0.4	0.5	0.6	0.6	0.4	0.7	0.4	0.7	0.6	0.4	0.5
Well No 9	0.5	0.3	0.4	0.4	0.1	0.4	0.5	0.7	0.3	0.6	0.3	0.5	0.4
Well No 13	2.3	2.2	2.2	2.2	2.9	3.6	3.0	3.8	4.0	4.0	3.5	3.9	3.1
Well No 16	0.2	0.9	0.8	0.9	0.4	0.5	0.7	0.8	0.7	0.6	0.5	0.5	0.6
Well No 18	0.7	0.9	0.9	0.8	0.4	1.0	1.0	1.4	0.9	0.7	0.6	0.8	0.8
Well No 21	2.3	2.2	2.2	2.2	4.2	5.2	4.2	5.2	6.5	5.3	5.1	6.1	4.2
Well No 22	0.3	0.4	0.4	0.5	0.0	0.4	0.4	0.3	0.6	0.4	0.3	0.5	0.4
Well No 26	0.4	0.5	0.5	0.4	0.2	0.4	0.5	0.5	0.3	0.3	0.3	0.4	0.4
Well No 27	2.3	2.2	2.2	2.2	4.6	5.6	6.8	6.0	5.0	5.1	5.0	5.0	4.3
Well No 29	2.3	2.2	2.2	2.2	2.1	3.0	1.5	1.7	1.7	1.8	1.7	1.6	2.0
Well No 30	2.1	2.2	2.2	2.2	1.4	1.5	1.4	1.0	1.4	1.2	1.0	1.3	1.6
Well No 31	0.4	0.6	0.4	0.5	0.5	0.5	0.1	0.1	0.5	0.6	0.4	0.5	0.4
Well No 32	0.5	0.6	0.6	0.5	0.0	0.1	0.3	0.5	0.4	0.5	0.3	0.4	0.4
Well No 34	1.4	1.1	1.1	1.2	0.6	1.0	1.3	1.5	1.1	1.1	1.0	1.0	1.1
Well No 35	2.3	2.2	2.2	2.2	0.9	4.5	6.4	6.8	4.5	3.5	0.3	4.2	3.3
Well No 36	1.9	1.5	1.5	1.4	0.9	1.4	2.1	2.0	1.4	1.6	1.4	1.5	1.6
Well No 37		2.2	2.2	2.2	6.3	8.0	11.5	9.0	8.0	8.5	8.1	8.3	6.8
Well No 38		0.7	0.6	0.5	0.7	0.9	1.0	1.0	6.5	6.0	5.0	6.2	2.6
Well No 39		2.2	2.2	2.2	2.6	5.6	4.4	4.0	3.5	3.5	3.0	3.7	3.4
Well No 40		2.1	2.0	2.0	1.7	2.4	1.8	2.0	2.0	1.6	1.4	1.8	1.9
Well No 41		0.5	0.5	0.6	0.3	0.4	0.7	0.9	0.7	0.5	0.3	0.6	0.5
Well No 42		1.0	0.9	0.8	0.5	1.4	1.2	1.3	1.8		1.5	1.7	1.2

Note: NA = Not Available

Annex 2. Continued.

Table B4. Chloride (Cl $^-$) Content (mg/l).

Well number	January	February	March	April	May	June	July	August	September	October	November	December
Well No 1	NA	24	23	24	18	20	23	23	29	32	30	35
Well No 3	NA	544	275	321	238	346	367	275	253	241	237	213
Well No 4	NA	36	32	36	18	25	41	37	29	39	25	27
Well No 5	NA	36	41	32	28	20	28	32	46	52	58	43
Well No 9	NA	30	32	23	14	25	23	23	61	88	45	29
Well No 13	NA	73	321	363	275	198	275	147	128	148	118	139
Well No 16	NA	24	28	24	14	15	18	23	31	24	20	23
Well No 18	NA	42	28	30	23	25	37	41	35	38	20	31
Well No 21	NA	5,203	2,616	3,250	2,340	4,009	4,635	4,222	4,521	4,601	2,524	4,801
Well No 22	NA	30	37	41	32	20	28	18	21	29	25	26
Well No 26	NA	24	23	24	14	15	23	41	38	31	15	19
Well No 27	NA	6,473	4,085	7,263	8,262	4,578	5,140	4,727	5,216	5,940	2,970	3,403
Well No 29	NA	121	138	132	115	40	160	174	153	41	50	101
Well No 30	NA	30	28	32	28	20	28	32	29	31	35	43
Well No 31	NA	24	18	23	23	15	23	18	16	21	25	32
Well No 32	NA	30	28	11	18	10	18	14	18	35	5	11
Well No 34	NA	24	32	37	41	15	28	18	28	44	20	58
Well No 35	NA	24	37	32	46	20	32	46	41	53	10	61
Well No 36	NA	24	28	24	28	15	23	23	36	39	30	53
Well No 37	NA	847	459	363	367	396	367	344	292	254	208	256
Well No 38	NA	72	69	73	87	54	55	83	148	128	15	36
Well No 39	NA	3,751	2,249	2,800	1,927	1,831	1,377	1,744	1,703	1,903	940	971
Well No 40	NA	363	183	202	3	69	96	92	62	63	45	75
Well No 41	NA	18	37	41	55	15	23	37	23	43	30	41
Well No 42	NA	18	23	18	83	20	28	46	41		5	28

Note: NA = Not Available

Annex 2. Continued.

Table B5. Sulphate (So_4^{2-}) Content (mg/l).

Well number	January	February	March	April	May	June	July	August	September	October	November	December
Well No 1	NA		4	5	8	4	4	7	11	15	18	18
Well No 3	NA		84	95	81	89	101	95	98	81	76	72
Well No 4	NA		5	9	14	6	10	12	13	18	19	20
Well No 5	NA		8	9	7	9	9	11	21	34	32	36
Well No 9	NA		11	8	12	19	18	24	31	42	15	11
Well No 13	NA		190	198	134	155	172	160	141	138	141	154
Well No 16	NA		7	13	15	21	28	30	21	12	15	13
Well No 18	NA		5	6	6	7	9	8	11	23	20	29
Well No 21	NA		530	563	490	575	493	512	566	523	348	590
Well No 22	NA		25	35	20	27	32	35	29	33	39	24
Well No 26	NA		3	4	9	6	7	9	10	15	15	21
Well No 27	NA		1,310	1,600	1,710	1,675	1,470	1,320	1,401	1,453	1,100	1,254
Well No 29	NA		39	44	38	54	32	43	39	31	48	55
Well No 30	NA		20	23	24	30	27	31	29	30	36	31
Well No 31	NA		6	7	8	6	7	8	10	15	16	15
Well No 32	NA		3	2	11	6	8	9	9	12	8	12
Well No 34	NA		1	9	9	6	11	12	13	21	18	34
Well No 35	NA		16	19	22	21	34	42	37	45	13	43
Well No 36	NA		22	25	20	27	30	36	31	26	24	32
Well No 37	NA		259	275	302	326	372	408	281	210	189	228
Well No 38	NA		11	13	15	29	42	46	64	69	13	23
Well No 39	NA		111	135	136	145	104	94	158	138	98	118
Well No 40	NA		44	52	48	44	36	43	39	43	49	52
Well No 41	NA		10	14	17	21	16	20	24	32	28	31
Well No 42	NA		19	24	30	25	16	17	31		9	12

Note: *NA = Not Available*

Annex 2. Continued.

Table B6. Sodium (Na^+) Content (mg/l).

Well number	January	February	March	April	May	June	July	August	September	October	November	December	Average
Well No 1	NA	27	24	20	17	19	44	25	20	10	40	14	24
Well No 3	NA	350	65	85	260	332	520	29	23	220	200	195	207
Well No 4	NA	20	19	25	13	16	20	22	20	25	28	28	21
Well No 5	NA	40	40	32	44	36	40	40	65	110	90	112	59
Well No 9	NA	17	27	23	17	16	24	54	125	50	32	26	37
Well No 13	NA	170	308	330	325	250	150	195	155	180	180	188	221
Well No 16	NA	34	34	39	85	30	32	32	28	35	45	39	39
Well No 18	NA	18	17	24	16	16	10	4	5	5	18	10	13
Well No 21	NA	150	224	382	480	1200	700	53	1500	1050	680	1,245	697
Well No 22	NA	34	34	42	34	26	44	28	30	35	38	40	35
Well No 26	NA	18	14	15	13	5	14	15	6	5	18	12	12
Well No 27	NA	750	930	1,011	1,280	1,340	2,000	1,500	2,300	2,000	1,500	1,806	1492
Well No 29	NA	130	180	168	400	292	240	175	115	140	100	198	194
Well No 30	NA	75	65	68	90	56	55	35	48	55	66	61	61
Well No 31	NA	14	10	12	17	8	10	7	8	5	23	8	11
Well No 32	NA	17	20	5	11	6	10	6	12	20	4	9	11
Well No 34	NA	29	18	24	5	24	24	14	5	5	23	10	16
Well No 35	NA	95	140	129	90	150	135	124	130	170	32	181	125
Well No 36	NA	29	18	25	73	20	28	35	15	10	23	15	26
Well No 37	NA	725	340	298	320	704	450	500	275	340	280	363	418
Well No 38	NA	80	65	75	100	90	50	105	210	240	26	44	99
Well No 39	NA	750	650	662	320	800	720	900	510	600	250	318	589
Well No 40	NA	113	105	100	146	130	450	165	85	100	80	123	145
Well No 41	NA	18	23	24	30	12	24	28	13	10	23	15	20
Well No 42	NA	90	105	98	160	218	200	132	122		7	16	115

Note: NA = Not Available

Annex 2. Continued.

Table B7. Calcium (Ca^{++}) content (mg/l).

Well number	January	February	March	April	May	June	July	August	September	October	November	December
Well No 1	NA	36	48	39	26	36	31	35	36	46	42	48
Well No 3	NA	74	37	45	37	36	78	67	135	146	144	135
Well No 4	NA	22	55	40	18	55	392	47	46	40	41	41
Well No 5	NA	44	44	35	29	29	24	27	35	41	40	45
Well No 9	NA	11	16	17	22	22	12	16	28	43	47	30
Well No 13	NA	110	111	103	37	58	274	204	39	46	49	46
Well No 16	NA	29	29	33	15	26	43	47	42	31	50	52
Well No 18	NA	44	59	52	11	18	82	94	54	51	33	41
Well No 21	NA	166	147	239	255	146	156	149	154	172	151	198
Well No 22	NA	41	44	56	27	26	55	55	48	37	41	41
Well No 26	NA	15	41	38	37	33	35	39	28	20	22	28
Well No 27	NA	332	92	352	380	182	196	149	164	173	158	201
Well No 29	NA	55	55	63	60	14	47	51	45	39	36	42
Well No 30	NA	41	22	26	22	36	24	27	22	29	33	31
Well No 31	NA	11	37	33	23	33	20	12	15	19	22	24
Well No 32	NA	37	37	12	11	26	12	8	10	15	12	18
Well No 34	NA	52	48	53	53	33	47	51	43	45	45	48
Well No 35	NA	92	29	33	45	22	47	51	48	53	16	55
Well No 36	NA	103	37	35	37	18	35	39	42	48	47	46
Well No 37	NA	37	38	43	52	14	47	47	34	39	39	56
Well No 38	NA	70	33	37	37	14	43	39	32	37	24	38
Well No 39	NA	331	89	327	290	292	310	275	265	23	196	185
Well No 40	NA	92	147	89	80	29	78	82	74	70	73	78
Well No 41	NA	77	26	80	52	14	43	47	33	39	32	40
Well No 42	NA	103	33	29	79	14	67	59	51		8	22

Note: NA = Not Available

Annex 2. Continued.

Table B8. Magnesium (Mg^{++}) content (mg/l).

Well number	January	February	March	April	May	June	July	August	September	October	November	December
Well No 1	NA	16	16	10	13	9	14	12	10	15	13	19
Well No 3	NA	34	67	57	44	49	48	33	53	51	50	41
Well No 4	NA	20	25	22	40	17	33	26	18	24	26	28
Well No 5	NA	31	4	6	11	16	17	19	23	29	27	29
Well No 9	NA	11	33	22	18	29	36	33	43	35	5	6
Well No 13	NA	56	45	49	111	44	48	33	31	26	24	33
Well No 16	NA	20	36	30	38	44	31	17	18	12	21	20
Well No 18	NA	31	42	40	64	62	36	16	19	20	14	25
Well No 21	NA	302	447	421	265	443	523	457	421	443	328	510
Well No 22	NA	9	16	23	11	20	12	14	16	18	19	16
Well No 26	NA	13	11	13	7	18	12	12	15	18	18	22
Well No 27	NA	324	229	307	290	421	499	504	524	565	483	545
Well No 29	NA	34	11	19	25	35	26	19	25	18	16	28
Well No 30	NA	245	38	35	38	31	31	21	29	26	28	30
Well No 31	NA	20	31	38	25	35	19	26	29	24	27	31
Well No 32	NA	20	20	7	7	11	12	17	25	20	5	8
Well No 34	NA	20	42	46	23	60	26	26	21	26	26	22
Well No 35	NA	51	13	18	21	13	21	19	15	23	5	26
Well No 36	NA	31	74	70	68	78	50	36	26	28	27	25
Well No 37	NA	78	22	27	45	58	48	38	40	31	32	63
Well No 38	NA	59	29	32	31	44	38	36	39	36	5	10
Well No 39	NA	335	469	318	252	355	245	238	243	244	111	143
Well No 40	NA	89	24	86	75	44	49	34	39	41	35	39
Well No 41	NA	25	42	33	36	55	38	33	24	26	23	25
Well No 42	NA	72	16	9	61	58	55	49	45		5	6

Note: NA = Not Available

Annex 2. Continued.

Table B9. Potassium (K^+) content (mg/l).

Well number	January	February	March	April	May	June	July	August	September	October	November	December
Well No 1	NA	3.4	6.6	4.2	7.0	0.6	0.4	0.5	4.8	2.0	5.2	1.6
Well No 3	NA	3.0	5.0	15.3	3.5	7.0	10.0	5.6	1.0	6.0	6.0	3.1
Well No 4	NA	3.4	8.0	9.3	2.0	0.6	0.2	1.0	2.8	0.8	2.0	1.3
Well No 5	NA	5.2	7.2	8.5	5.6	6.0	3.8	4.0	6.8	1.0	6.4	2.3
Well No 9	NA	3.4	4.0	4.1	8.4	4.0	3.2	3.8	3.5	4.0	4.4	3.1
Well No 13	NA	7.5	55.0	48.6	5.0	10.0	0.5	1.6	4.5	3.0	2.5	3.1
Well No 16	NA	4.6	4.4	6.8	6.0	1.6	4.6	0.8	2.0	5.6	5.2	6.3
Well No 18	NA	2.8	3.0	5.1	2.4	1.4	5.0	1.4	2.8	4.0	5.6	3.1
Well No 21	NA	1.5	20.0	53.3	10.0	38.0	7.0	6.0	22.5	5.0	9.0	8.4
Well No 22	NA	5.2	10.8	12.1	8.0	13.6	2.6	7.4	6.4	16.0	6.4	12.4
Well No 26	NA	1.6	7.4	6.5	4.0	2.8	0.2	1.0	3.2	2.4	2.4	3.5
Well No 27	NA	110.0	110.0	158.0	70.0	120.0	80.0	165.0	60.0	80.0	75.0	10.4
Well No 29	NA	7.5	22.0	29.3	5.0	3.5	12.5	1.4	4.8	2.0	6.0	3.5
Well No 30	NA	4.0	5.0	8.3	4.8	3.4	4.5	9.8	2.8	2.4	4.8	2.8
Well No 31	NA	4.8	10.8	9.2	2.0	7.2	3.4	2.8	8.0	3.2	3.6	2.1
Well No 32	NA	7.0	10.0	3.2	12.0	7.6	6.8	4.5	0.6	4.0	5.6	3.1
Well No 34	NA	3.2	12.0	14.3	7.0	4.8	5.4	4.0	3.6	5.6	6.8	7.3
Well No 35	NA	1.5	2.0	6.5	8.0	2.0	10.0	6.0	1.6	1.0	5.8	2.1
Well No 36	NA	1.6	2.0	12.8	5.4	0.8	4.4	2.6	2.4	12.0	8.6	12.5
Well No 37	NA	32.0	64.0	52.3	5.0	8.0	1.0	2.0	6.5	4.0	5.5	2.1
Well No 38	NA	4.0	5.0	8.2	4.5	5.6	4.8	1.6	0.5	2.0	4.6	3.5
Well No 39	NA	10.0	26.0	29.5	5.0	7.0	6.0	8.5	24.0	15.0	11.0	9.5
Well No 40	NA	4.0	12.5	14.3	4.8	5.0	3.2	8.5	9.2	7.0	4.4	6.2
Well No 41	NA	4.0	2.5	3.2	8.0	1.6	1.4	1.0	11.6	7.2	2.0	6.8
Well No 42	NA	12.5	2.8	3.0	3.0	12.0	7.0	1.2	6.8		6.0	6.3

Note: NA = Not Available

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