ISERME 2024 Proceedings
2nd September 2024 – Sapporo, Japan
https://doi.org/10.31705/ISERME.2024.4

Session 2 – A

A Study of Groundwater Recovery Following Tunnel Construction in the Upper Highland Complex – A Case Study on the Ranwediyawa Tunnel

*Dissanayake[1] HM, Perumal[2] M and Lees[3] DJ
[1]*China State Construction Engineering Co. Ltd, Sri Lanka*
[2]*Program Management, Design and Supervision Consultant, Sri Lanka*
[3]*Program Management, Design and Supervision Consultant, Sri Lanka*
*Corresponding Author – Email: jdvdissa@yahoo.com

Abstract

In Sri Lanka, understanding the hydrogeological conditions is vital when constructing tunnels, especially geological regions such as the Highland Complex, where groundwater supports local communities and agriculture. While some recent data sheds light on groundwater reduction during tunneling, little is known about the recovery process. The Ranwediyawa tunnel construction, part of the Mahaweli Water Security and Investment Program (MWSIP), offered an opportunity to monitor groundwater impact closely. During excavation, considering seasonal variations, a reduction in groundwater levels was recorded, and following tunnel completion and installation of the waterproof lining, the groundwater recovery was monitored. The hydrogeological conditions of the Highland Complex present unique challenges as groundwater is vital for local communities and agriculture, so tunneling activities must be carefully managed to minimize disturbance. This paper outlines the planning, monitoring, and construction carried out for this project. Our findings stress the importance of comprehensive planning and monitoring during tunnel construction, understanding hydrogeological conditions and implementing effective waterproofing measures, to minimize environmental impact and ensure no disruption in domestic water supply and agriculture sustainability. It is hoped that the data and insights gained from this project can be used in future tunnel projects in similar hydrogeological settings, enhancing infrastructure project resilience and safeguarding groundwater resources for future generations.

Keywords: Aquifer, recovery, tunneling, water ingress, waterproof

1. Introduction

The Ranwediayawa tunnel was constructed as part of the Mahawelli Water Security Investment Program (MWSIP). The tunnel is part of the 17km North Western Province Canal Project (NWPCP) being built under contract No. NWPC-ICB2. The project is being constructed by China State Construction and Engineering Corporation (CSCEC) and is shown in Figure 1.

The alignment of the Ranwediyawa tunnel traverses a populated area of Ranwediyawa village with numerous domestic wells nearby. Groundwater sources, such as dug wells and deep tube wells, are crucial for meeting the daily water needs of the majority of communities in the area, with almost 100 percent of drinking water consumption reliant on groundwater.

During Ranwediyawa tunnel excavation, a significant reduction in water levels was observed in wells within and around the tunnel trace, with some wells drying up completely. This can be attributed to several factors, including the predominance of shallow dug wells drawing water from the relatively shallow groundwater table with well bottom levels higher than the tunnel invert level, and the potential interconnection of deep and shallow aquifers during excavation. To address declining groundwater levels, proactive measures were implemented. A robust waterproofing system was installed along the Ranwediyawa tunnel to prevent groundwater infiltration, while control backfilling operations were conducted at tunnel portals to facilitate groundwater level recovery in the region.

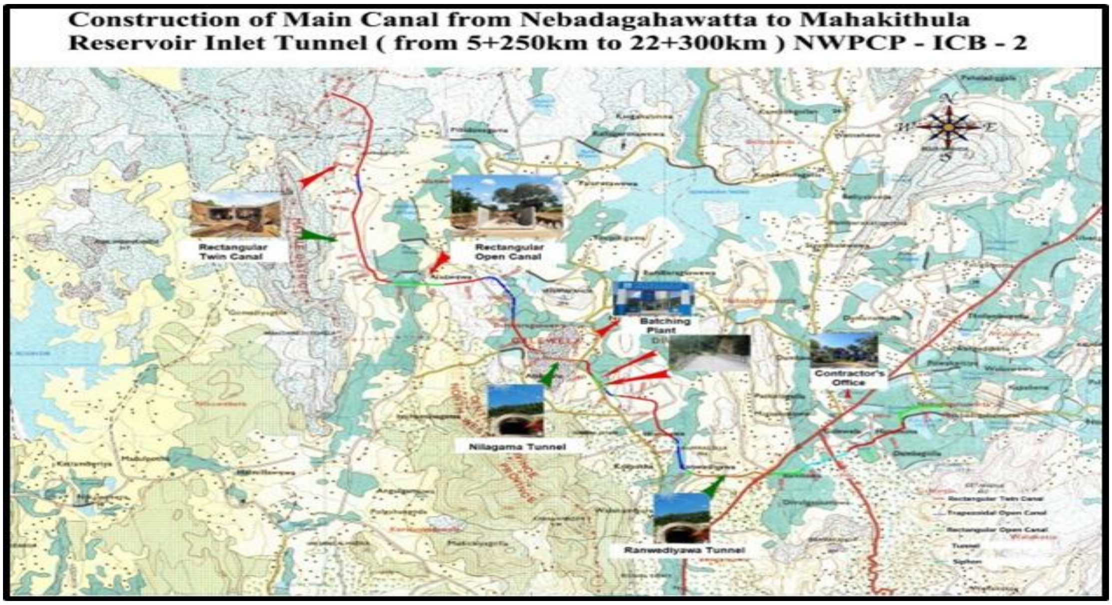


Figure 1: Project location

2. Geologic Setting

The geological composition of Sri Lanka primarily comprises Precambrian metamorphic rocks, which is divided into several groups, including the Highland Complex, Wanni Complex, Vijayan Complex, and smaller subdivisions as shown in Figure 2. The project area is situated within the Wanni and Highland complexes, both of which consist of high-grade metamorphic rocks although the Wanni Complex is younger than the Highland Complex. These metamorphic rocks exhibit distinct characteristics such as well-developed foliation and a presence of ductile and brittle structural features, including folds, faults, shear zones, joints, and fractures. These features are the result of the geological processes that took place under high pressure and high-temperature conditions during the metamorphic transformation.

In the vicinity of the tunnel route, various rock layers, including Quartzite, Garnetiferous Quartzofeldspathic Gneiss, Hornblende Biotite Gneiss, and Biotite Gneiss are present.

Deep weathering of the garnetiferrous granulitic gneiss rock produces deep rich soils. Lineaments are clearly marked by elongated valleys where deep weathering of garnetiferrous granulitic gneiss rock exists. The depth of weathering varies depending on the rock type and degree of fracturing. Along the riverbeds and creeks quite fresh rock is usually exposed while on the valley slopes decomposed and highly weathered rock can generally be found to depth of up to 8 m [1].

According to the British Geological Survey (BGS) and Water Resources Board (WRB) of Sri Lanka [2] two types of aquifers occur in this crystalline hard-rock terrain: (1) the shallow regolith (weathered zone) aquifer, and (2) the deep fracture zone aquifer. The thickness of the weathered zone ranges from 2 m to 10 m and the deep fracture zone is located deeper than 30 to 40 m from the surface.

Herbert et al., 1988 states that the regolith aquifers of the Central Highland area of Sri Lanka are somewhat unique, and suggests that most dug wells penetrate only to the top of the underlying "sap rock" horizon as digging becomes more difficult past this point as shown in Figure 3 [3].

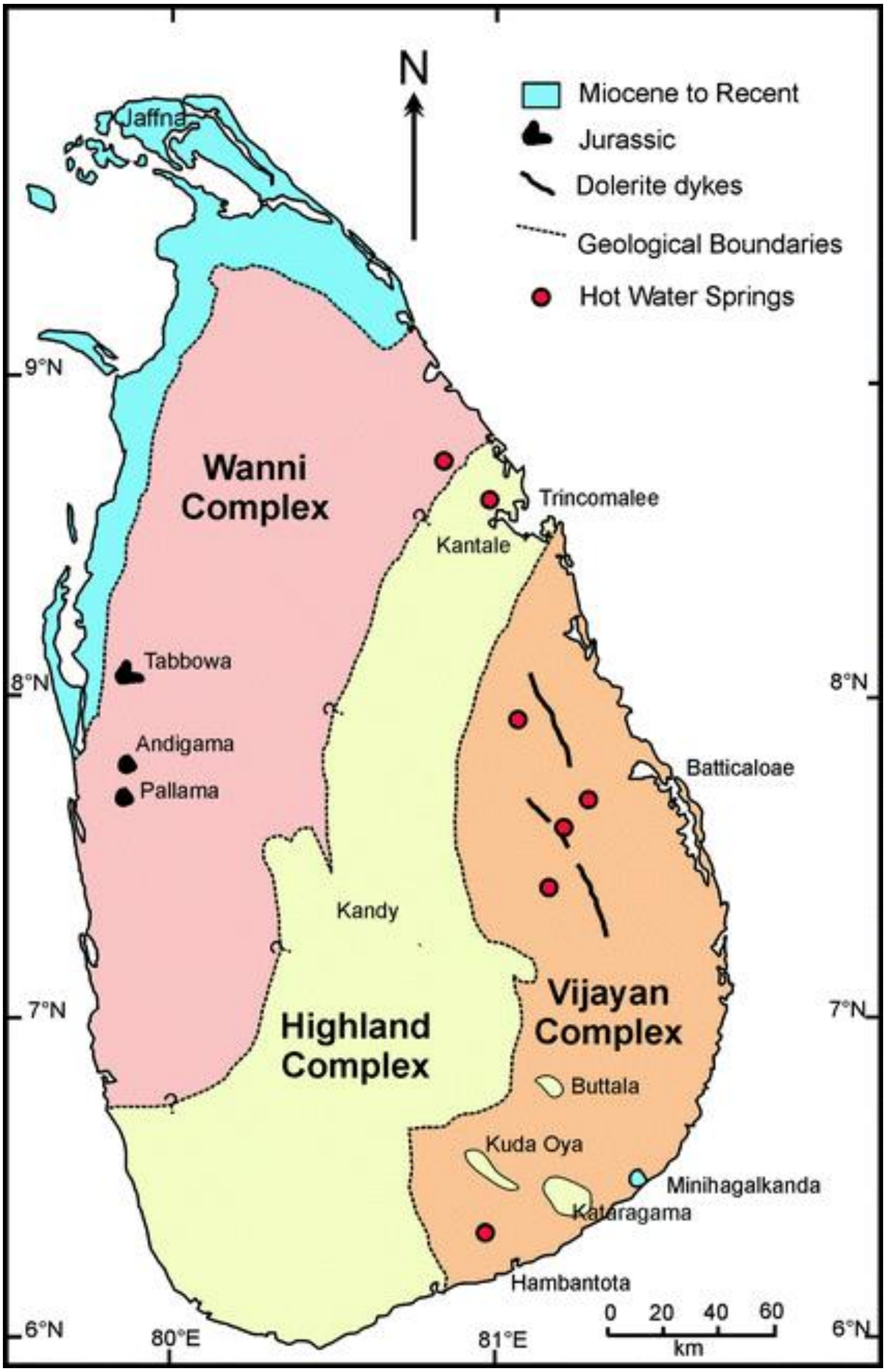


Figure 2: Geological map of Sri Lanka with lithotectonic subdivision (after Cooray, 1994)

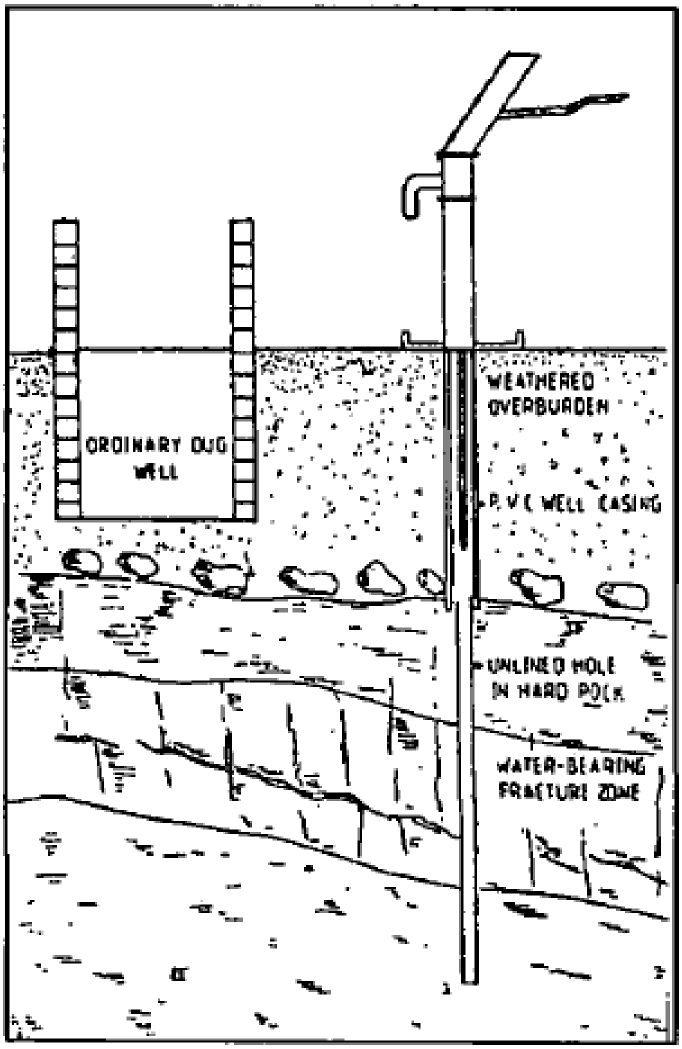


Figure 3 Shallow dug wells in overburden and deep wells in fractured rock [2]

The Ranwediyawa tunnel, in particular, traverses soft weathered rock at both portals and transitions to hard rock in the middle section. Geological mapping illustrates variations in rock conditions, ranging from completely weathered to highly weathered biotite gneiss to very strong slightly weathered to fresh biotite gneiss and quartz feldspathic gneiss as shown in Figure 4.

3. Construction of Ranwediyawa Tunnel Using the New Austrian Tunneling Method (NATM)

Ranwediyawa Tunnel was constructed by drill and blast techniques. The tunnel is 620 m long and 4.2 m diameter. Construction excavation commenced in March 2020 and was successfully completed by March 2022.In the weathered rock sections, excavation was by mechanical breaker with traditional drill and blast methods deployed in the hard rock sections. Water ingress occurred throughout the excavation process which was managed by drainage systems.

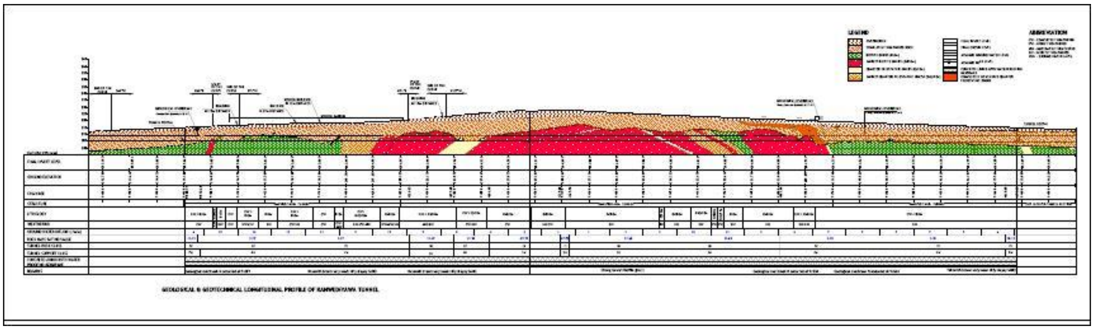


Figure 4: Geological Longitudinal Profile of the Ranwediyawa Tunnel

The transition from highly weathered rock to hard fresh rock required changes in rock support and the excavation process to ensure structural integrity and stability. Monitoring systems were installed to continuously assess ground movements, facilitating real-time adjustments to construction methodologies with the application of rock reinforcement measures such as rock bolting and shotcrete in accordance with NATM principles. On completion of the excavation a waterproof lining was installed. This involved the installation of a PVC membrane and a cast in-situ concrete lining as shown in Figure 5. Application of a waterproofing membrane and lining concrete commenced in August 2022 and was completed by May 2023 and this is seen is shown in Figure 6.

Figure 5: Applying of tunnel waterproofing

Figure 6: Comparison Before and After Application of Tunnel Waterproofing

Tunnel portal trench back-filling was required to complete the restoration of the ground water conditions.

4. The Groundwater Monitoring Program for the RanwediyawaTunnel Construction

The groundwater monitoring program started in October 2017, preceding the commencement of tunnel construction activities in the Ranwediyawa tunnel area. The program was designed in accordance with international guidelines and engineering standards [4].

Initially, the monitoring efforts focused on a comprehensive set of 51 wells, including a variety of shallow hand-dug wells. Additionally, four piezometers were strategically installed to enhance the groundwater monitoring data. The location of the monitoring wells is shown in Figure 7.

In addition to monitoring well water levels, the program included monitoring rainfall in the tunnel area, tracking tunnel water ingress, identifying points of water leakage in the tunnel, and conducting water quality testing.

The main objectives of the groundwater monitoring program are to obtain up-to-date information on groundwater levels, quickly identify changes in well water levels, detect areas of water pollution, and facilitate prompt action or supervision of remediation measures as needed. The monitoring protocol initially employed weekly assessments during tunnel excavation and subsequently transitioned to daily monitoring following the installation of the tunnel waterproofing system and backfilling at the tunnel portal trenches.

Analysis of groundwater level trends reveals a discernible decline in groundwater levels (GWL) concurrent with tunnel excavation activities, together with a corresponding escalation in tunnel water ingress as excavation progresses. Noteworthy is the transient increase in well water levels during rainy periods, indicative of the sensitivity of this aquifer to precipitation and groundwater recharge. However, this rise is ephemeral in nature.

The impact of tunnel waterproofing measures is evident in the gradual elevation of groundwater levels, as reflected in well water levels observed throughout the application phase of the tunnel waterproof lining. Subsequent to the completion of tunnel waterproofing measures, this upward trend in well water levels persists, further accentuated by heavy rainfall events characteristic of the region. Following this period, observed water levels stabilize, indicating a return to equilibrium influenced by both the completion of waterproofing measures and the natural recharge processes associated with regional precipitation patterns.

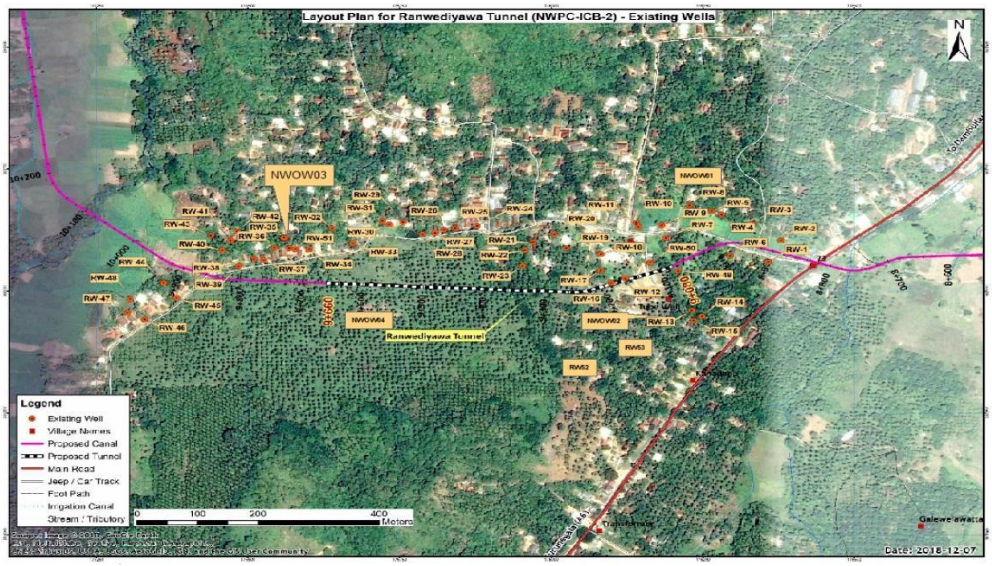
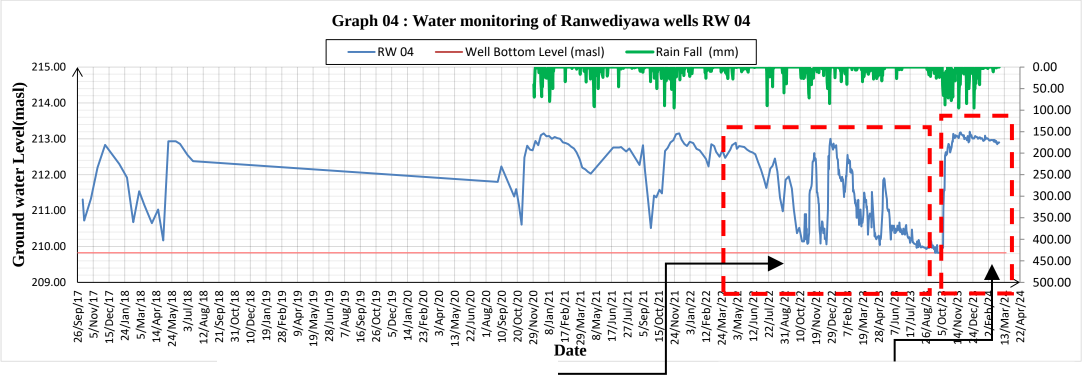


Figure 7: Monitoring well locations along Ranwediyawa tunnel

5. Results and Discussion

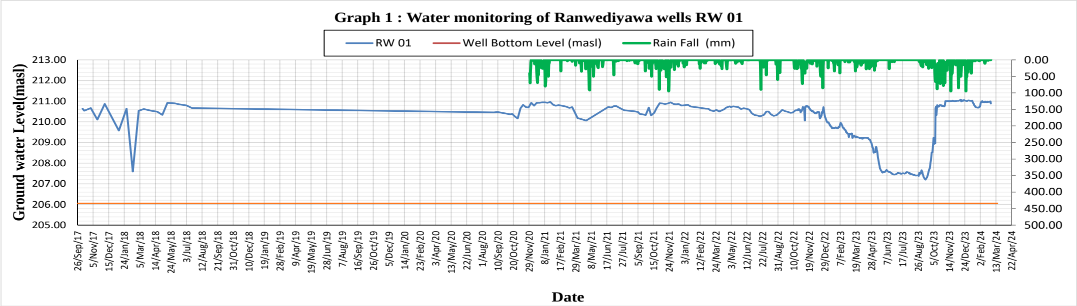
The tunnel portal excavation commenced in March 2020, and tunnel excavation was completed in March 2022. The data shows a decline of the water table through the tunnel excavation and construction process and seasonal weather changes. In August 2022, tunnel waterproofing operations were initiated and the completion of the cut and cover sections at each end of the tunnel and the ground water recovery is seen to begin. This is shown in Figures 8, 9 and 10.

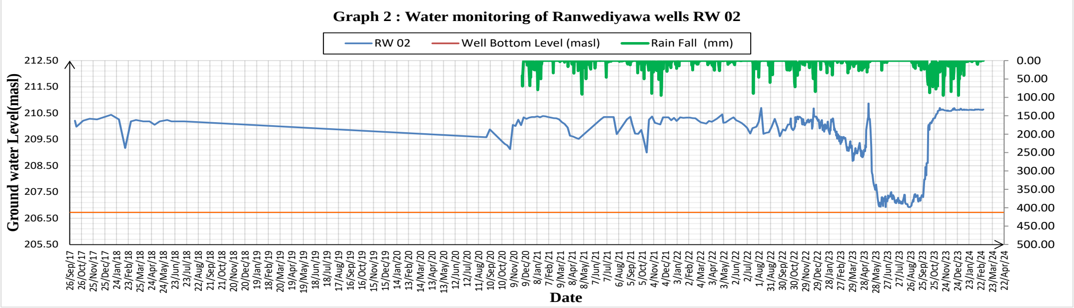


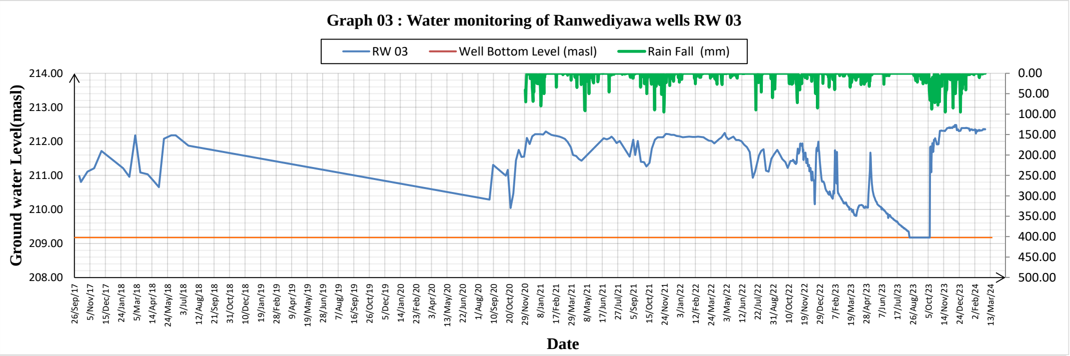
During Canal excavation

After completion of Control Backfilling

Figure 8: Groundwater Level Fluctuation during Canal Excavation and After Controlled Back-filling







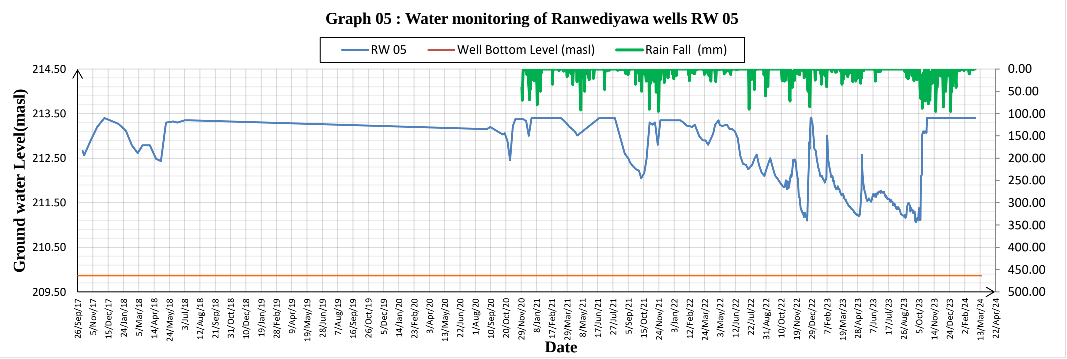
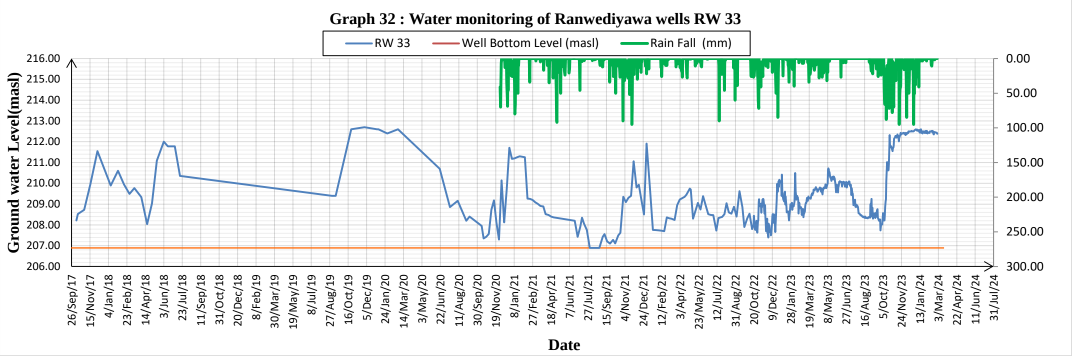
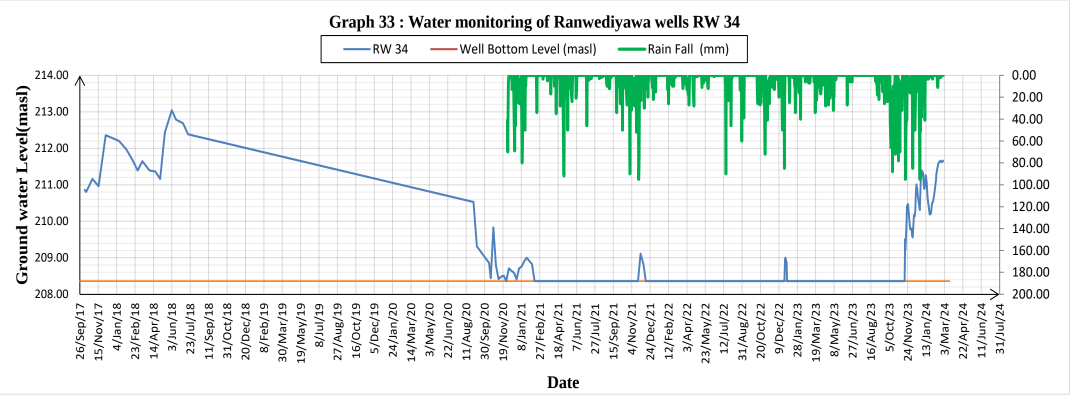


Figure 9: Groundwater Level Fluctuation at the Cut-and-Cover Section of the Tunnel Inlet Side





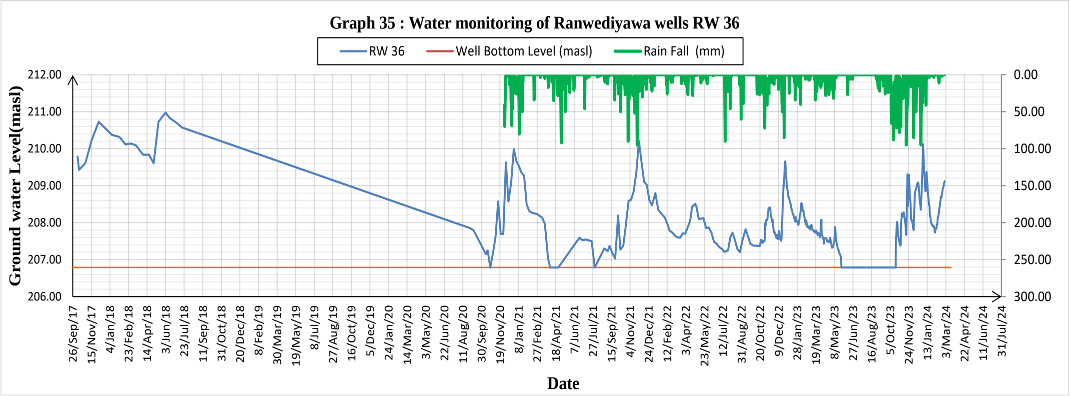
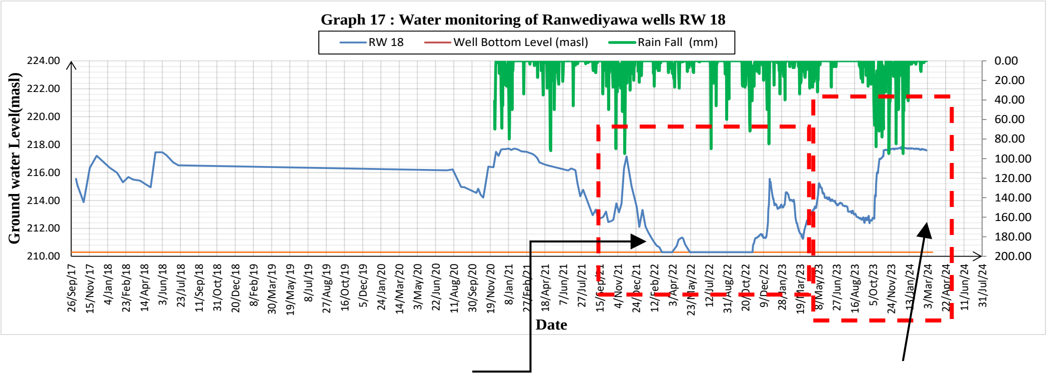


Figure 10: Groundwater Level Fluctuation at the Cut-and-Cover Section of the Tunnel Outlet Side

The elevation of the Ranwedijawa tunnel is just below the interface with the regolith aquifer, hence the drainage influence of the tunnel excavation caused a local reduction in the ground water within the regolith causing the local wells to dry out.

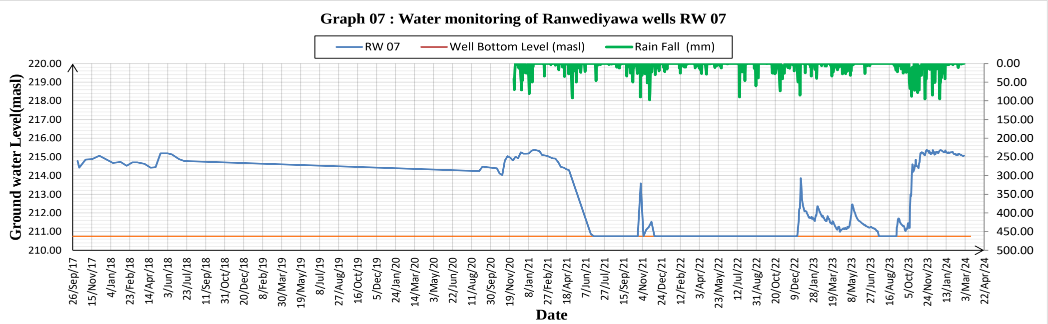
The wells situated in proximity to the tunnel trace experienced significant adverse effects during the excavation phase, with some wells even drying out completely. However, following the completion of tunnel waterproofing measures, a recovery trend was observed in all monitored wells. At present, all wells within the vicinity have fully regained their water levels as shown in Figures 11 and 12.



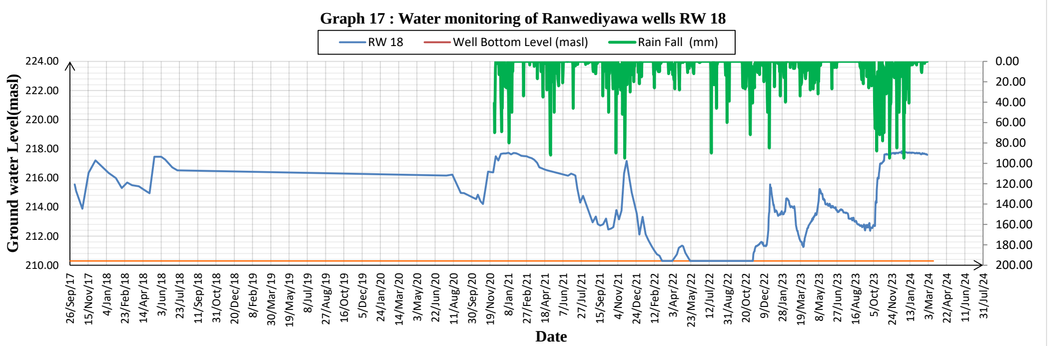
After tunnel excavation

After completion of tunnel waterproofing system

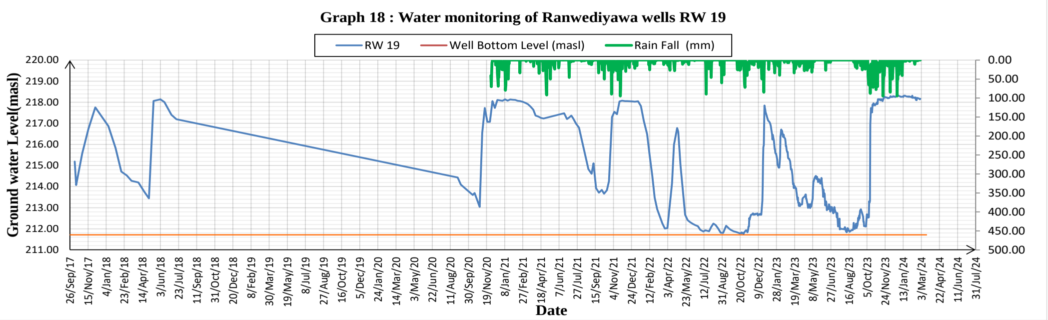
Figure 11: Groundwater Level Fluctuation during Tunnel Excavation and After Completion of tunnel waterproofing system



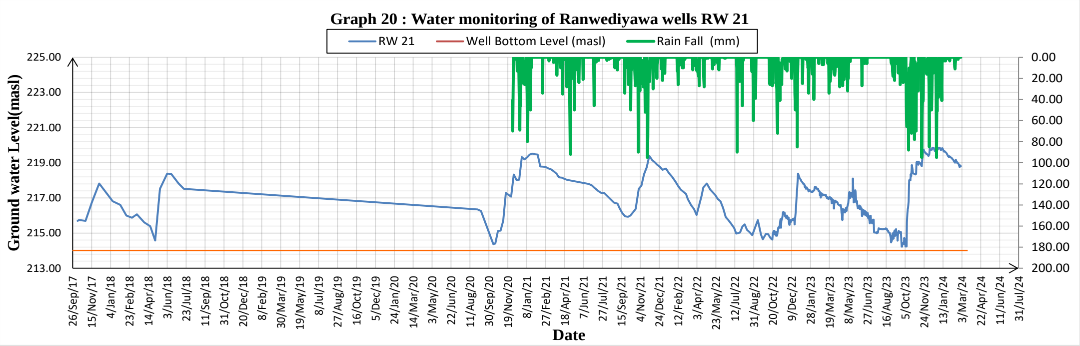
Graph 07 : Water monitoring of Ranwediyawa wells RW 07



Graph 17 : Water monitoring of Ranwediyawa wells RW 18

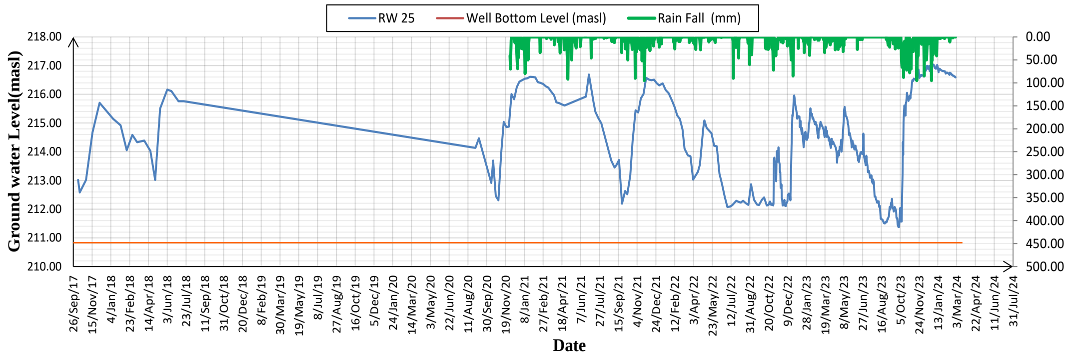


Graph 18 : Water monitoring of Ranwediyawa wells RW 19

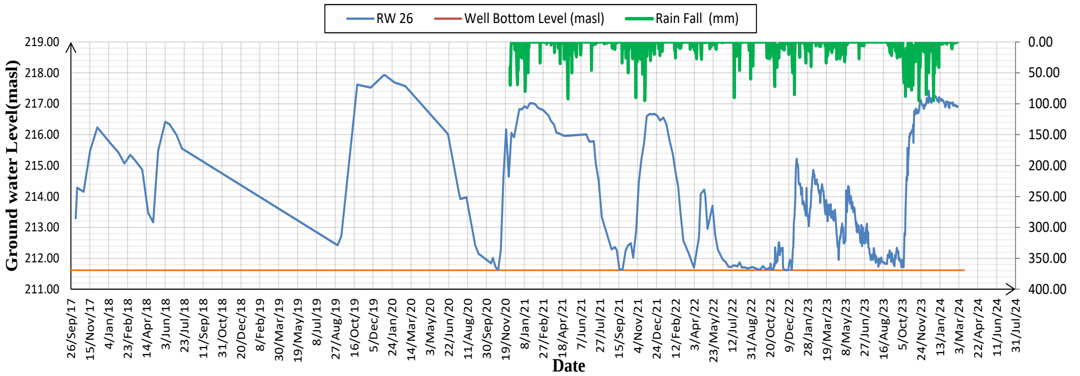


Graph 20 : Water monitoring of Ranwediyawa wells RW 21

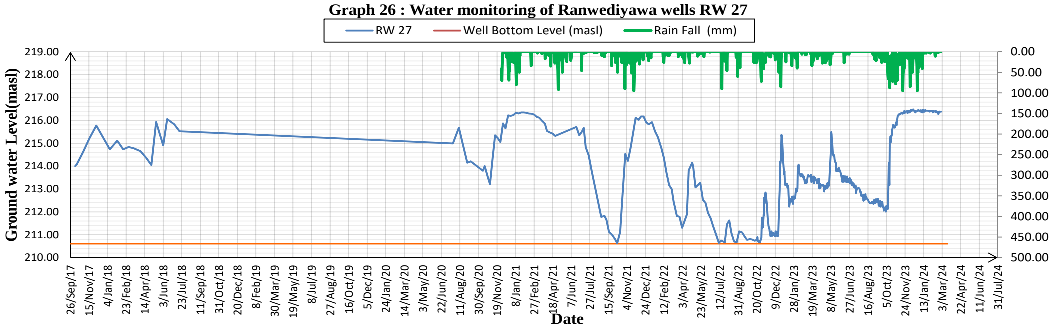
Graph 24 : Water monitoring of Ranwediyawa wells RW 25



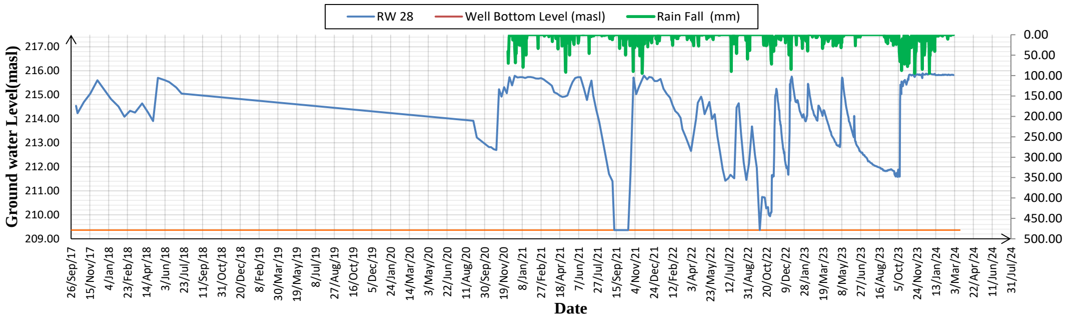
Graph 25 : Water monitoring of Ranwediyawa wells RW 26

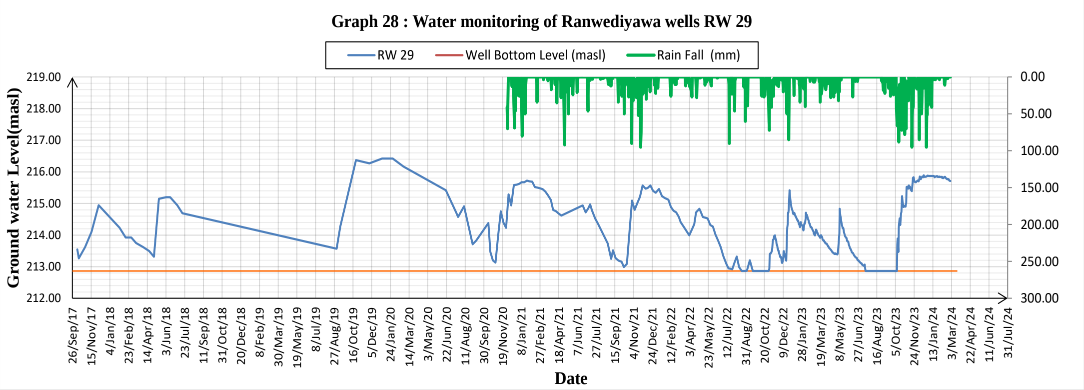


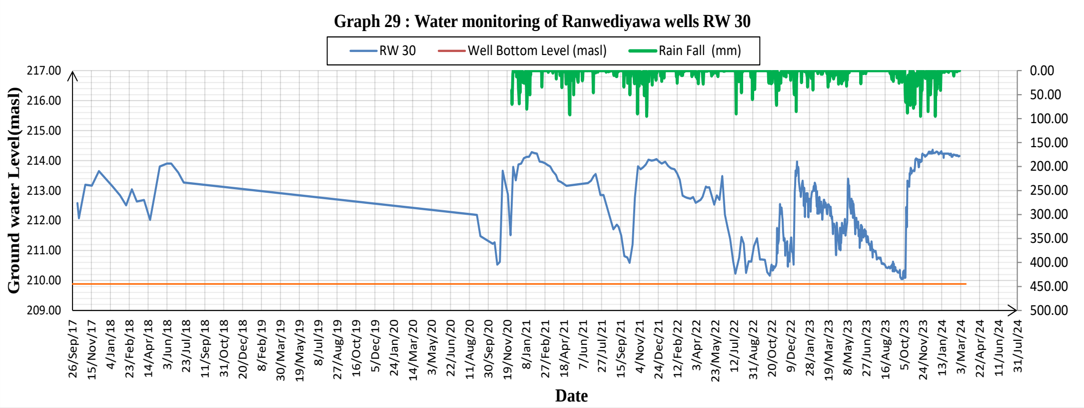
Graph 26 : Water monitoring of Ranwediyawa wells RW 27

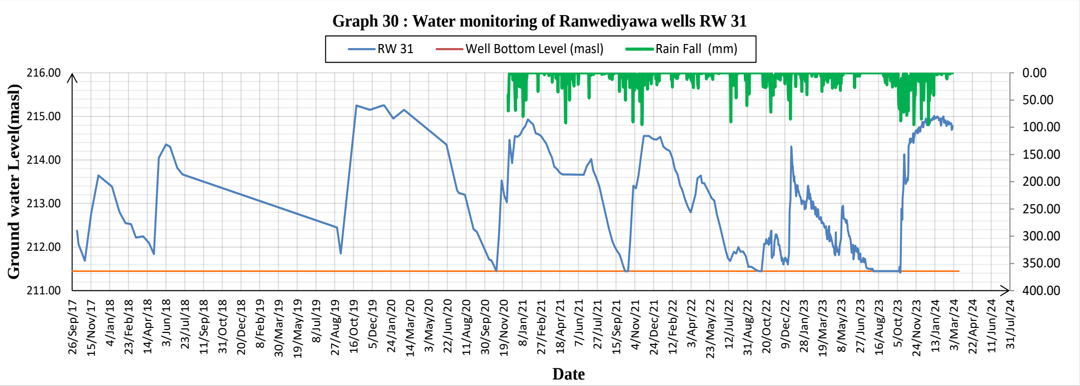


Graph 27 : Water monitoring of Ranwediyawa wells RW 28




Graph 28 : Water monitoring of Ranwediyawa wells RW 29


Graph 29 : Water monitoring of Ranwediyawa wells RW 30


Graph 30 : Water monitoring of Ranwediyawa wells RW 31

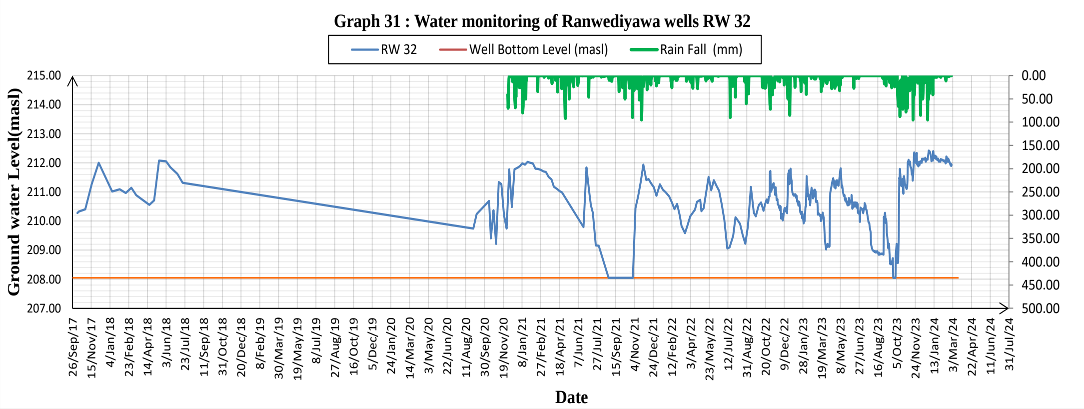

Graph 31 : Water monitoring of Ranwediyawa wells RW 32

Figure 12: Groundwater Level Fluctuation during Tunnel Excavation and After Completion of the Tunnel Waterproofing System at the Center Section of the Tunnel Trace.

5.1 Water Ingress from the Tunnel

The application of the tunnel waterproofing membrane and lining concrete was successfully completed on May 26, 2023 reducing the water ingress as shown in Figure 13.

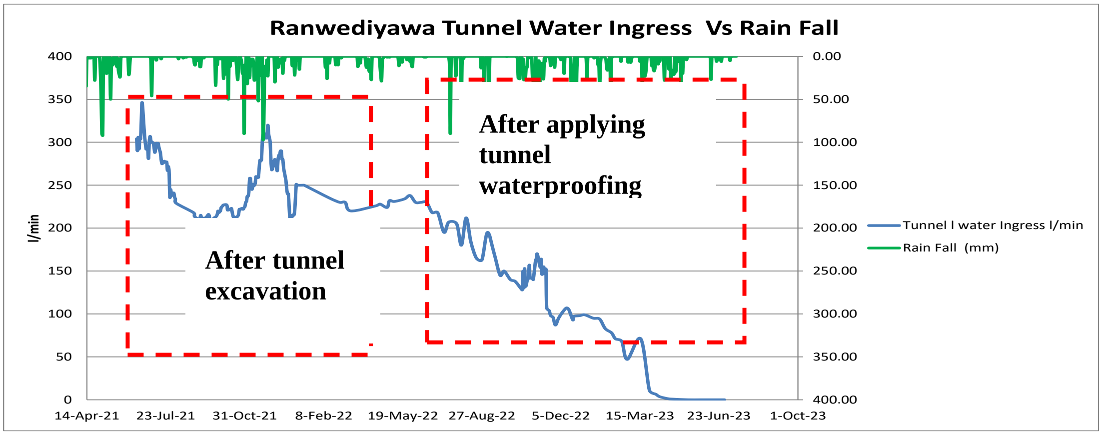


Figure 13: Characteristics of Tunnel Water Ingress

5.2 Water Quality Issue

A local school which relied on a deep tube well for water supply, noted a reduction in water quality subsequent to the completion of waterproofing measures for the Ranwediyawa tunnel. The emergence of an unusual odour in the water during May 2023 raised concerns among students and staff regarding its suitability for consumption and school-related activities.

Water testing and investigations were undertaken. Laboratory results indicated that the bacteriological quality of the well water was within drinkable limits, however, chemical analysis revealed elevated levels of iron, manganese, and free ammonia exceeding acceptable drinking water requirements as per SLS 614:2013 [5].

It was considered that the lowering of the ground water created a change in the geochemical condition creating an oxidized zone which, when the water table was restored, affected the geo-chemistry of the groundwater. To overcome this tube well cleaning was initiated on May 24th and 28th, 2023. A water sample was collected on June 26, 2023, and sent to the National Water Supply and Drainage Board Laboratory for testing, which revealed improved conditions. A further quality assessment was carried out on February 8, 2024, which revealed that the pertinent parameters now adhere to the prescribed limits outlined in SLS 614:2013. Additionally, the previously noted odour has completely dissipated, indicating that the well water at the school is now deemed suitable for potable consumption.

Table 1 Water quality test results Ranwediyawa School

Parameter	Unit	Requirment (Maximum) as SLS 614:2013	Test Results		
			As June 26, 2023	As September 29, 2023	As February 8, 2024
Free Ammonia(As NH_3)	(mg/l)	**0.06**	0.36	0.09	0.06
Chloride(As Cl^-)	(mg/l)	**250**	28	18	28
Fluoride(As F)	(mg/l)	**1**	0.16	0.04	0.2
Iron(As Fe)	(mg/l)	**0.3**	0.82	<0.05	<0.1
Manganese(	(mg/l)	**0.1**	0.2	<0.01	<0.1
Shulphate(As SO_4^{-2})	(mg/l)	**250**	2	1.4	4
Total Alkalinity (As $CaCO_3$)	(mg/l)	**200**	100	145	40
Total Dissolved Solids(max)	(mg/l)	**200**	164	218	87

5.3 Groundwater recovery rate of the Ranwediyawa tunnel area Calculation and Analysis

Groundwater level monitoring of 24 wells located around Ranwediyawa tunnel area, continued after the tunnel construction was complete these results are presented in Table 2.

The Average Groundwater Recovery Rate is calculated from the date of completion of the waterproof lining and is about 0.009 m/day.

5.4 Correlation between geological formation and groundwater recovery rate

These wells within the Ranwediyawa tunnel area are strategically positioned within the overburden layer, primarily composed of completely decomposed biotitic gneiss. typically presented as **silty sand** and **sandy clay**. The correlation between geological formation and groundwater recovery rate was analyzed for each group. The results are presented in Table 2. The mean recovery rate was then calculated for each formation:

For Silty sand formations: Mean recovery rate = 0.014 m/day

For Sandy clay formations: Mean recovery rate = 0.007 m/day

Table 2: Details of Monitoring wells at Ranwediyawa tunnel

Well No.	Initial GWL before tunnel Excavation (masl)	Start of Recovery		Fully Revovered		Groundwater Recovery Rate (m/day)	Distance from Center Line(m)	well depth (m)	Well Bottom Level (masl)	Geological Formation
		Date	Level(masl)	Date	Level(masl)					
RW-07	214.7	20-Dec-22	210.75	25-Oct-23	214.85	0.0133	58	5.3500	210.7500	Silty SAND
RW-09	213.23	15-Oct-22	209.66	16-Oct-23	213.26	0.0098	83	5.0500	209.5500	Sandy CLAY
RW-10	214.03	2-Oct-22	211.94	14-Oct-23	214.18	0.0059	104	4.5000	211.2800	Sandy CLAY
RW-11	214.1	19-Oct-22	212.75	14-Oct-23	214.11	0.0038	94	2.9400	212.0000	Sandy CLAY
RW-12	215.81	27-Dec-22	212.77	20-Oct-23	215.83	0.0103	2	7.0100	212.7700	Silty SAND
RW-13	216.07	22-Dec-22	212.27	16-Oct-23	216.08	0.0128	93	5.8500	212.2700	Silty SAND
RW-14	215.66	20-Dec-22	213.52	14-Oct-23	215.99	0.0083	111	4.0400	213.5200	Sandy CLAY
RW-15	215.83	31-Oct-22	213.66	17-Oct-23	215.78	0.0060	114	5.0500	213.5700	Sandy CLAY
RW-17	215.56	17-May-23	214.39	21-Oct-23	215.71	0.0084	29	5.6700	214.3900	Sandy CLAY
RW-18	215.5	10-Nov-22	210.29	16-Oct-23	215.98	0.0167	64	8.2600	210.2900	Silty SAND
RW-19	214.28	12-Nov-22	211.98	14-Oct-23	216.93	0.0147	84	7.5200	211.7100	Silty SAND
RW-20	212.55	15-Oct-22	212.37	4-Nov-23	218.13	0.0150	110	7.4500	211.9600	Silty SAND
RW-21	217.07	8-Oct-22	214.7	16-Oct-23	218.01	0.0089	96	6.5600	214.0100	Sandy CLAY
RW-22	217.04	16-Nov-22	214.81	14-Oct-23	217.09	0.0069	79	6.2400	214.8100	Sandy CLAY
RW-23	217.24	12-Nov-22	214.66	27-Oct-23	217.4	0.0079	50	8.4700	214.6600	Sandy CLAY
RW-24	215.06	31-Oct-22	213.19	4-Nov-23	217.64	0.0121	121	7.2200	212.7700	Silty SAND
RW-25	214.33	3-Nov-22	212.19	4-Nov-23	216.21	0.0110	116	5.8300	210.8500	Silty SAND
RW-26	215.17	31-Oct-22	211.64	19-Oct-23	215.57	0.0111	112	6.8100	211.6100	Silty SAND
RW-27	214.78	31-Oct-22	210.67	14-Oct-23	215.01	0.0125	106	6.7400	210.6100	Silty SAND
RW-29	213.75	1-Nov-22	212.86	11-Oct-23	213.89	0.0030	124	3.8100	212.8600	Sandy CLAY
RW-30	212.63	5-Nov-22	210.9	14-Oct-23	213.33	0.0071	119	5.7500	209.8800	Sandy CLAY
RW-31	214.35	15-Oct-22	212.08	6-Nov-23	214.38	0.0059	124	4.2000	211.4500	Sandy CLAY
RW-49	215.91	4-Nov-22	213.27	8-Nov-23	215.95	0.0073	15	4.1600	213.2700	Sandy CLAY
RW-50	215.46	25-Oct-22	213.24	8-Nov-23	215.56	0.0061	20	4.4000	213.2400	Sandy CLAY

5.5 Correlation between the distance of wells from the centerline of the tunnel and groundwater recovery rate

Groundwater drawdown from a point follows a normal curve [6]. Therefore, it was considered that the recovery rate at any point along that curve will be different depending on the distance from the point of draw down. To find the correlation between the distance of wells from the centerline of the tunnel and groundwater recovery rate, correlation coefficient between these two variables was calculated using Pearson Correlation Coefficient Formula [7] as shown in Table 3 where:

$$y = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{[n(\sum x^2) - (\sum x)^2]} \times \sqrt{[n(\sum y^2) - (\sum y)^2]}}$$

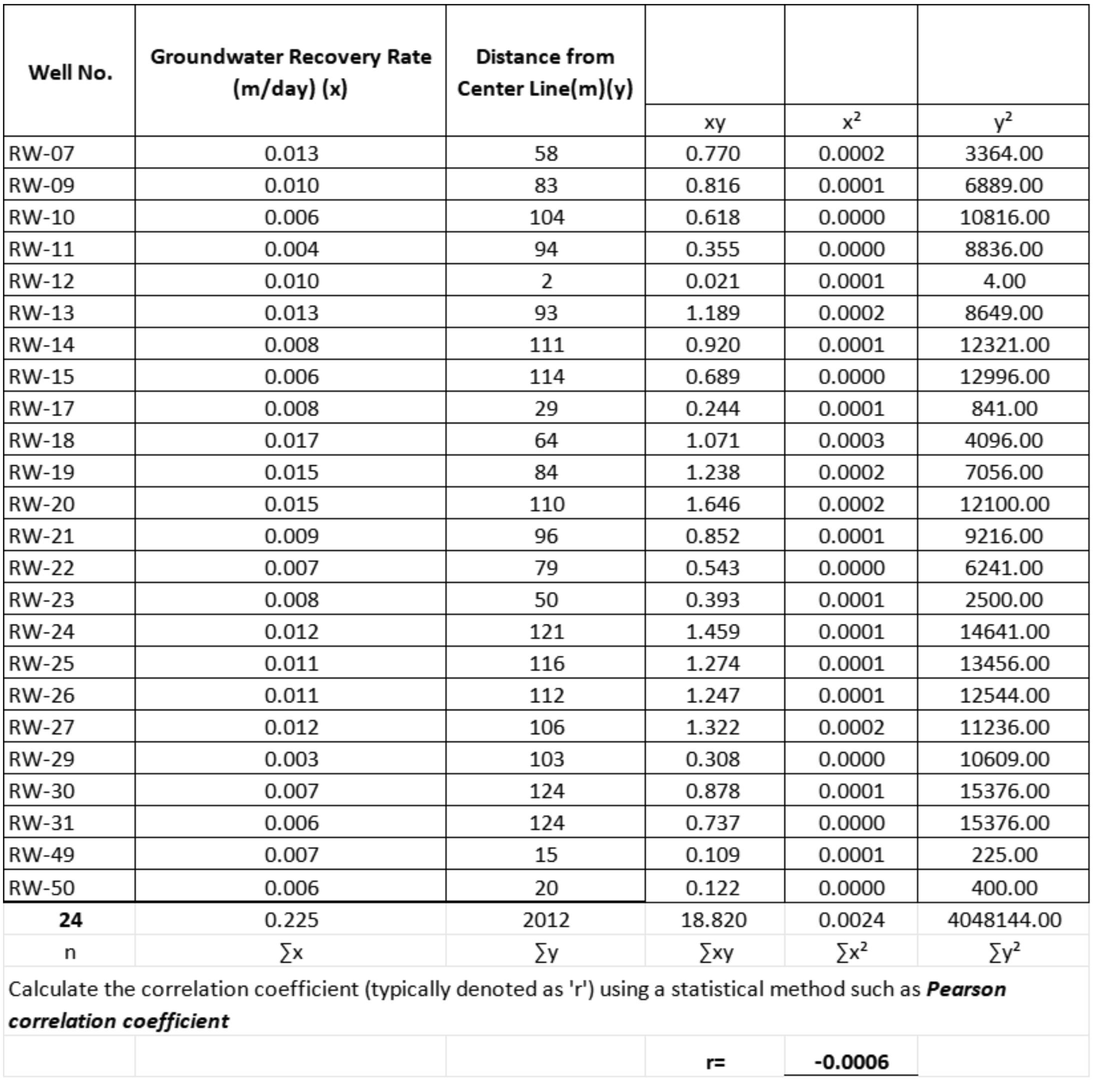
Where:

- *r* is the Correlation Coefficient
- *n* is the number of data points (in this case, the number of wells).
- *x* is the distance from the centerline of the tunnel in meters (m)
- *y* is the groundwater recovery rate in meter pay day(m/day)
- $\sum$ denotes the sum of the values.

This gives a correlation coefficient of approximately -0.0006.

With a correlation coefficient close to zero (*r* = 0), this suggests a very weak or negligible correlation between the distance of wells from the centerline of the tunnel and groundwater recovery rate.

Table 3: Distances between Ranwediyawa monitoring wells and tunnel center line.



Well No.	**Groundwater Recovery Rate (m/day) (x)**	**Distance from Center Line(m)(y)**			
			xy	x^2	y^2
RW-07	0.013	58	0.770	0.0002	3364.00
RW-09	0.010	83	0.816	0.0001	6889.00
RW-10	0.006	104	0.618	0.0000	10816.00
RW-11	0.004	94	0.355	0.0000	8836.00
RW-12	0.010	2	0.021	0.0001	4.00
RW-13	0.013	93	1.189	0.0002	8649.00
RW-14	0.008	111	0.920	0.0001	12321.00
RW-15	0.006	114	0.689	0.0000	12996.00
RW-17	0.008	29	0.244	0.0001	841.00
RW-18	0.017	64	1.071	0.0003	4096.00
RW-19	0.015	84	1.238	0.0002	7056.00
RW-20	0.015	110	1.646	0.0002	12100.00
RW-21	0.009	96	0.852	0.0001	9216.00
RW-22	0.007	79	0.543	0.0000	6241.00
RW-23	0.008	50	0.393	0.0001	2500.00
RW-24	0.012	121	1.459	0.0001	14641.00
RW-25	0.011	116	1.274	0.0001	13456.00
RW-26	0.011	112	1.247	0.0001	12544.00
RW-27	0.012	106	1.322	0.0002	11236.00
RW-29	0.003	103	0.308	0.0000	10609.00
RW-30	0.007	124	0.878	0.0001	15376.00
RW-31	0.006	124	0.737	0.0000	15376.00
RW-49	0.007	15	0.109	0.0001	225.00
RW-50	0.006	20	0.122	0.0000	400.00
24	0.225	2012	18.820	0.0024	4048144.00
n	$\sum x$	$\sum y$	$\sum xy$	$\sum x^2$	$\sum y^2$
Calculate the correlation coefficient (typically denoted as 'r') using a statistical method such as ***Pearson correlation coefficient***					
			r=	**-0.0006**	

5.6 The correlation between the well depth and groundwater recovery rate

To find the correlation between the well depth and groundwater recovery rate, the same approach was used as presented in Table 4- where;

- *x* is the well depth in meters (m).

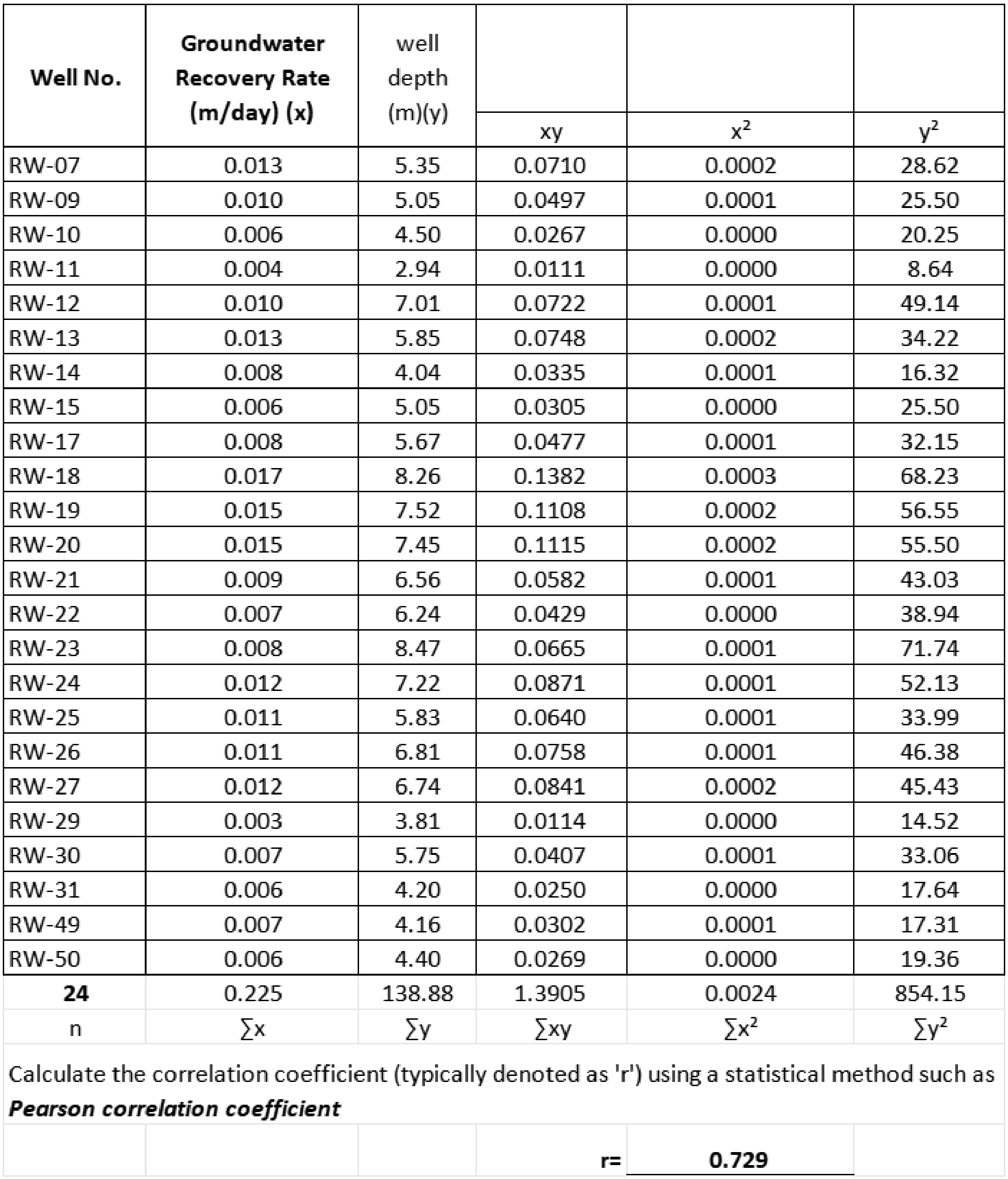
- y is the groundwater recovery rate in meters per day (m/day).

Using the formula:

$$y = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{[n(\sum x^2) - (\sum x)^2]} \times \sqrt{[n(\sum y^2) - (\sum y)^2]}}$$

The correlation coefficient was found to be close to *r* =1 suggesting a good correlation namely that the recovery rate tends to increase with depth.

Table 4: Well depths of Ranwediyawa monitoring wells



Well No.	**Groundwater Recovery Rate (m/day) (x)**	well depth (m)(y)			
			xy	x^2	y^2
RW-07	0.013	5.35	0.0710	0.0002	28.62
RW-09	0.010	5.05	0.0497	0.0001	25.50
RW-10	0.006	4.50	0.0267	0.0000	20.25
RW-11	0.004	2.94	0.0111	0.0000	8.64
RW-12	0.010	7.01	0.0722	0.0001	49.14
RW-13	0.013	5.85	0.0748	0.0002	34.22
RW-14	0.008	4.04	0.0335	0.0001	16.32
RW-15	0.006	5.05	0.0305	0.0000	25.50
RW-17	0.008	5.67	0.0477	0.0001	32.15
RW-18	0.017	8.26	0.1382	0.0003	68.23
RW-19	0.015	7.52	0.1108	0.0002	56.55
RW-20	0.015	7.45	0.1115	0.0002	55.50
RW-21	0.009	6.56	0.0582	0.0001	43.03
RW-22	0.007	6.24	0.0429	0.0000	38.94
RW-23	0.008	8.47	0.0665	0.0001	71.74
RW-24	0.012	7.22	0.0871	0.0001	52.13
RW-25	0.011	5.83	0.0640	0.0001	33.99
RW-26	0.011	6.81	0.0758	0.0001	46.38
RW-27	0.012	6.74	0.0841	0.0002	45.43
RW-29	0.003	3.81	0.0114	0.0000	14.52
RW-30	0.007	5.75	0.0407	0.0001	33.06
RW-31	0.006	4.20	0.0250	0.0000	17.64
RW-49	0.007	4.16	0.0302	0.0001	17.31
RW-50	0.006	4.40	0.0269	0.0000	19.36
24	0.225	138.88	1.3905	0.0024	854.15
n	$\sum x$	$\sum y$	$\sum xy$	$\sum x^2$	$\sum y^2$
Calculate the correlation coefficient (typically denoted as 'r') using a statistical method such as ***Pearson correlation coefficient***					
			r=	**0.729**	

6. Conclusion

This study provided a comprehensive analysis on groundwater recovery following tunnel excavation in the Highland Complex. This focused analysis of the Ranwediyawa Tunnel, has provided invaluable insights into the intricate dynamics of hydrogeological systems in the Highland Complex and the contingency measures required to address these. This study and analysis have provided further data between tunnel construction activities, groundwater dynamics, and environmental impacts.

The study has shown that with groundwater recovery there may be a change in geochemistry creating concentration of pollutants, such as iron, manganese, and free ammonia, in the ground water. However, these chemical concentration decrease with time and the rate of reduction of these concentrations can be enhanced by well flushing.

Analysis of the recovery following the application of the waterproof lining indicates a recovery rate of about 0.009 m/day, but that this recovery rate is dependent on depth, with a faster recovery rate in areas of deeper lowering of the groundwater.

References

[1] Lees D. J. and Gunatilake J. (2017). The Hydrogeology of the Central Highlands in Sri Lanka and its effect on tunnel construction. 16th Australasian Tunnelling Conference 2017 Sydney, Australia, 30 October – 1 November 2017.
[2] Panabokke, C.R. (2007) Groundwayer Conditions in Sri Lanka (A Geomorphic Perspective). Published by the National Science Foundation of Sri Lanka, Colombo 2007
[3] Herbert R., Ball, D.K., Rodrigo, I.C.P. and Wright, E.P. (1988). The regolith aquifer of hard-rock areas and its exploitation with particular reference to Sri Lanka. Journal of the Geological Society of Sri Lanka 1. pp 64–72.
[4] Ravencroft, P. and Lytton, L. (2022). Practical Manual on Groundwater Monitoring. International Bank for Reconstruction and Development / The World Bank, Washington USA
[5] Sri Lanka Standard (2013). SLS 614:2013. Specification for Potable Water; Published (First Revision). Sri Lanka Standards Institution, Colombo
[6] Bear, J. (1979). Hydraulics of Groundwater. McGraw-Hill. New York 1979
[7] Boslaugh, S. (2012). Statistics in a Nutshell, 2nd Edition. O'Reilly Media Inc 2012