Ash in Mine Backfilling

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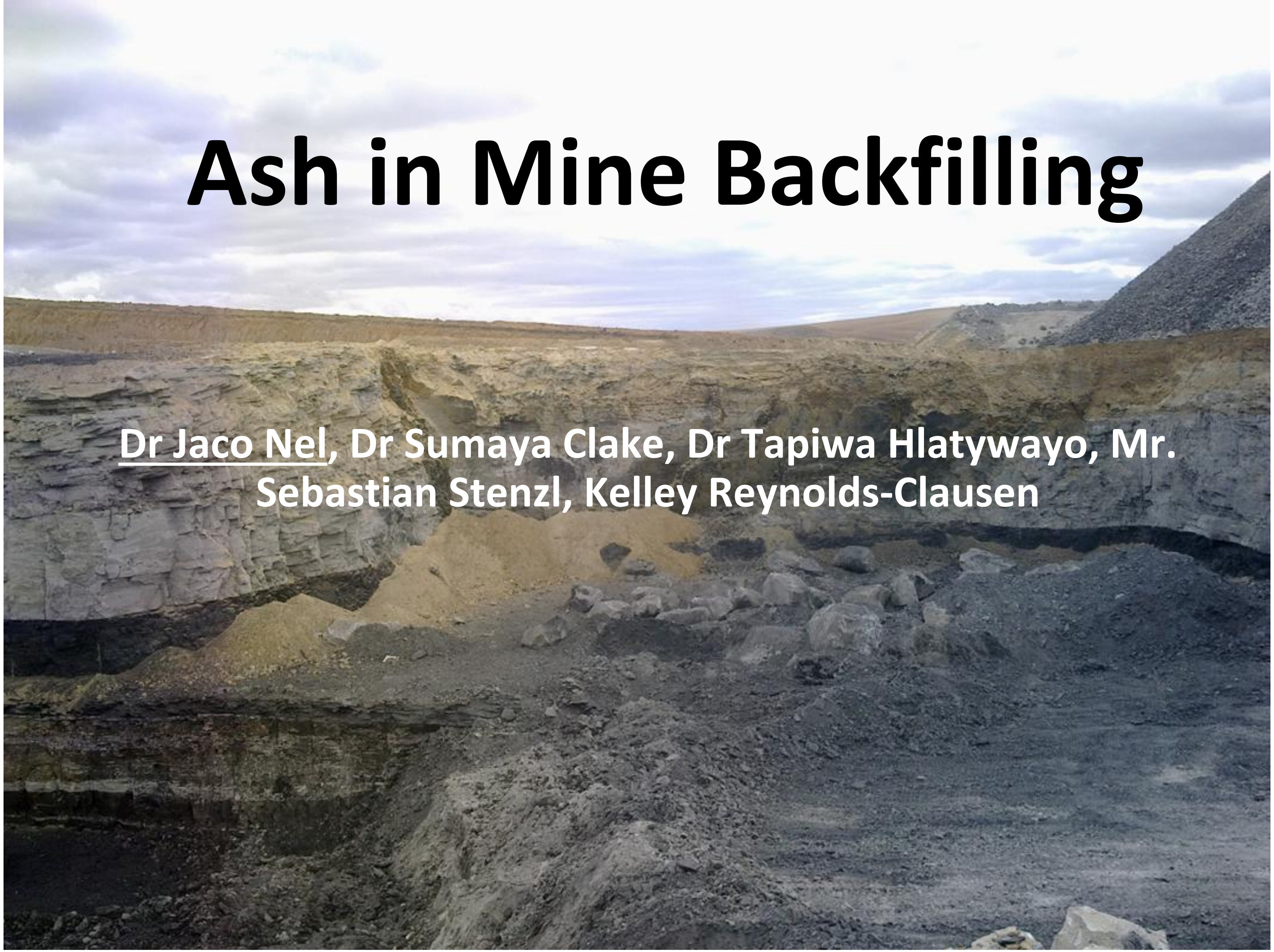


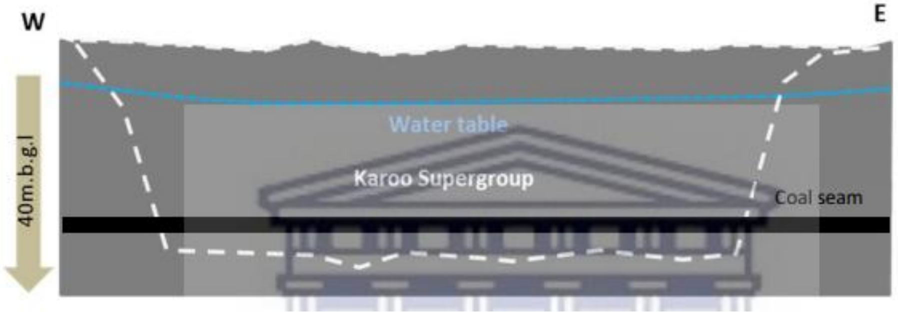
Outline

- Main components of the research
- Coal Mining stages
- Mine working principles
- Acid Mine Drainage
- Why ASH in mine backfilling?
- Ash variability
- Performance in Batch and lysimeter experiments
- Modeling – Lysimeter based and Field site based

Main components of the research

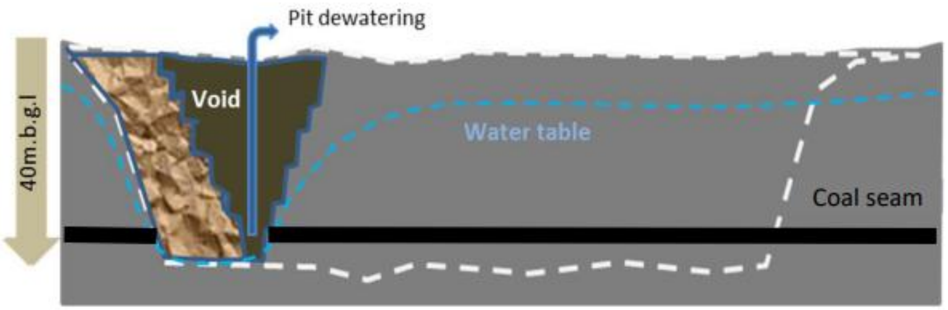
- Ash variability over time – Sampling was done at 4 power stations. The sampling was done hourly (over 24 hrs) weekly (over 5 weeks) and monthly (over 4 months).
- Ash lysimeters – Several laboratory experiments towards understanding the behavior of Ash: e.g. Acid neutralizing capacity, Sorption studies, mineral composition
- Hydrocensus: Field measurements of water quality of mine decant, river water, boreholes 5km radius around a test site
- Modeling backfilling scenarios, flow and transport

Open cast coal mining



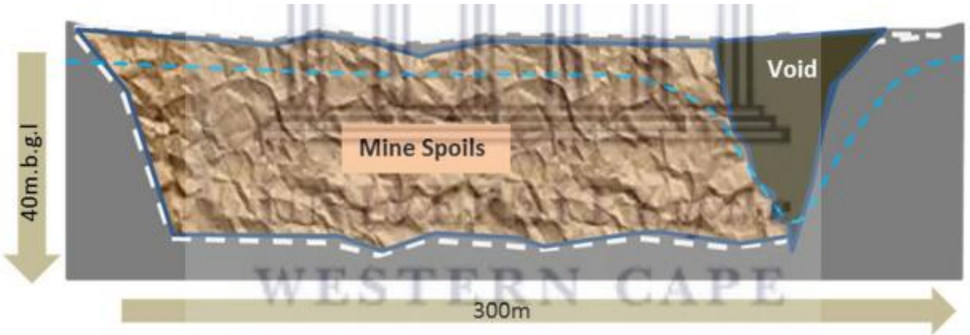
Pre-mining conditions

Undisturbed land, with coal seam identified



Operational mining conditions

Blasting to break up rock/overburden, removed, until target coal seam is reached, overburden disposed of in the mine



Decommissioning and closure

Post Mine closure: Monitoring required, tailings, mine discharge water, vegetation cover

Mine Working principles

The mine backfilling is based on two fundamental principles namely:

- Flooding/water cover
- The acid neutralizing ability of coal fly ash.

AMD is generally managed via 3 steps: Prevention, control & treatment

Flooding: it is an economical alternative for controlling AMD formation. Oxygen is necessary for AMD formation, however it has a low solubility and diffusion rate through water. Thus if the water level is raised by creating a barrier, the oxidation of reactive waste is minimised reducing the generation of AMD.

Acid neutralising ability of CFA: Due to the chemical properties (high degree of alkalinity) of CFA, it has been used in the neutralization of AMD. **research from our labs and other researchers attest to this.*

Acid mine drainage (AMD) formation

AMD refers to the outflow of acidic water from metal or coalmines.

There are 3 essential components that initiates AMD formation; oxygen, water & Thiobacillus ferrooxidans bacteria

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+ \qquad (1)$$

$$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O \qquad (2)$$

$$Fe^{3+} + 3H_2O \rightarrow FeOOH + H_2O + 3H^+ \qquad (3)$$

$$FeOOH + H_2O + 3H^+ \rightarrow Fe(OH)_3 + 3H^+ \qquad (4)$$

Ash variability testing

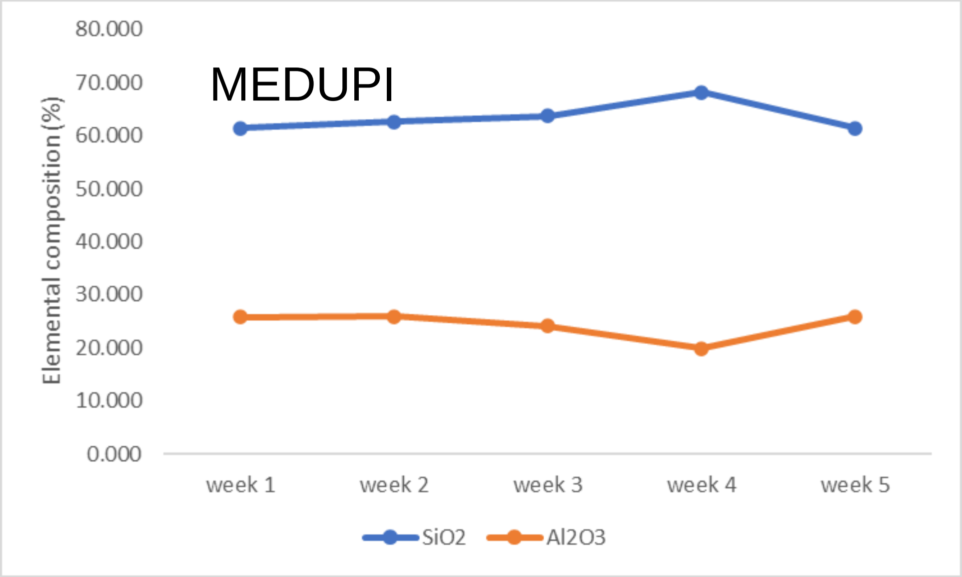
The determination of the ash geochemistry and particle sizes consisted of the following components:

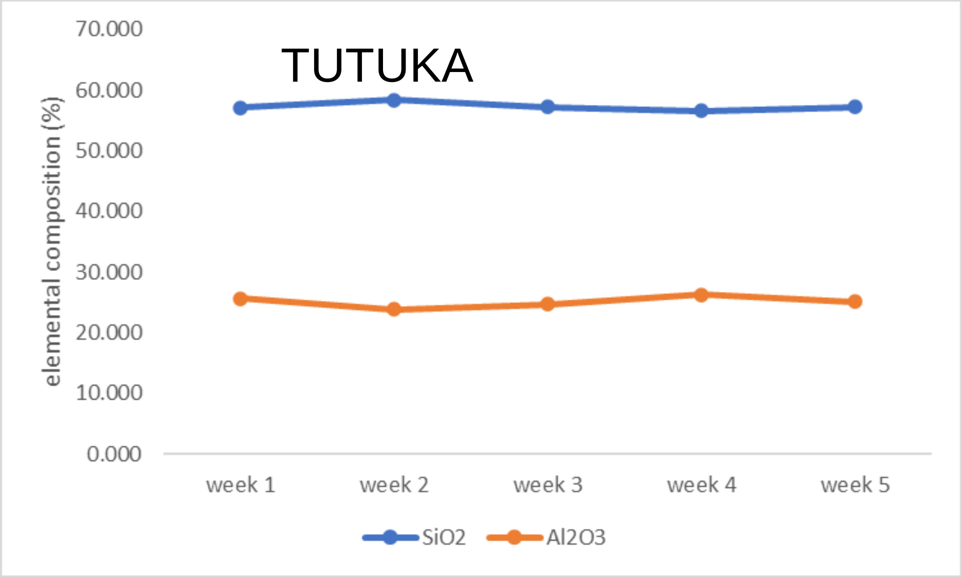
Sampling

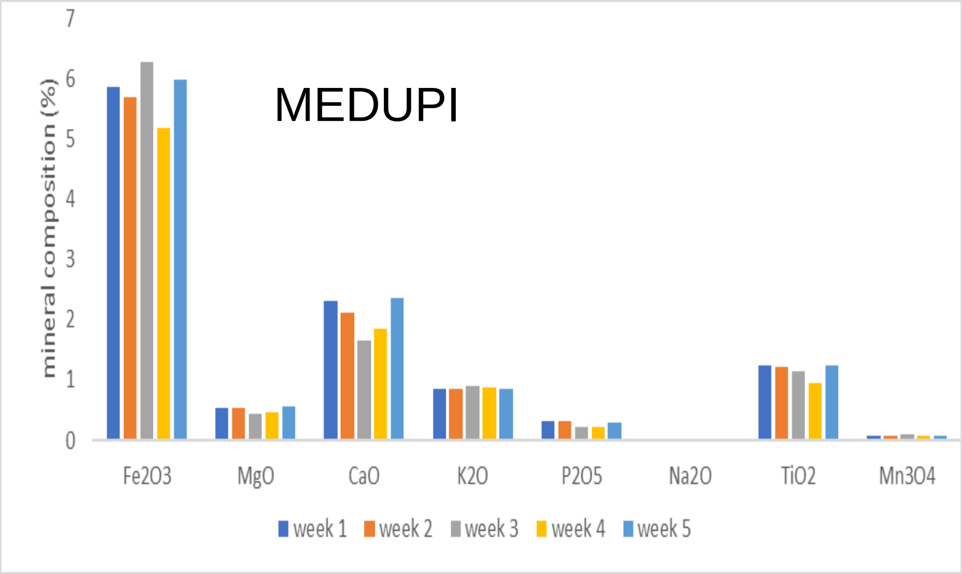
Laboratory Testing:

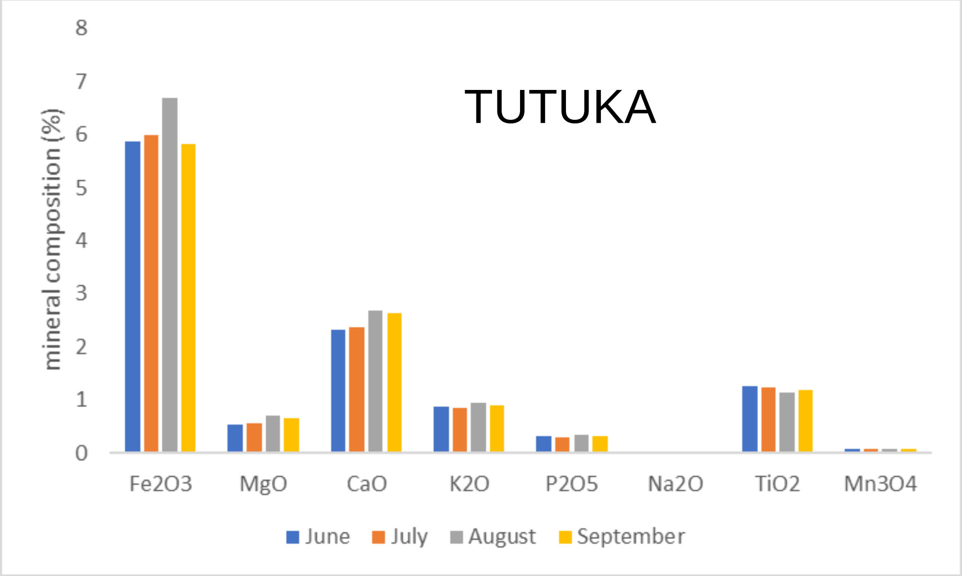
- Elemental Composition
- Mineralogy
- Particle Size Analyses, and
- Acid-Base accounting.

Comparison of Medupi and Tutuka ash variability (ELEMENTAL -5 WEEKS)

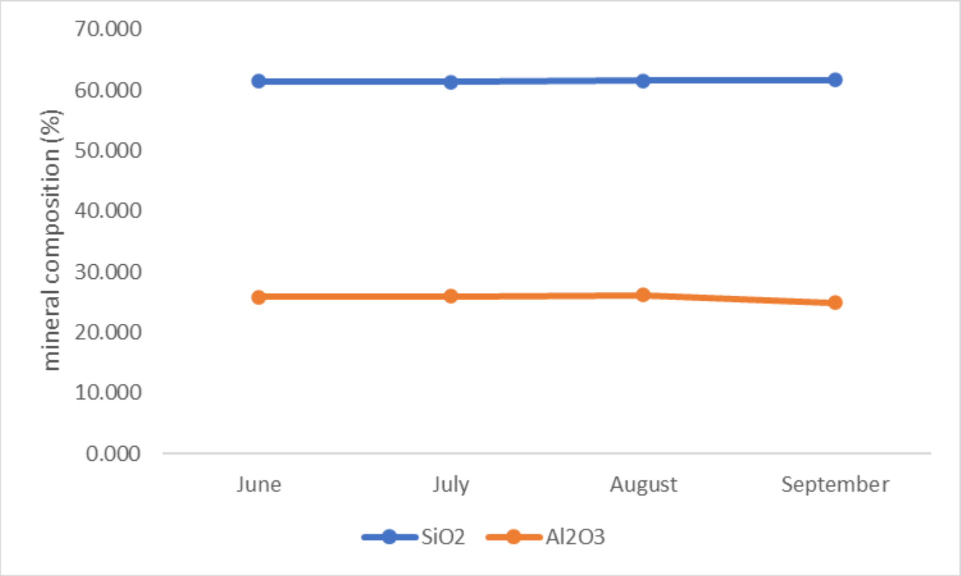


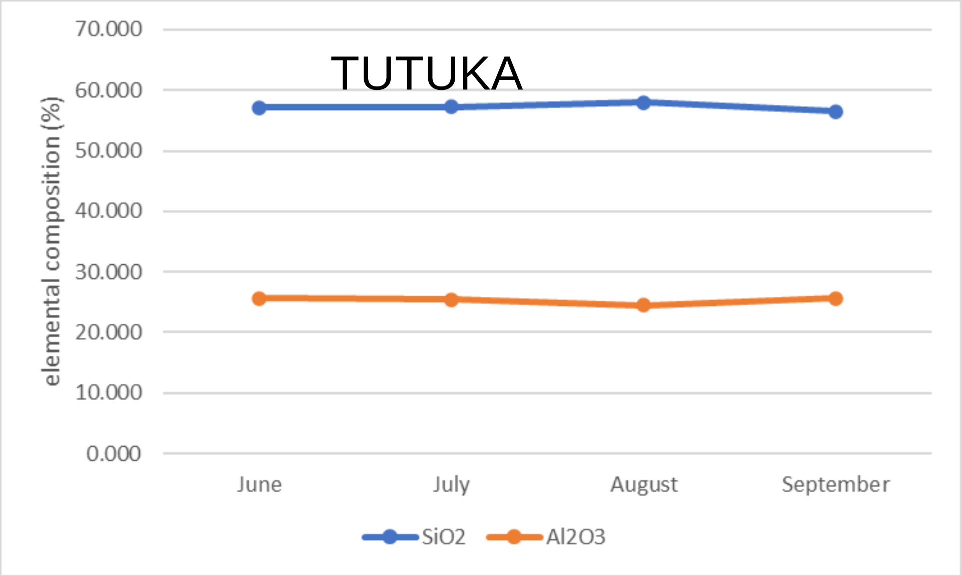


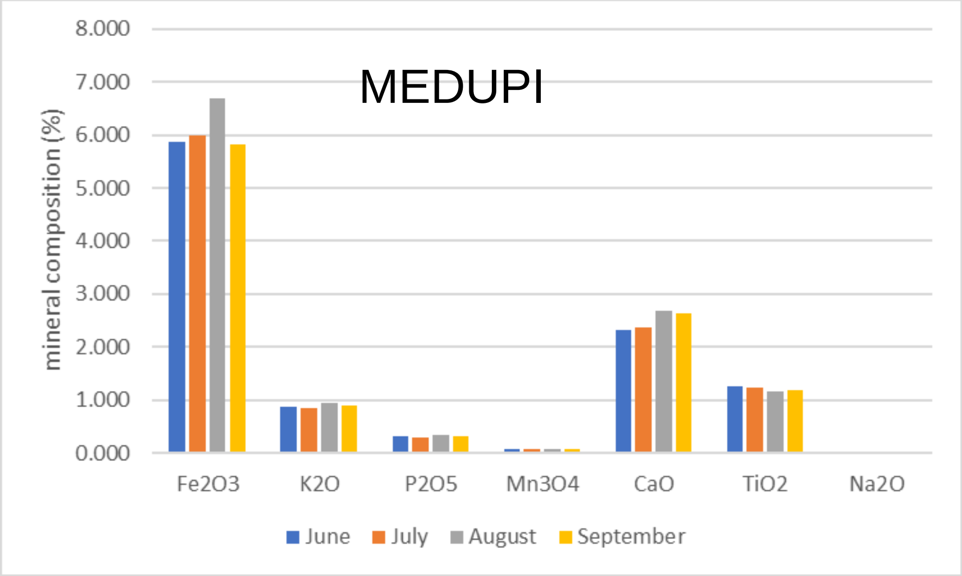


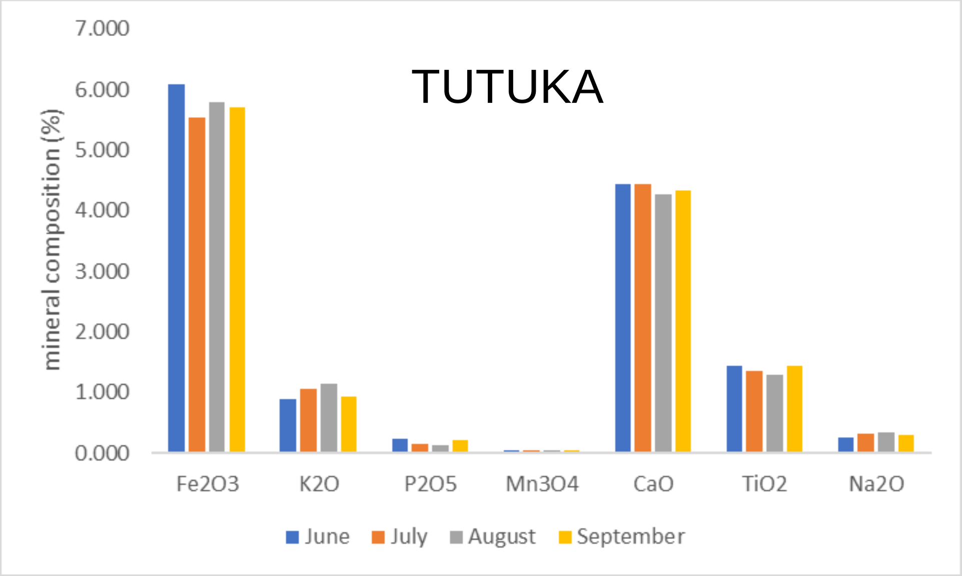


Comparison of Medupi and Tutuka ash variability (ELEMENTAL -4 MONTHS)

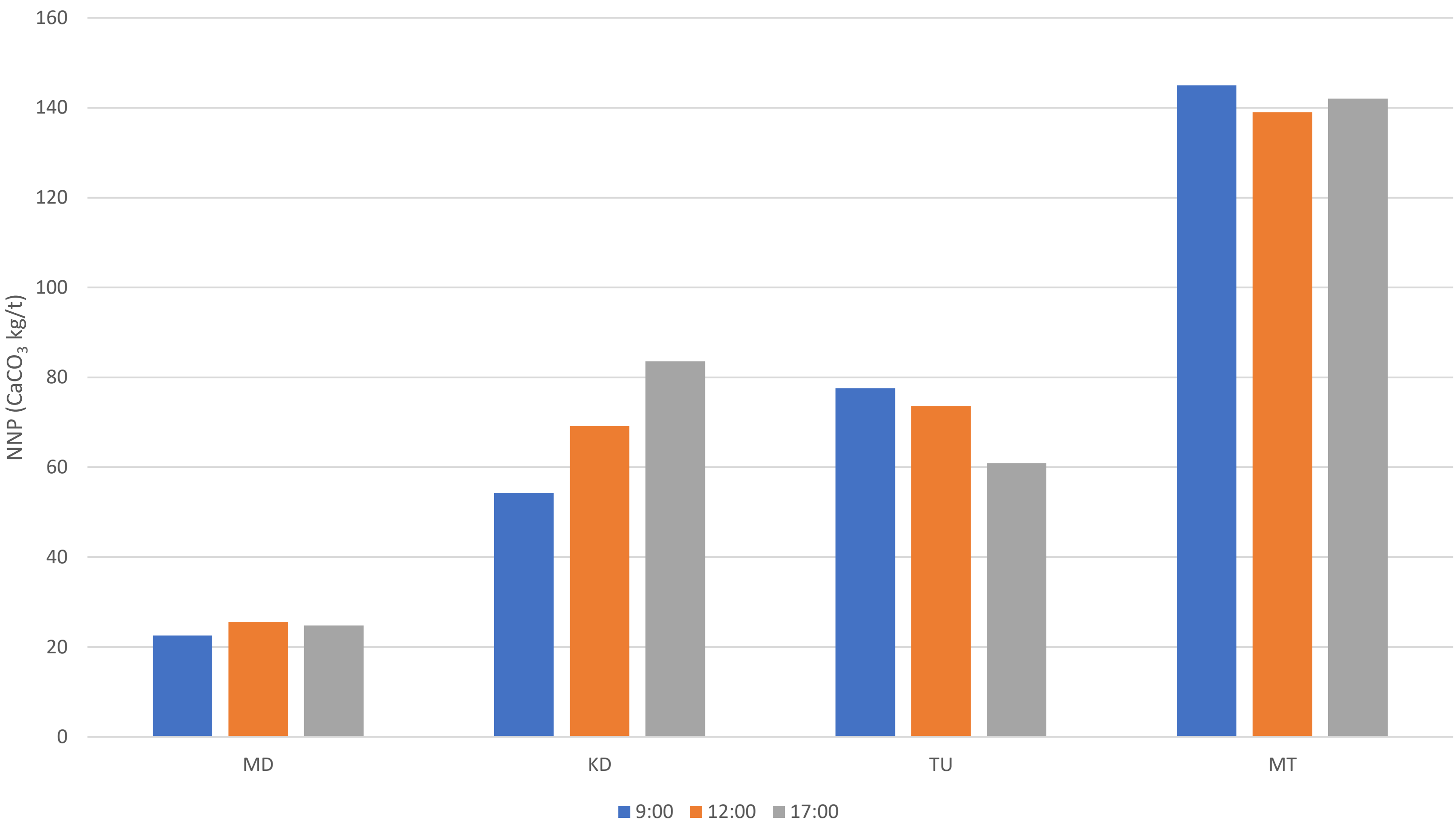






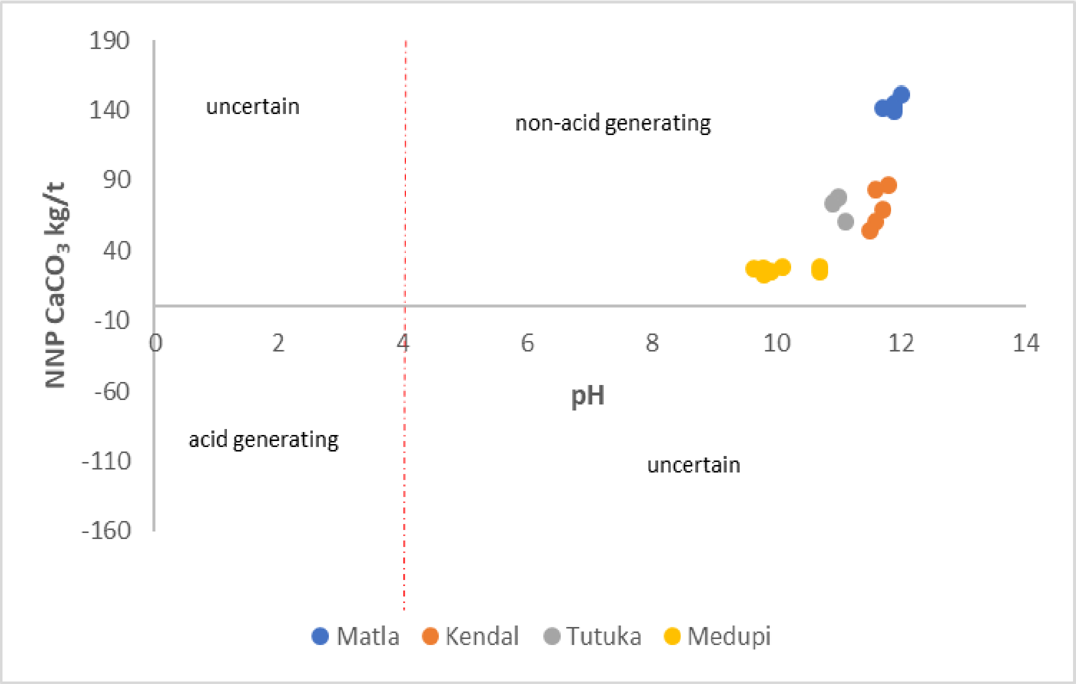


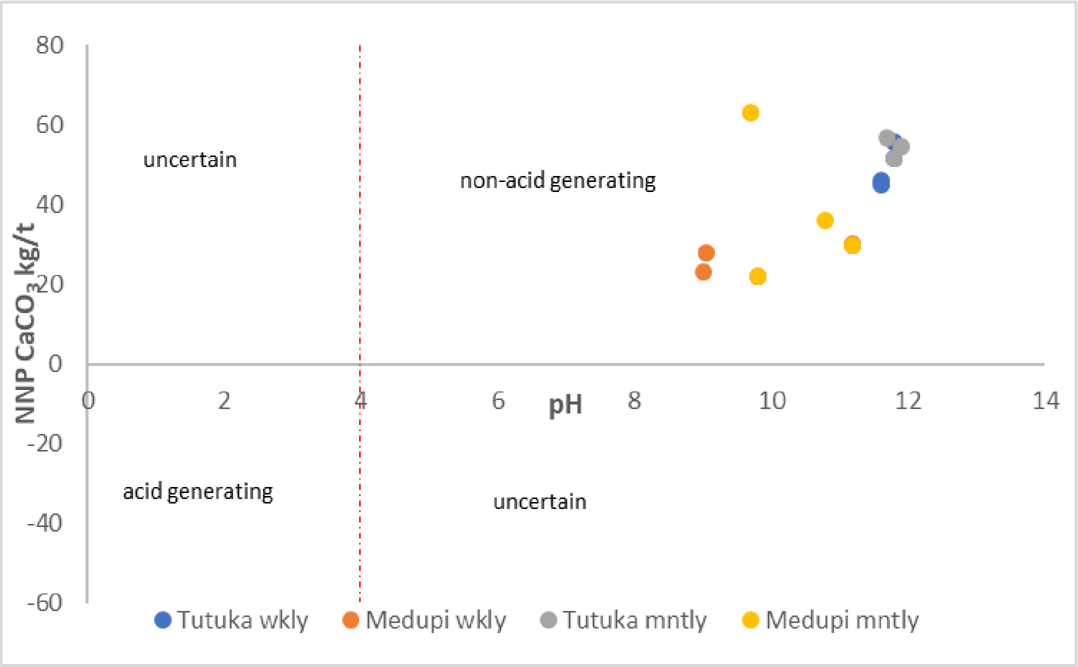
Acid-Base accounting



Net Neutralization Potential of (MD), (KD), (TU) and (MT) Power Station Ash with time

Net neutralizing capacity





Based on the static test results classification, all the samples tested for daily, weekly, and monthly analysis were in the non-acid generating class

Mine backfilling…First attempt

SECOND ATTEMPT

Field observations: Attempt 1

- **The unmodified CRA was washed away completely while the activated CFA was more stable.**

Field observations: Attempt 2

Again the CFA was washed away

During big storm events

Field challenges and proposed action

- The barrier (unmodified ash) was washed away before the ash formed a stable cake strong enough to withstand the rising water level, impacted by high rainfall and rapid flow rate during storms.

- The channel bed was also very loose and chances are that if a strong barrier is created some of the water will flow beneath the barrier.

- To allow the barrier to strengthen it would be ideal to construct it during the dry season.

- Since the modified ash was found to be more stable, the front of the barrier will be constructed using the modified ash.

Activated vs Unmodified CFA

The field barrier was made of unmodified CFA one side and activated CFA on the other.

Unmodified CFA

limitations

- lower engineering strength
- More prone to toxic metal leaching *(*mostly As, B & Se)*

advantages

- cheap and needs no modification

Activated CFA

limitations

- lower permeability and extra cost

advantages

- improved engineering strength
- lower toxic metal leaching

So will the activated CFA be more active in the remediation of AMD? *lab studies will confirm this.

Bench experiments…the lysimeter

Synthetic AMD was be prepared based on average values from analysed samples.

Lysimeter packing material

- Unmodified CFA
- Unmodified CFA mixed with granular material
- Activated CFA
- Activated CFA mixed with granular material

**the introduction of granular material is to enhance permeability.*

Depending on the outcomes from the bench experiments, appropriate modification to the field setup can be made.

Ash has been sampled from the mine site (the ash used for the field testing) 22nd June 2023, to ensure that the results are comparable.

Bench experiments…the lysimeter

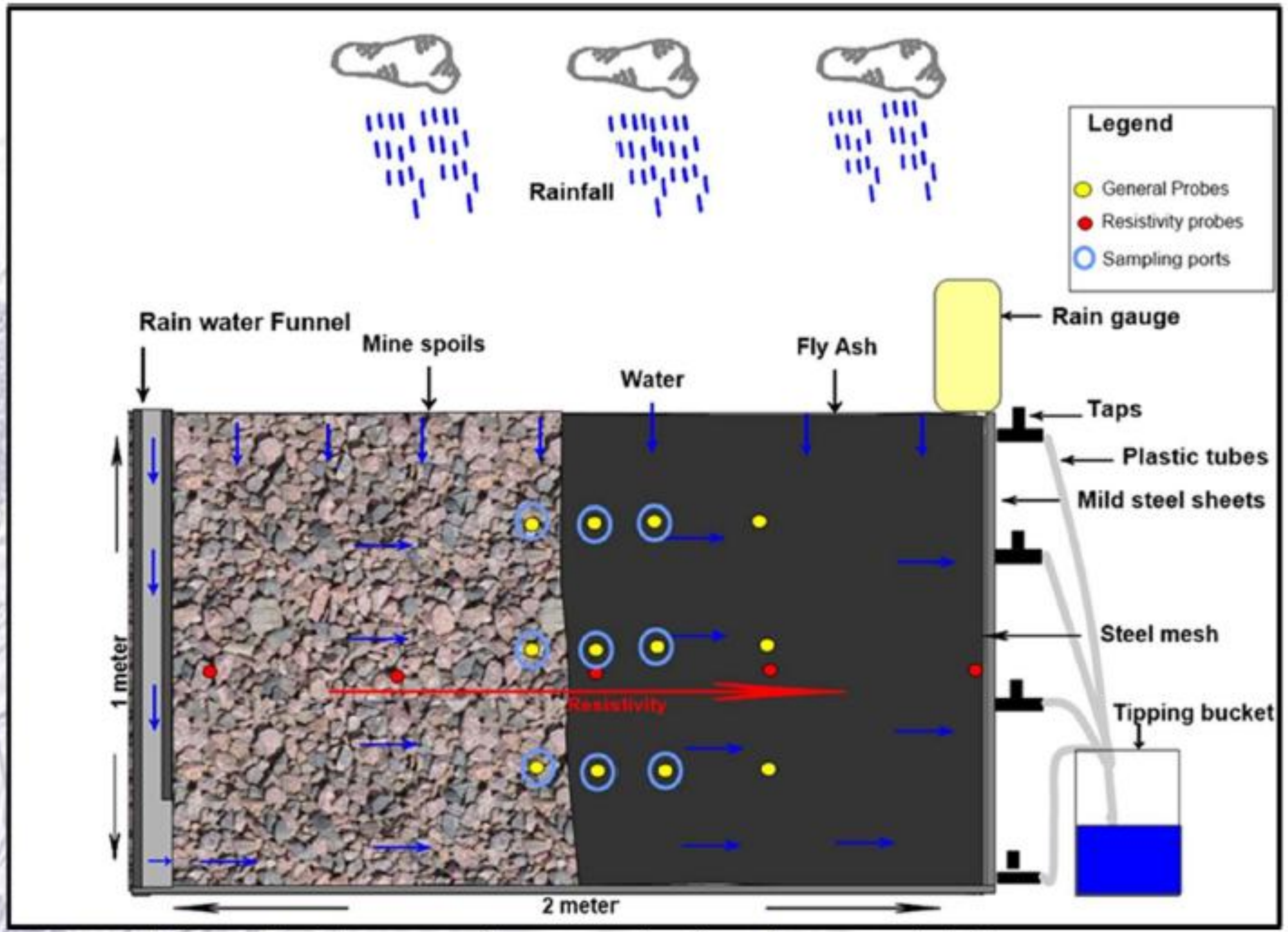
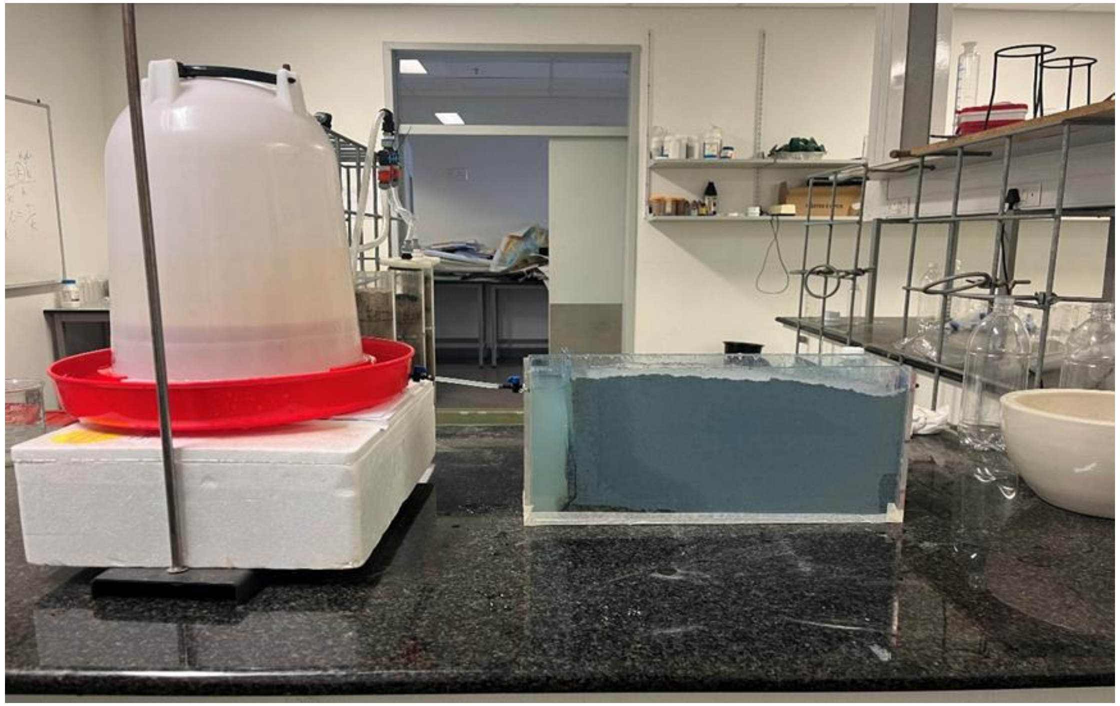


Figure 7: Schematic diagram of a free drainage field lysimeter

Synthetic AMD composition

- The synthetic AMD solution was made combining 10 litres of water and the following measurements of compounds,
- 20g Ferrous sulphate ($FeSo4$),
- 6g Cupric Sulphate pentahydrate ($CuSO4 \bullet 5H20$) and
- 1g each of Zinc Sulphate($ZnSO4 \bullet 7H20$),
- Calcium sulphate ($CaSO4$ $2H20$) and
- Magnesium sulphate Heptahydrate ($MgSO4.7H2O$).

Experimental Work



Coal Fly Ash with no modification and continuous flow

Synthetic AMD was allowed to saturate the ASH over 18 to 24 hours,
hourly sampling took place after that.

Time series experiments, allowed for monitoring metal sorption by CFA and CBA (Fe, Zn, Mn, and Cu), changes in pH and EC

Some Results

Binder and ash (no continuous flow)		
Time sampled	pH	EC(ms/cm)
T0 (Initial reading)	1.92	16.35
T1	6.30	5.65
T2	6.19	5.60
T3	6.29	6.10
T4	6.01	6.40
T5	6.24	6.30

ASH with a constant flow		
Flow rate	100ml per 13 minutes 37 seconds	
Time sampled	pH	EC
T0 (Initial reading)	1.71	10.25
T1	6.11	2.45
T2	6.25	3.30
T3	6.25	3.30
T4	6.26	3.15
T5	6.26	3.25
T6(20h continuous flow)	6.38	2.85
T7(2H continuous flow)	6.45	2.65

Results

- pH values have increased from highly acidic (1.7 to 2.6) to near neutral and even above 7 for certain experiments.
- The results revealed that the CFA had higher acid neutralization capacity relative to that of CBA.
- The addition of the binder and coarse material increased the overall performance of the adsorbents and outperformed the adsorbents without additives
- The CBA and CFA were highly effective in removing the heavy metals from the AMD, tests showed that Fe, Cu, Zn and Mn had removal efficiency above 70% up to 99% in batch experiments

Site Monitoring

Water Quality

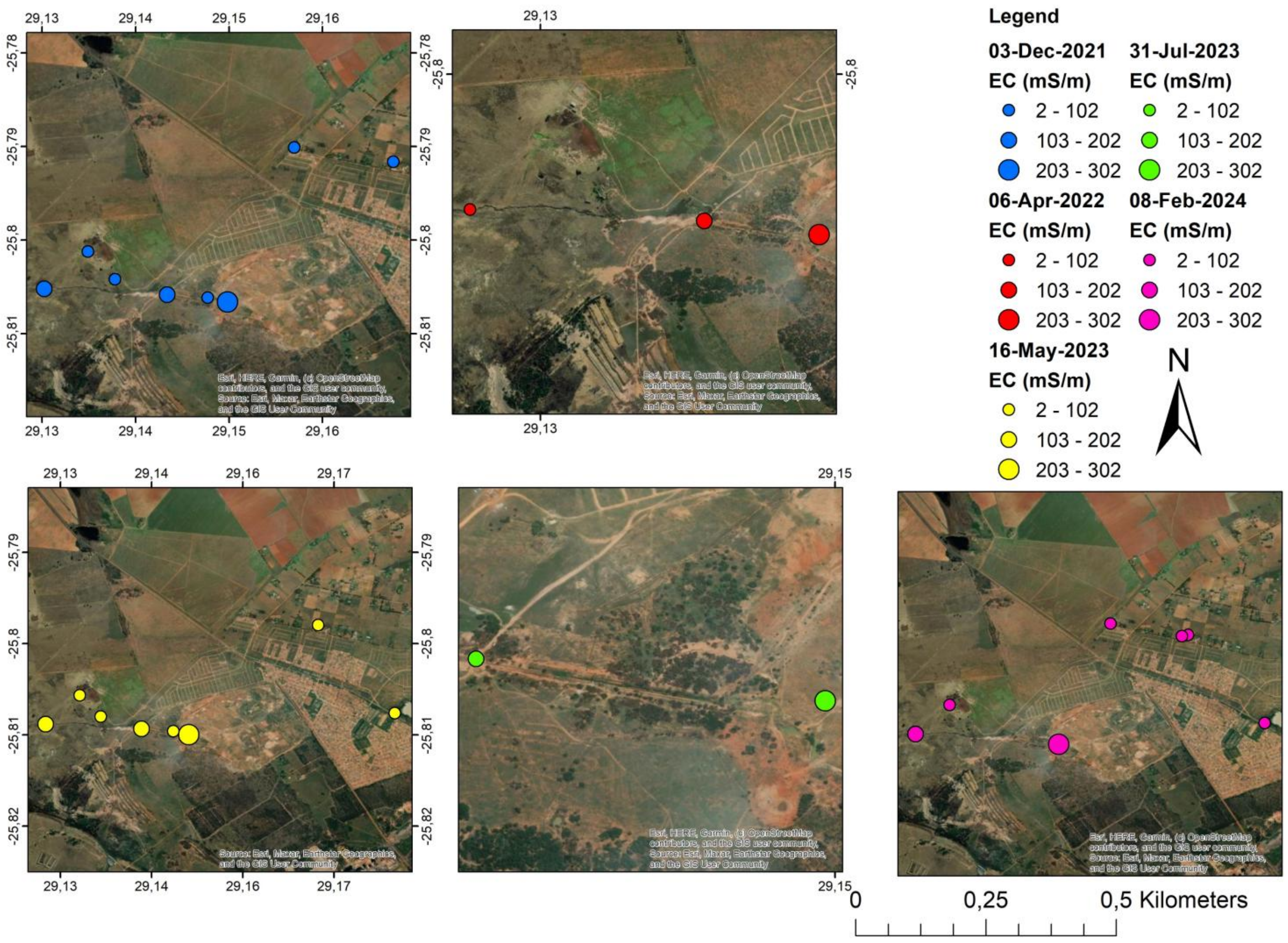
- Surface water quality vs SANS standards

- Mine Decant Point, Trench Middle and Trench End are samples of mine water discharge and show poor water quality exceeding the limits for EC, TDS , pH (acidic), sulphate (SO_4), iron (Fe), manganese (Mn), aluminium (Al) and nickel (Ni). Drainage water from coal mines is strongly acidic and often leads to acidification of water bodies which allows for mobilisation of metals.
- Mine Decant Point and Trench Middle exceeded the water quality limits of magnesium (Mg).

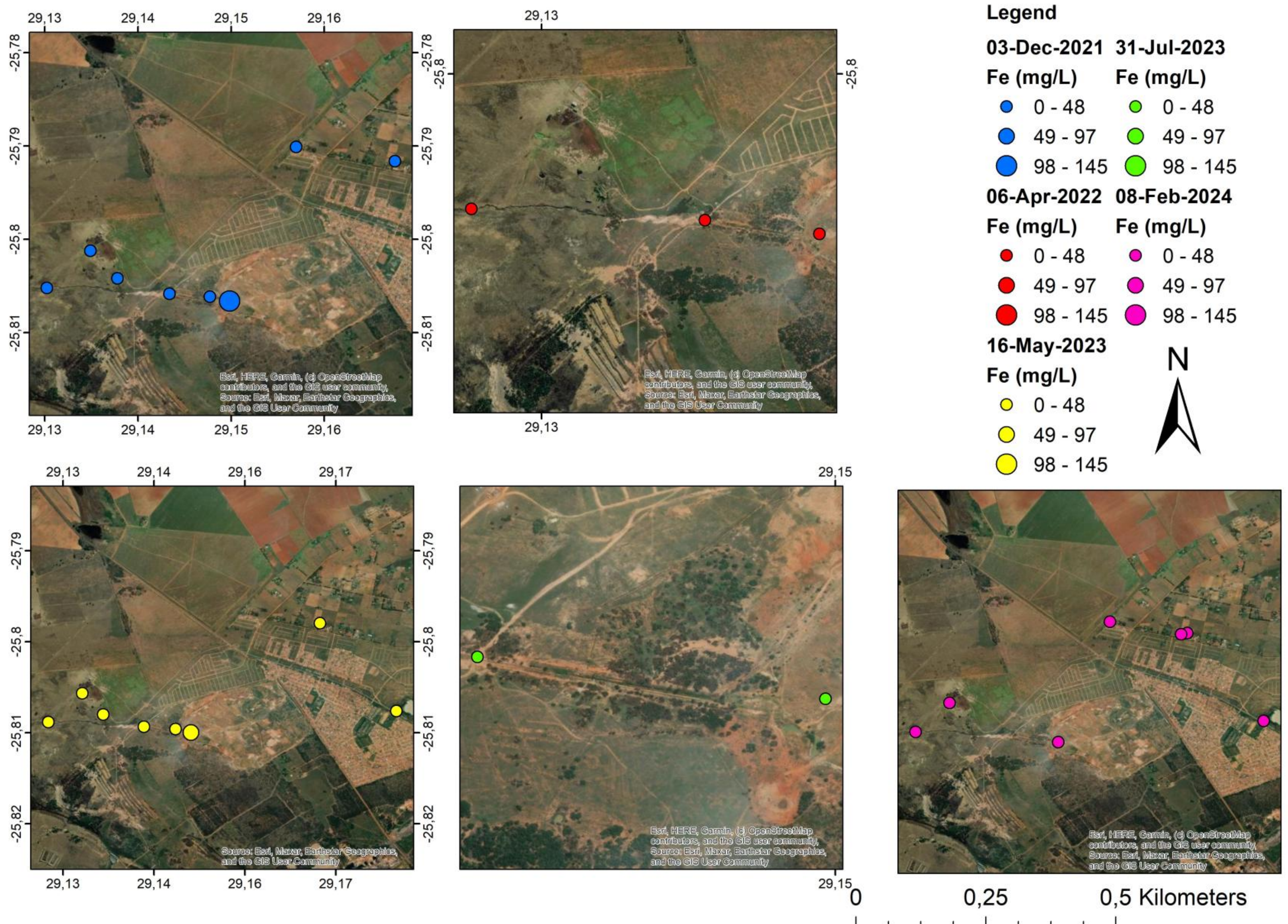
Water Quality

- Groundwater quality vs SANS standards
- Three (3) boreholes (BH6, BH7, BH91A) indicated good water quality for human consumption as they did not exceed the standards.
- Manganese concentrations exceeded the standard limit in BH4A and BH15 indicating poor water quality due to acidification of drainage water from historical coal mining.

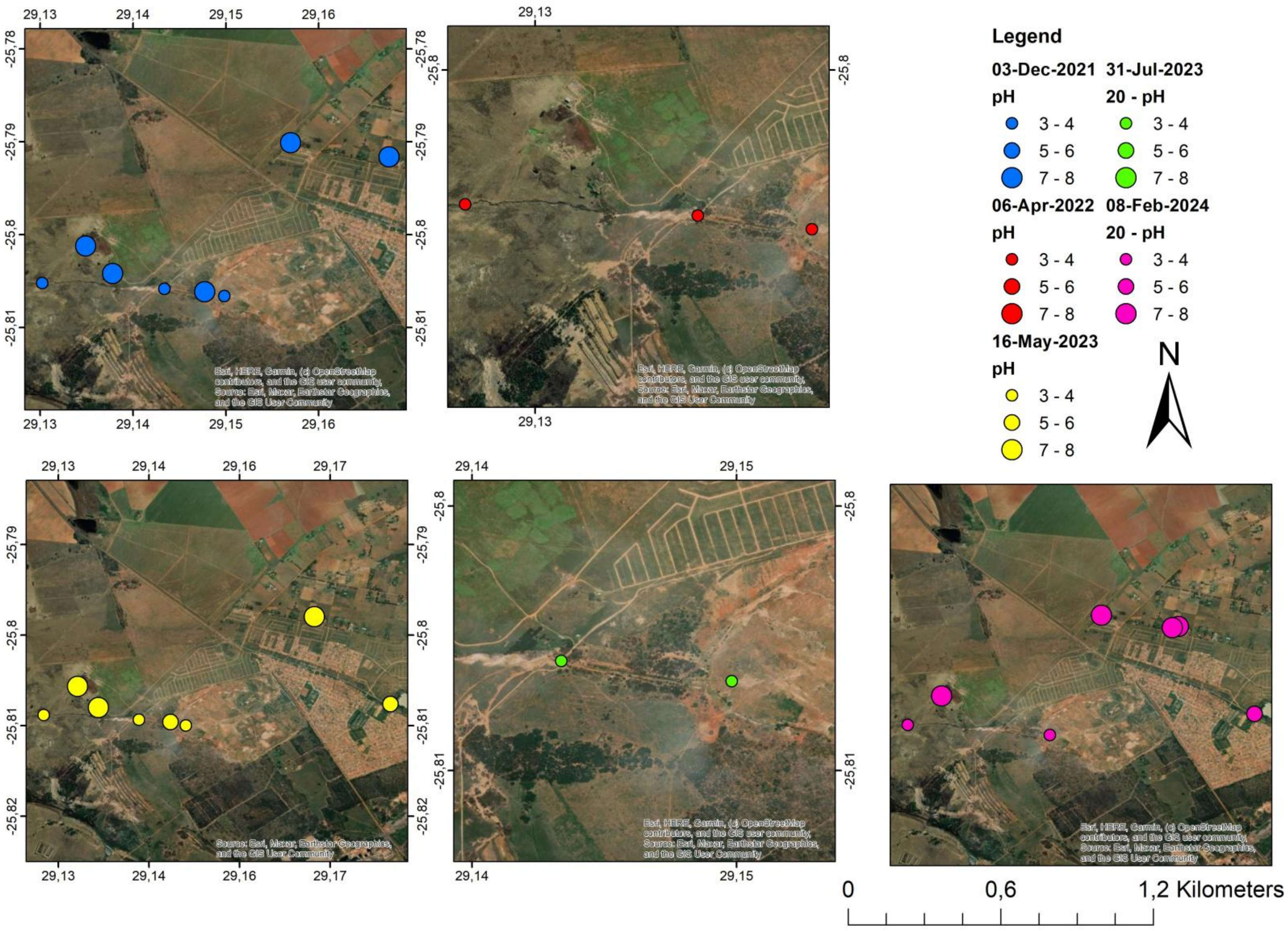
Distribution of EC at monitoring points



Distribution of Fe concentrations



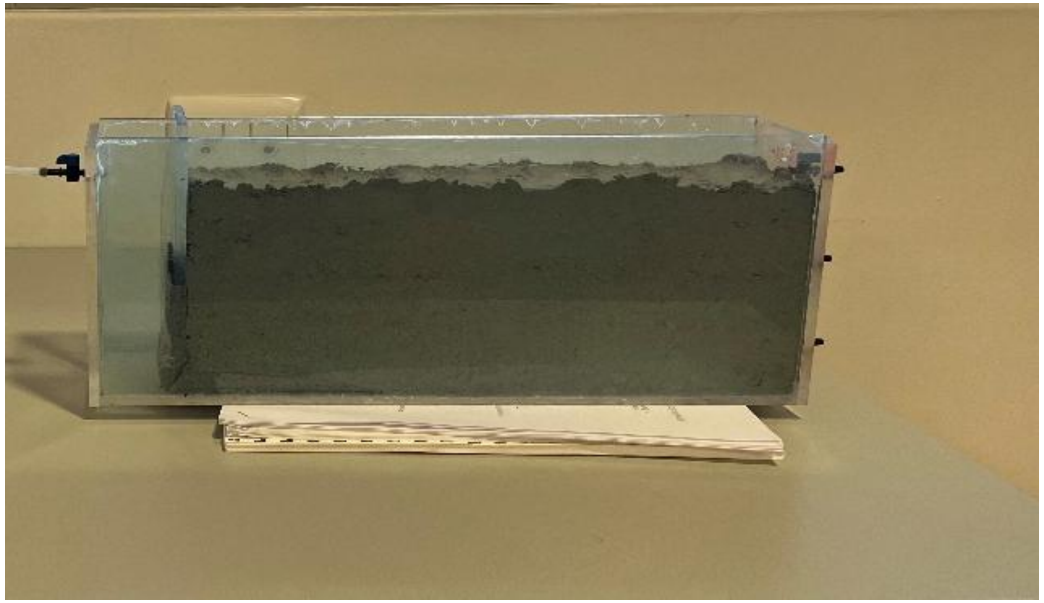
Distribution of pH

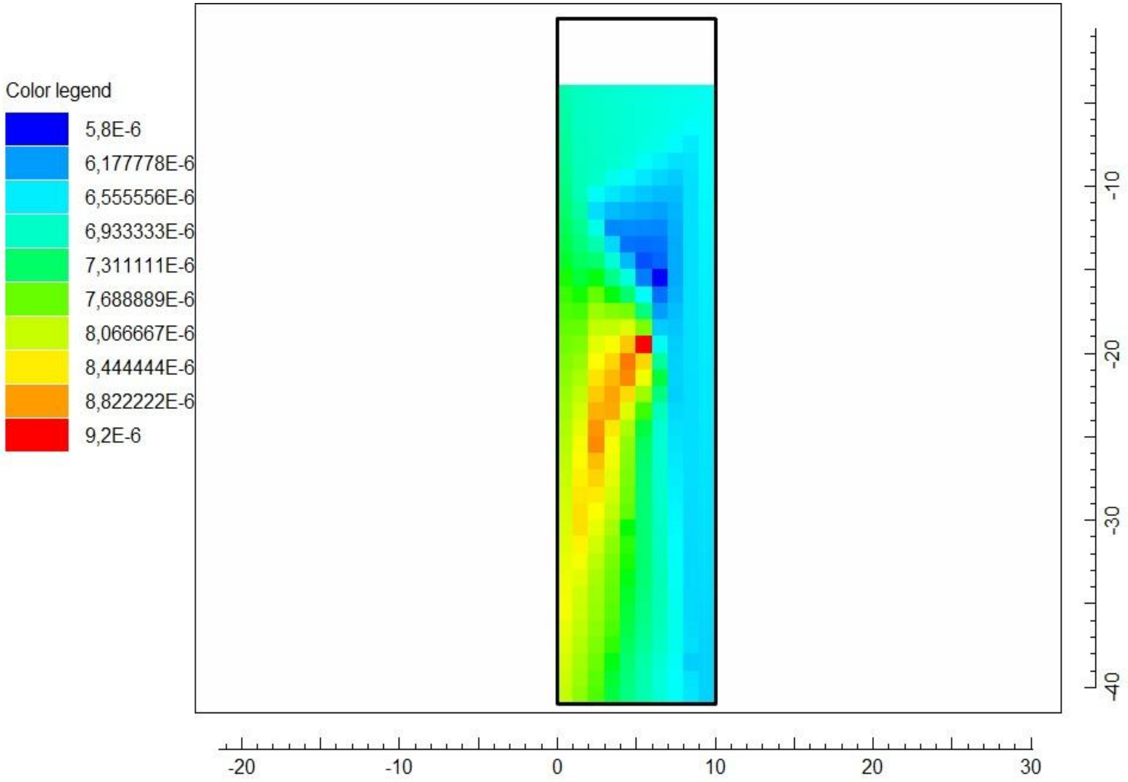


Modeling

- Start with Conceptualizing theoretical scenarios and site conditions
- Scenarios/conceptual models were constructed using the hydraulic properties: CFA/CBA, mine spoils, river flow, hydraulic conductivity values and geological formations
- simulate the changes in the hydrogeological flow regime, such as the hydraulic head and flow direction, using numerical groundwater flow models
- Identify changes in contaminant concentrations and plume migrations, using numerical solute transport models

Modelling





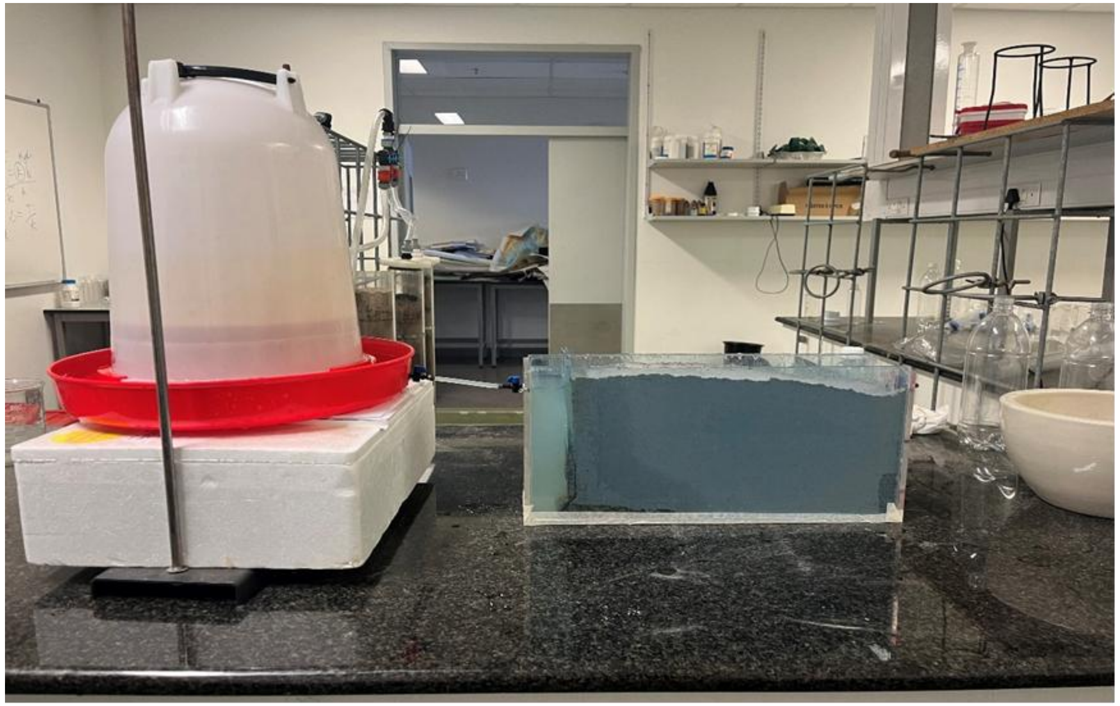
For Lysimeters:

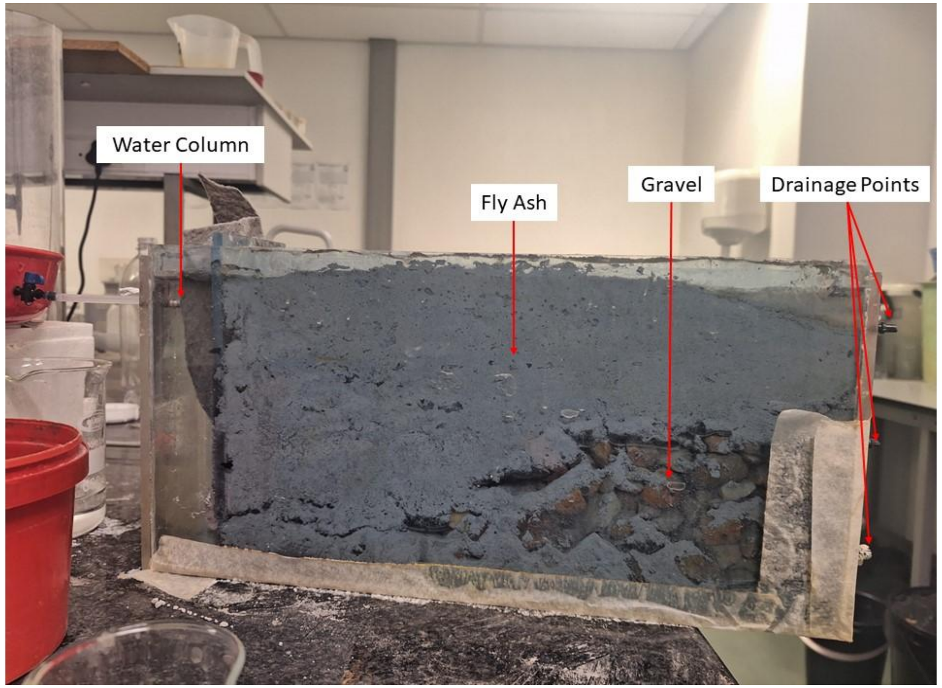
1) Scenario 1: filled with only fly ash,

2) Scenario 2: filled with a random mix of gravel and fly ash,

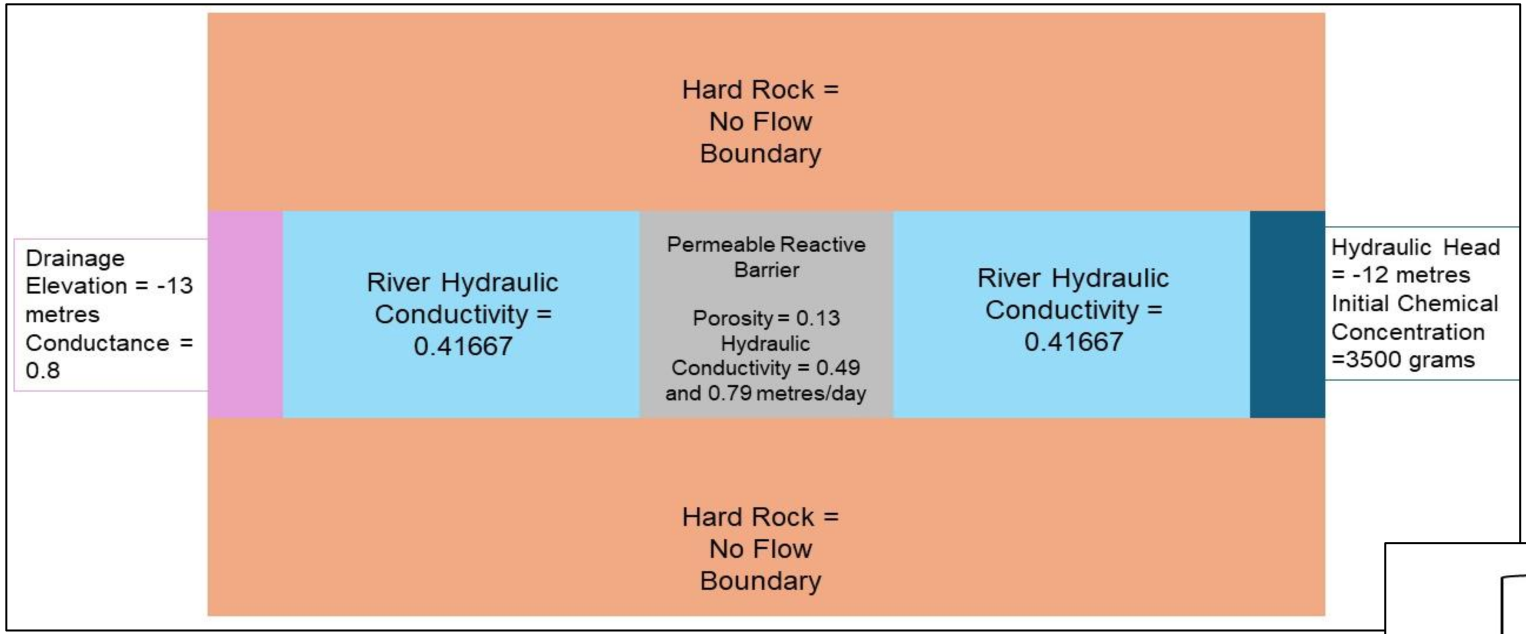
3) Scenario 3: an arranged mix of gravel and fly ash

Scenarios

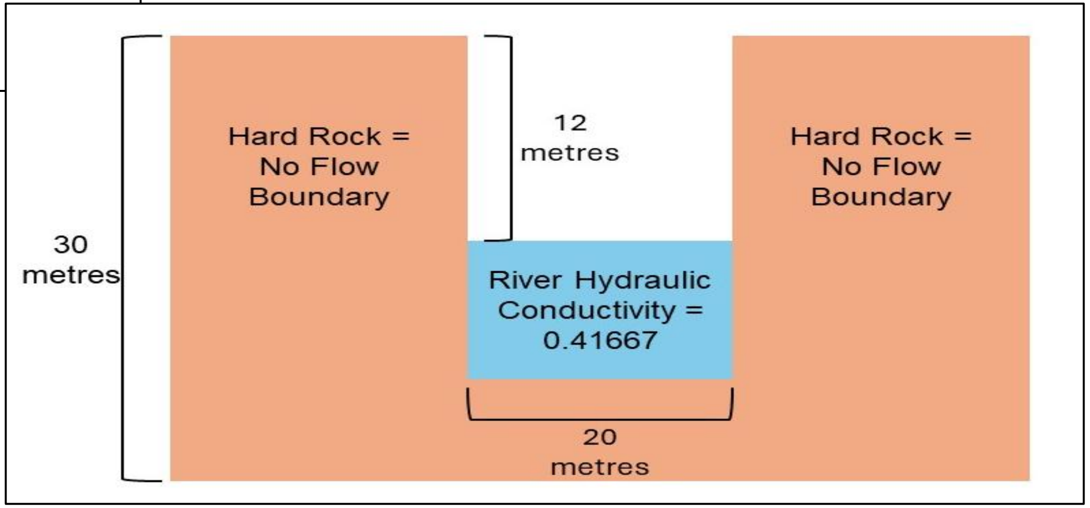




Field Model



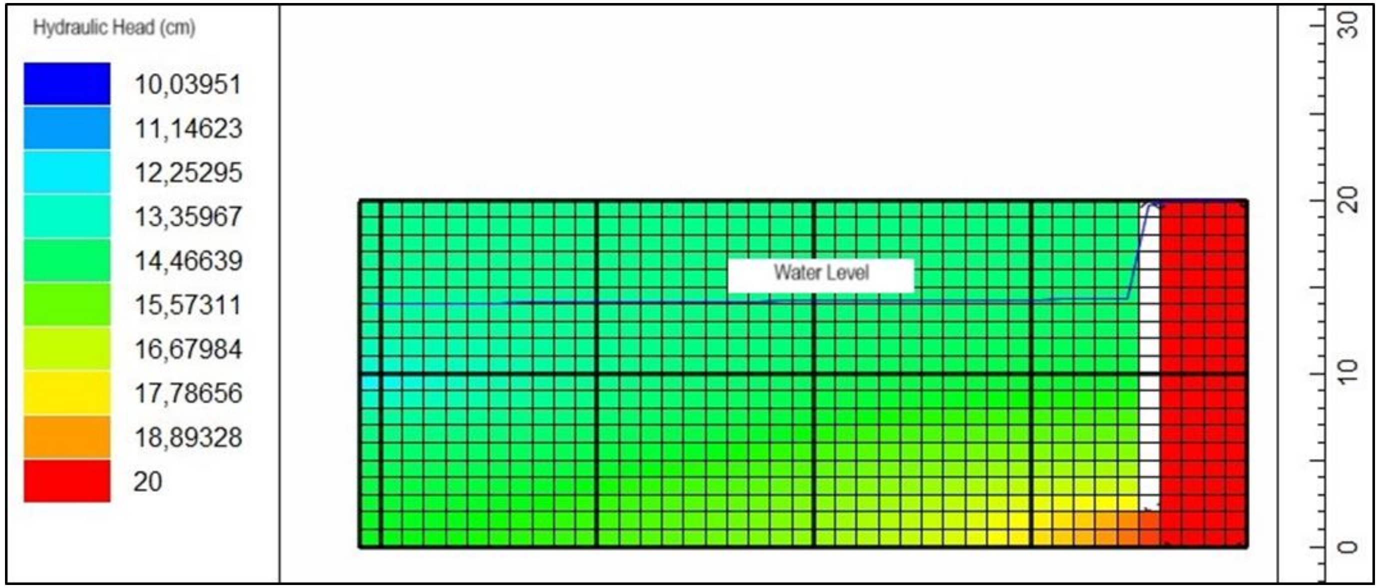
Measured parameters, values from literature if not able to measure. Important that values are as close as possible to actual values for reliable results



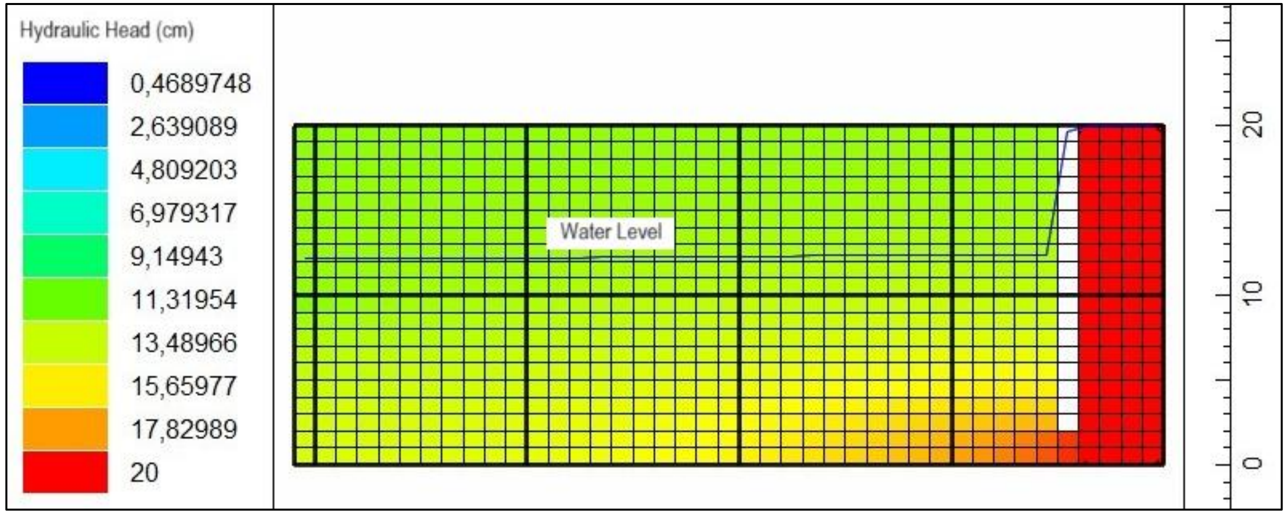
Results

Scenario 1:

- Water flow is as expected, away from the constant head towards the drainage point on the opposite side of the lysimeter. Water flow for Scenario 1 is considered to be slower when compared to the other two scenarios.



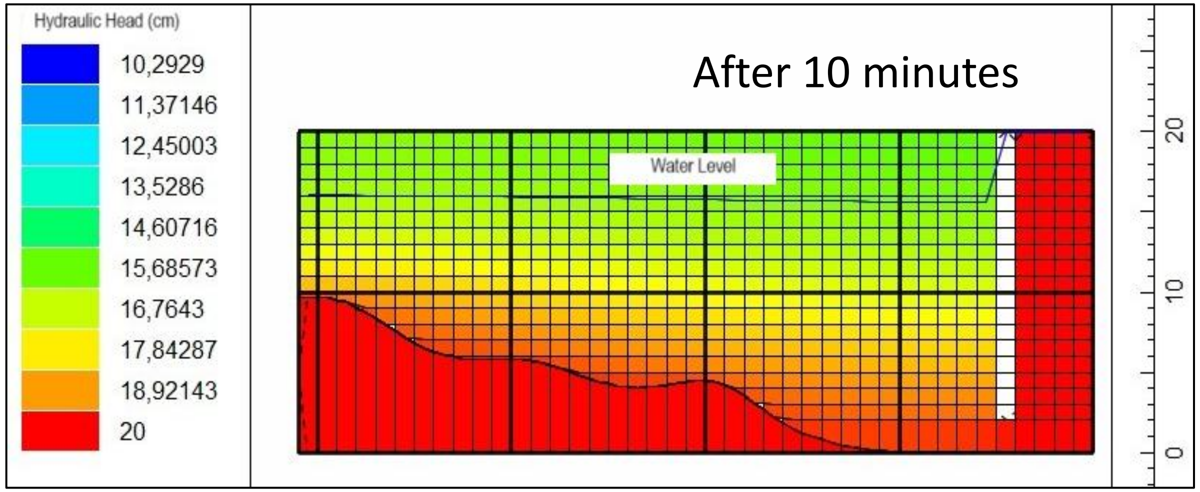
Scenario 2



Similar to Scenario 1, water flows away from the constant head towards the drainage point on the opposite side of the lysimeter (direction: right to left). The speed at which water flows through the lysimeter is faster than the flow of water in Scenario 1.

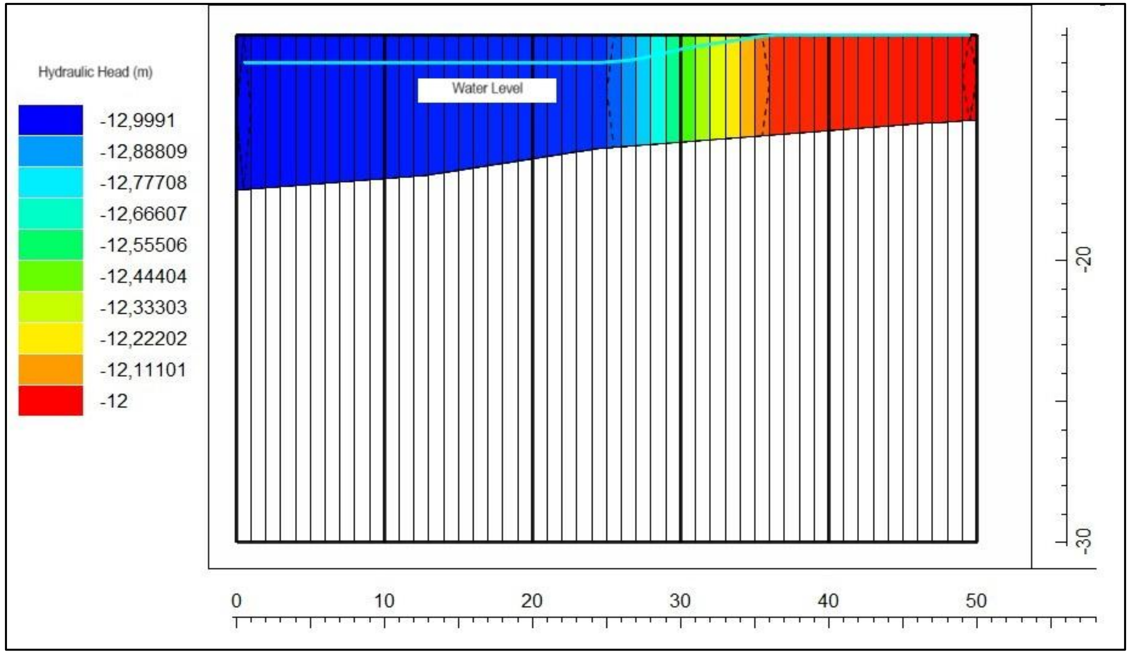
The water flows in three distinct paths shown in the Figure. The contamination plume is concentrated along these flow paths and in the saturated zone of the lysimeter which is comparable to the contamination plume simulated in Scenario 1.

Modelling



- Scenario 3:
- The speed at which water flows through the lysimeter is the fastest compared to Scenarios 1 and 2.
- Scenario 3 the lysimeter is more saturated than the other scenarios. This is most likely due to the porosity of the gravel layer which allowed water to infiltrate faster and saturate the fly ash above the gravel layer much faster.

Modelling of Field Scenario



- The results of the permeable reactive barrier model suggests that a state of equilibrium is achieved after one hour of full saturation of the barrier.
- The design of the barrier allows for controlled water movement, slowing down water but not obstructing flow completely
- Because advection and dispersion did not reduce contaminant concentrations, actual chemical and reactive chemical simulations are recommended to understand contaminant behaviour.

Concluding remarks

- The experiments demonstrates that the ASH has successfully increased the pH in both experimental designs and we were able to remove metals from AMD up to 99% removal.
- The EC of the water has also been reduced. This relates to possible sorption or attenuation of dissolved constituents of the water.
- With respect to monitoring, it is evident that the mine decant has a greater impact on the river water quality than the groundwater, probably due to the geological make –up and water rock interaction which changes the water composition over time
- Model results show that flow of dissolved chemical species and water movement differs depending on the composition of the barrier material/back fill material mixture. Models simulate flow, dispersion and advection. Continued work on chemical reactions with flow needs to follow on from this work.