Evaluating the Toxicity of Produced Water for Beneficial Reuse in the Permian Basin

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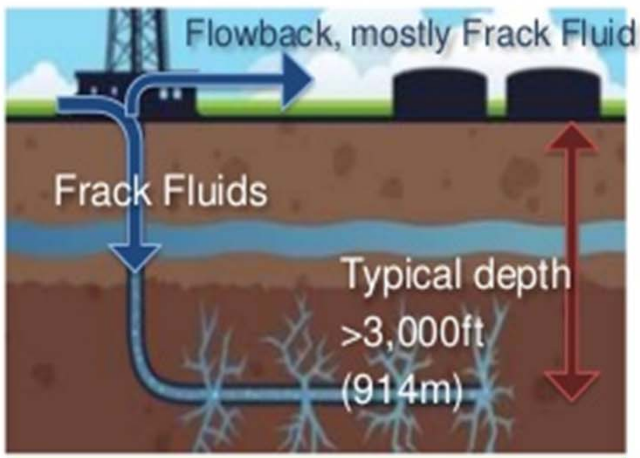
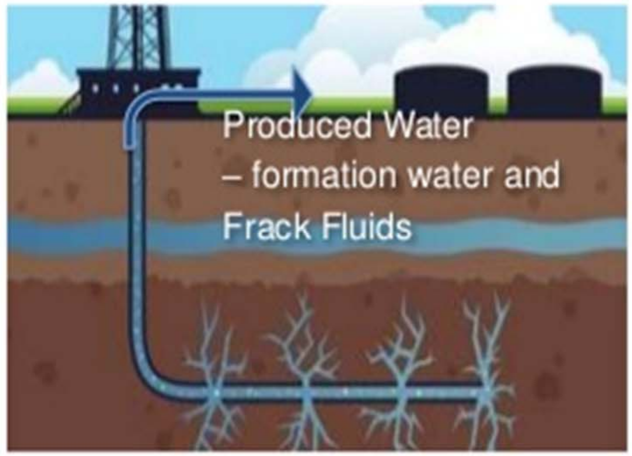
Background

What is produced water from shale oil and gas production?



Flowback water



Produced water

Produced water (PW)

- Generated continuously throughout the life of the well
- High levels of total dissolved solids (TDS)
- Hazardous organic and inorganic contaminants
- Great risks to the human health and environment

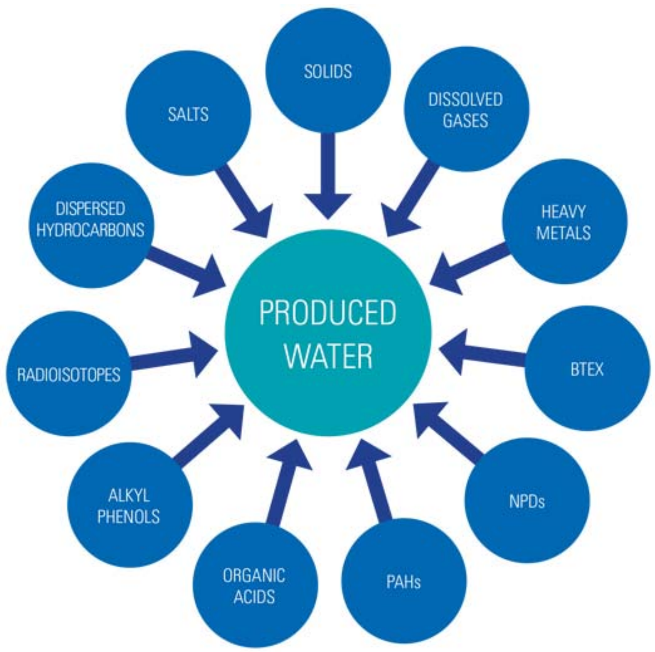
✓ Intense freshwater consumption and significant hazardous wastewater production

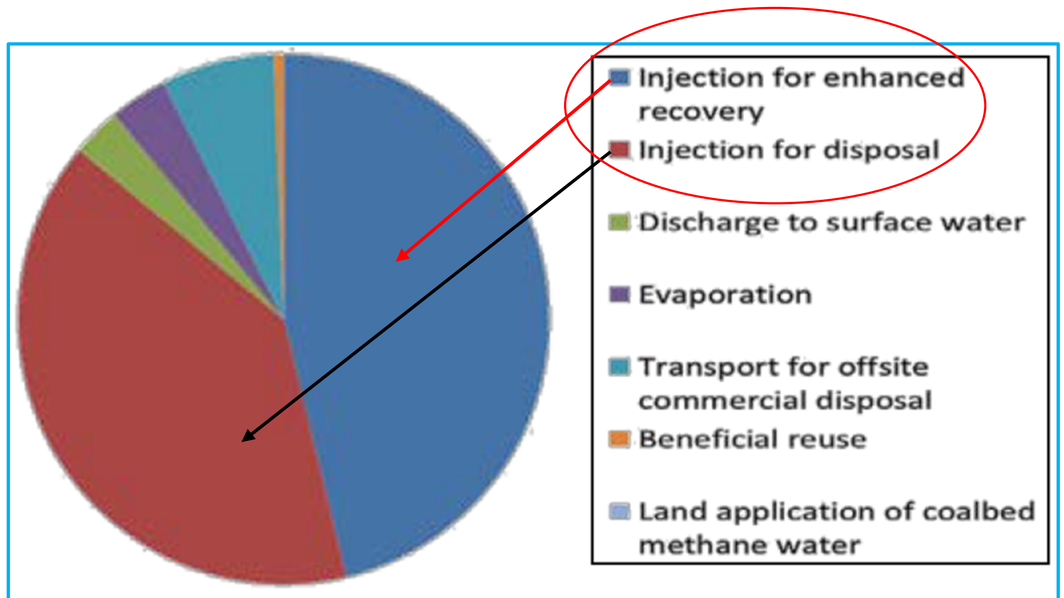
✓ PW is the largest waste stream associated with shale oil and gas production

A. Kondash, A. Vengosh, Water footprint of hydraulic fracturing, Environmental Science & Technology Letters 2 (2015) 276-280

Background

Produced water management





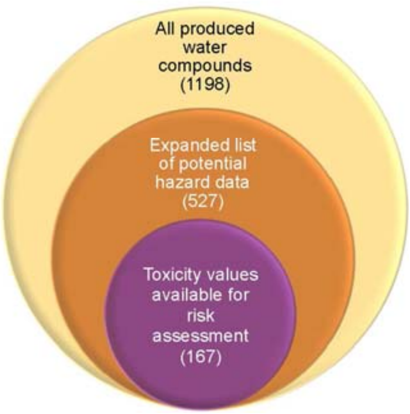
Management of PW in the U.S. in 2018

- Deep-well injection (>90%) is the main technology for PW disposal in the U.S.
- Effective and economically feasible management for PW is in urgent need

http://www.veilenvironmental.com/publications/pw/prod_water_volume_2012.pdf

Research motivation

- Monitoring water quality parameters alone cannot ensure the safe discharge and reuse



Complexity of PW Composition

More than 1000 chemicals detected: salts, heavy metals, radionuclides, oil and grease, BTEX, PAHs, phenols, etc.

Necessity of toxicity assays

- The assessment of toxicity should be done for PW management.

Pretreatment	Advanced Treatment	Posttreatment
SS and organic removal	Salinity and CEC removal	Concentrate management
Physical and biological processes	AOP and Membrane processes	Disposal processes

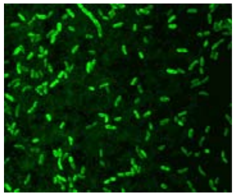
- The performance of existing treatment technologies on toxicity reduction needs to be investigated.

C. Danforth, et al., An integrative method for identification and prioritization of constituents of concern in produced water from onshore oil and gas extraction, Environment intl. 134 (2020) 105280

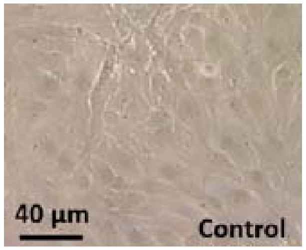
Research Methodology

***In vitro* acute and chronic toxicity assays based on various organisms**

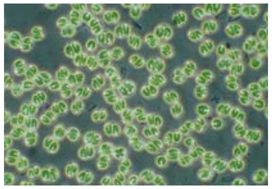
- **Microtox toxicity**
  - Acute toxicity towards a marine luminescent bacterium *Vibrio fischeri*
  - Bioluminescence intensity measurement



- **Cytotoxicity**
  - Acute toxicity towards fish cell line RTgill-W1 (gill epithelia, rainbow trout)
    - Cell viability by MTT assay (metabolic active cells)
    - Cell lysis by lactate dehydrogenase (LDH) assay (Damage of cell plasma membrane)



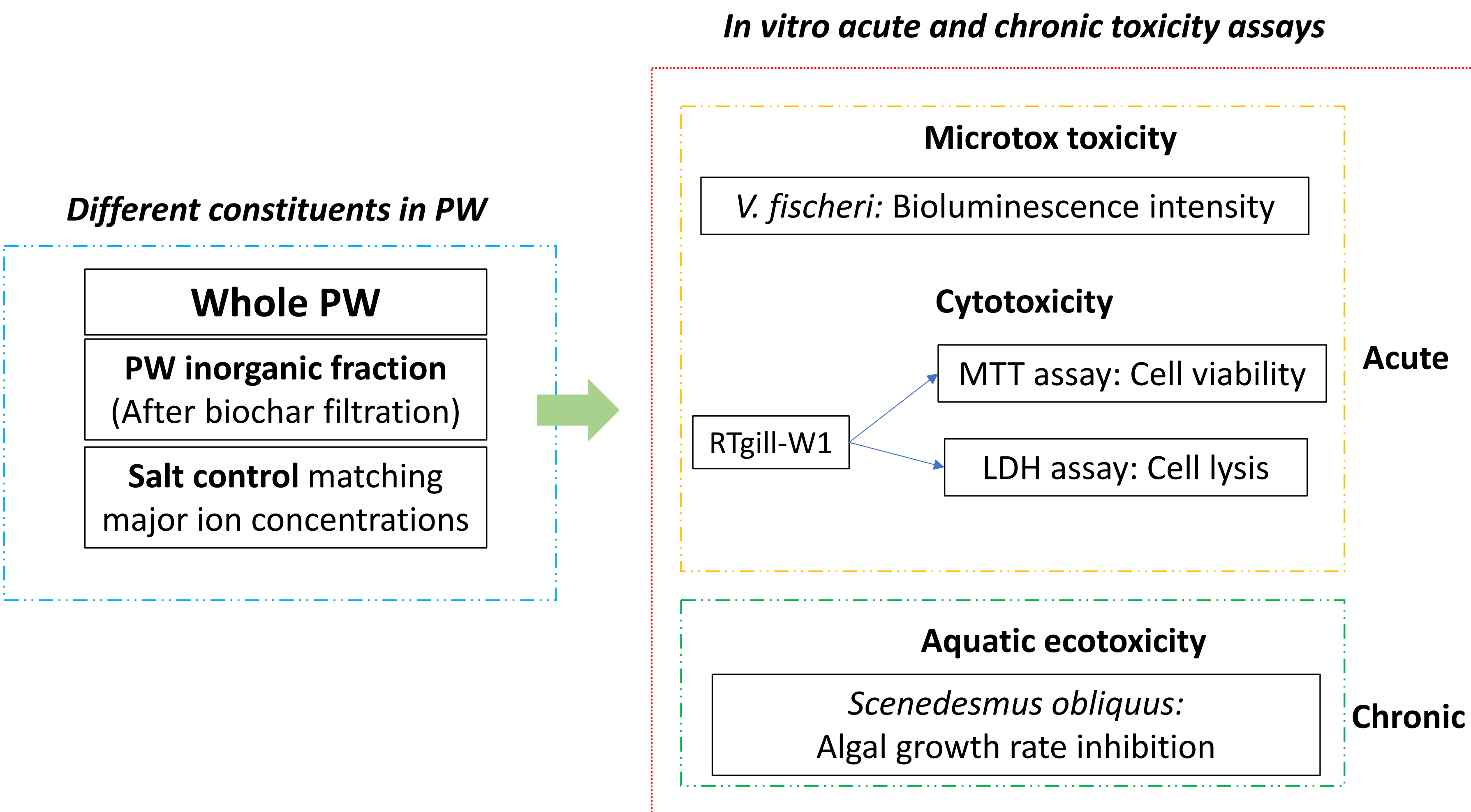
- **Aquatic ecotoxicity**
  - Chronic toxicity towards freshwater algae *Scenedesmus obliquus*
  - Algal growth at Abs680



Providing a short list of toxicity assays for a quick assessment of PW

https://www.sigmaaldrich.com/technical-documents/protocols/biology/roche/cell-proliferation-kit-i-mtt.html

Research Methodology



Results

Physicochemical characteristics of PW

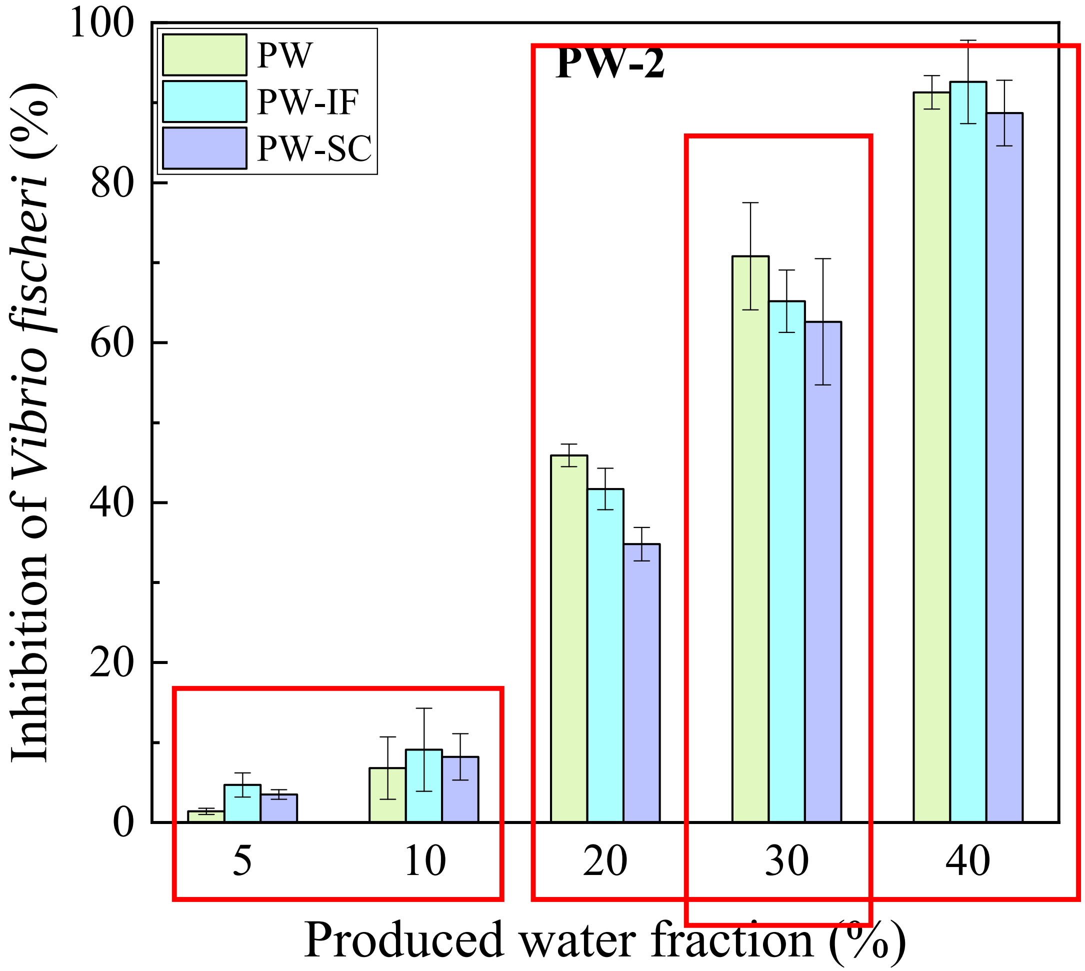
Parameter	Symbol	Unit	Mean value		
			PW-1	PW-2	PW-3
pH	-	-	6.8	6.9	6.6
Electrical conductivity	-	$mS\ cm^{-1}$	226.4	241.4	310.5
Total organic carbon	TOC	$mg\ L^{-1}$	52.1	72.5	139.7
Total dissolved solids	TDS	$g\ L^{-1}$	160.4	172.2	219.6
Total nitrogen	TN	$mg\ L^{-1}$	381.2	507.8	691.5
Ammonium	NH_4^+	$mg\ L^{-1}$	483.4	654.4	879.3
Boron	B	$mg\ L^{-1}$	51.3	53.6	51.9
Bromide	Br^-	$mg\ L^{-1}$	651.7	916.8	972.3
Chloride	Cl^-	$mg\ L^{-1}$	88276	95576	116582
Magnesium	Mg	$mg\ L^{-1}$	932.1	1167.5	1327.3
Sodium	Na	$mg\ L^{-1}$	38755	41867	56629
Strontium	Sr	$mg\ L^{-1}$	805.7	924.6	723.1
Arsenic	As	$mg\ L^{-1}$	1.69	1.66	1.83
Barium	Ba	$mg\ L^{-1}$	2.513	2.758	2.612
Cadmium	Cd	$\mu g\ L^{-1}$	0.76	0.75	0.83
Chromium	Cr	$\mu g\ L^{-1}$	1.52	2.31	1.68
Cobalt	Co	$\mu g\ L^{-1}$	7.52	7.96	7.53
Iron	Fe	$mg\ L^{-1}$	12.08	21.95	22.08
Manganese	Mn	$mg\ L^{-1}$	1.12	1.36	1.36

- TOC: 52.1~139.7 mg/L
- TDS: **160.4~219.6 g/L**.

- **PW-3** has the **highest** concentrations of **TDS, TOC, TN and heavy metals**.

Results

Microtox® toxicity



PW: Whole PW

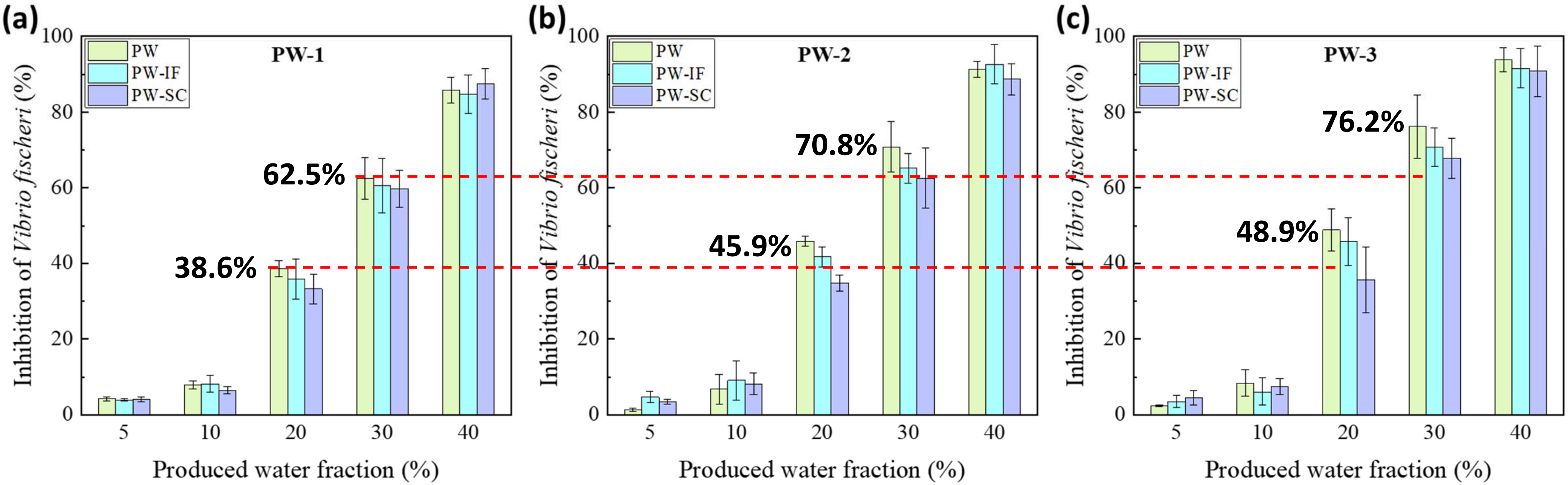
PW-IF: PW inorganic fraction

PW-SC: PW salt control

- Enhanced toxicity was probably attributed to the **increased salinity** in PW.
- **Organics** were partially responsible for the acute toxicity.
- High salinity was **the predominant toxicological driver**.

Results

Microtox® toxicity



Increased toxicity

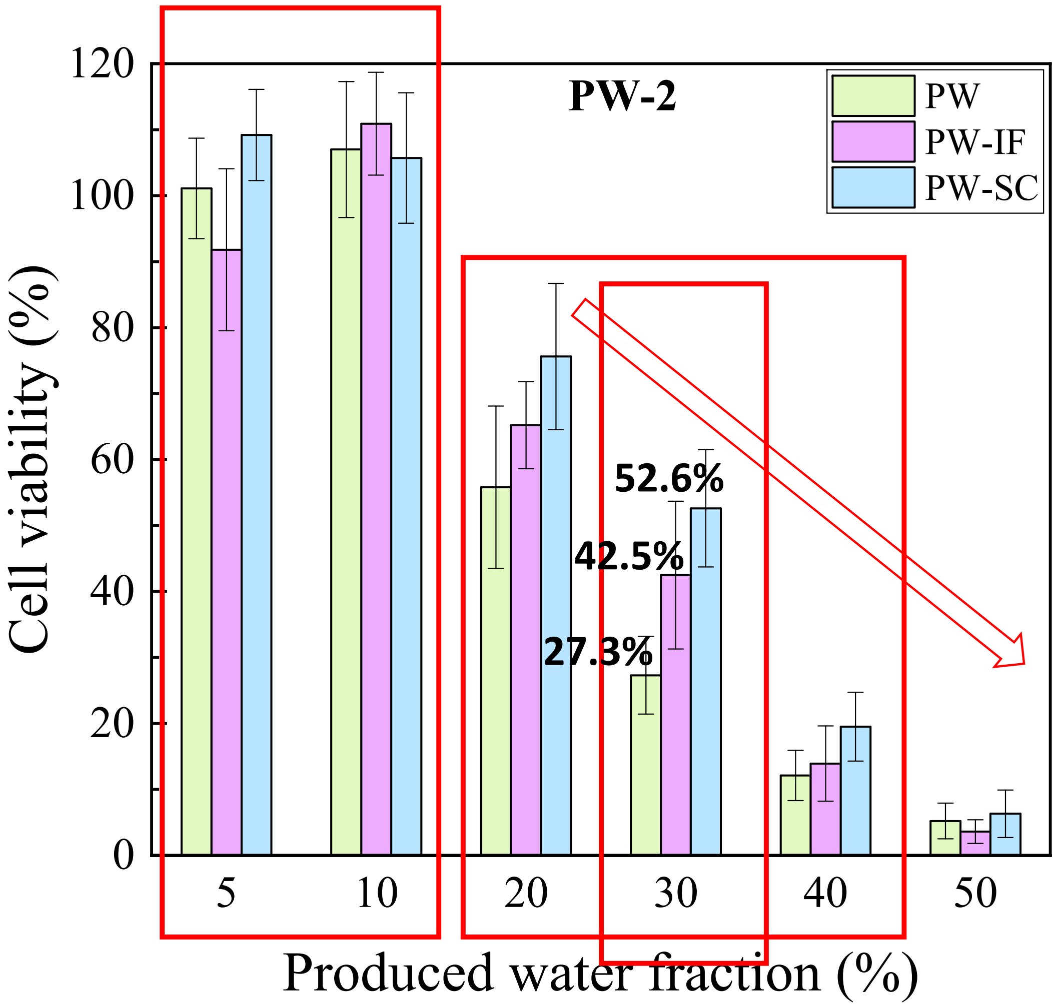
Water Quality Results

	PW-1	PW-2	PW-3
TOC (mg/L)	52.1	72.5	**139.7**
TDS (g/L)	160.4	172.2	**219.6**
NH_4^+ (mg/L)	483.4	654.4	**879.3**

- Inhibition effect: **PW-1 < PW-2 < PW-3**

Results

Cytotoxicity toxicity---MTT viability assay

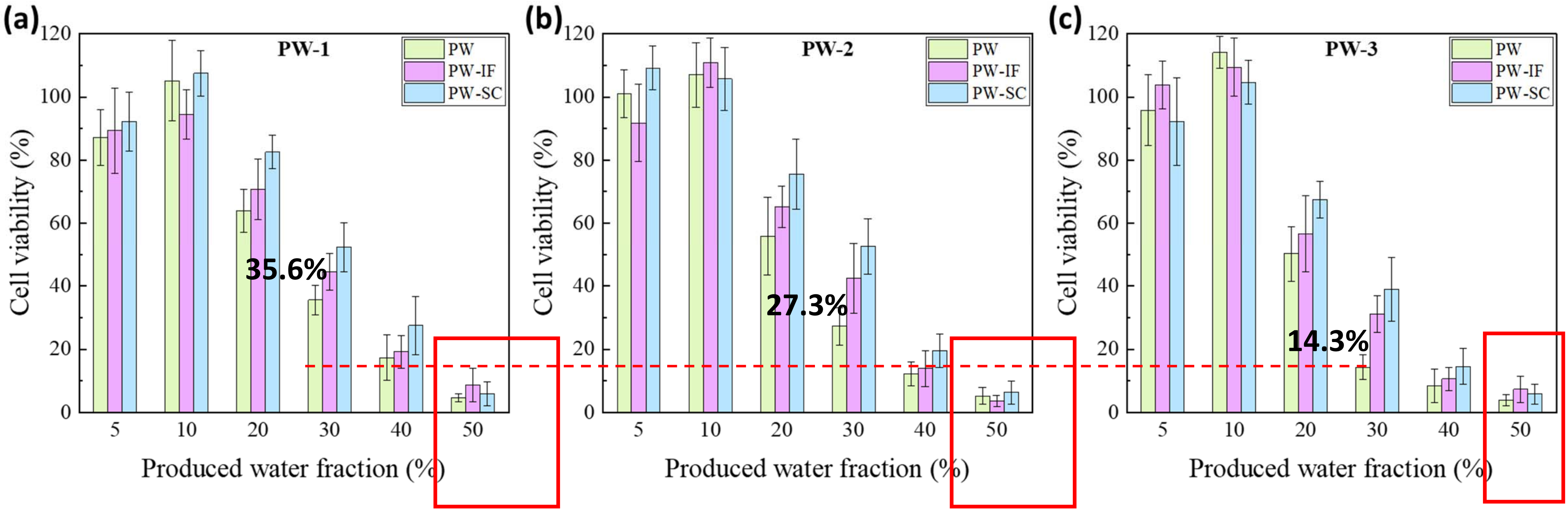


PW: produced water
PW-IF: produced water inorganic fraction
PW-SC: produced water salt control

- Lower cell viability reflects the higher cytotoxicity.
- Cell viability : **PW < PW-IF < PW-SC**.
- **Organic** fraction caused a **stronger lethal effect** on RTgill-W1.

Results

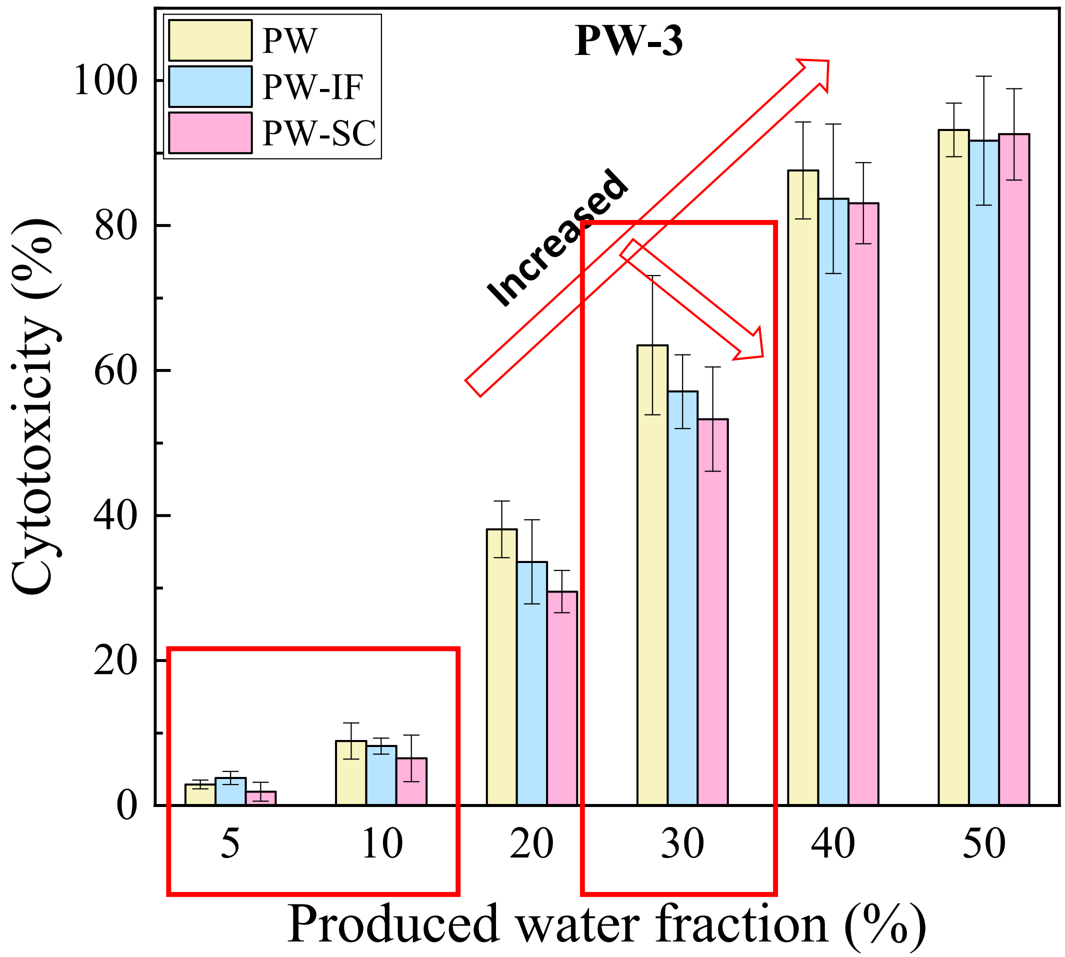
Cytotoxicity toxicity---MTT viability assay



- Cell viability: **PW-1 > PW-2 > PW-3**.
- PW-3 was the **most toxic** one.
- High salinity may **mask the toxicological effects** posed by other constituents

Results

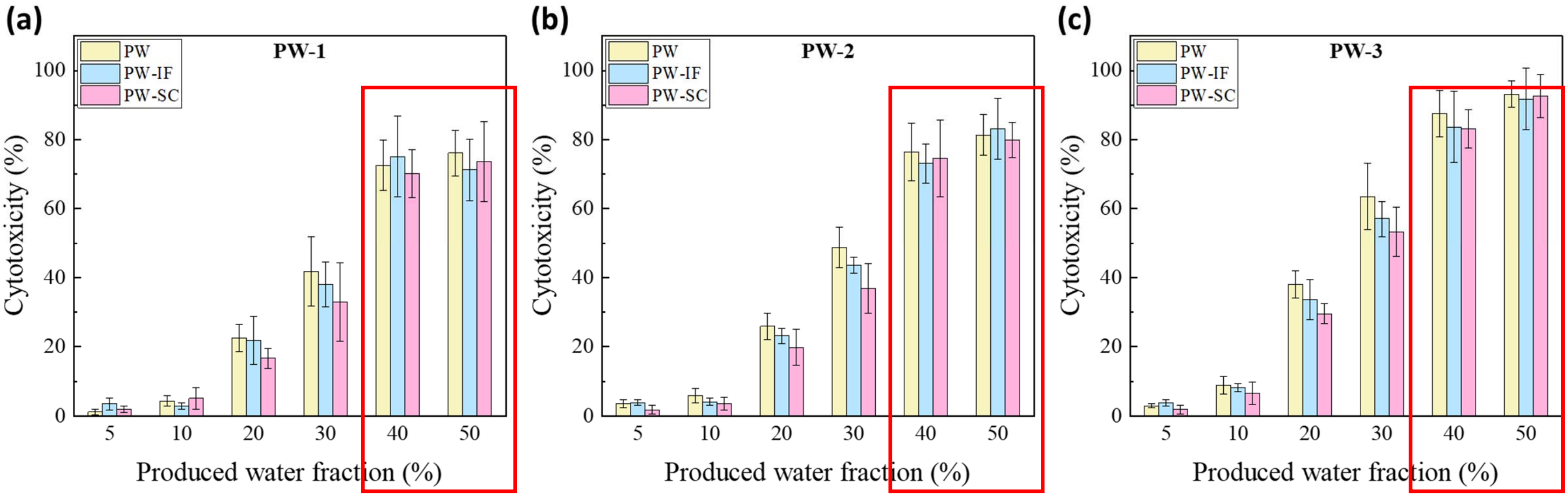
Cytotoxicity toxicity---LDH release assay



- Cytotoxicity: **PW-1 < PW-2 < PW-3**.
- **Organics** had an important impact on the cytotoxicity.

Results

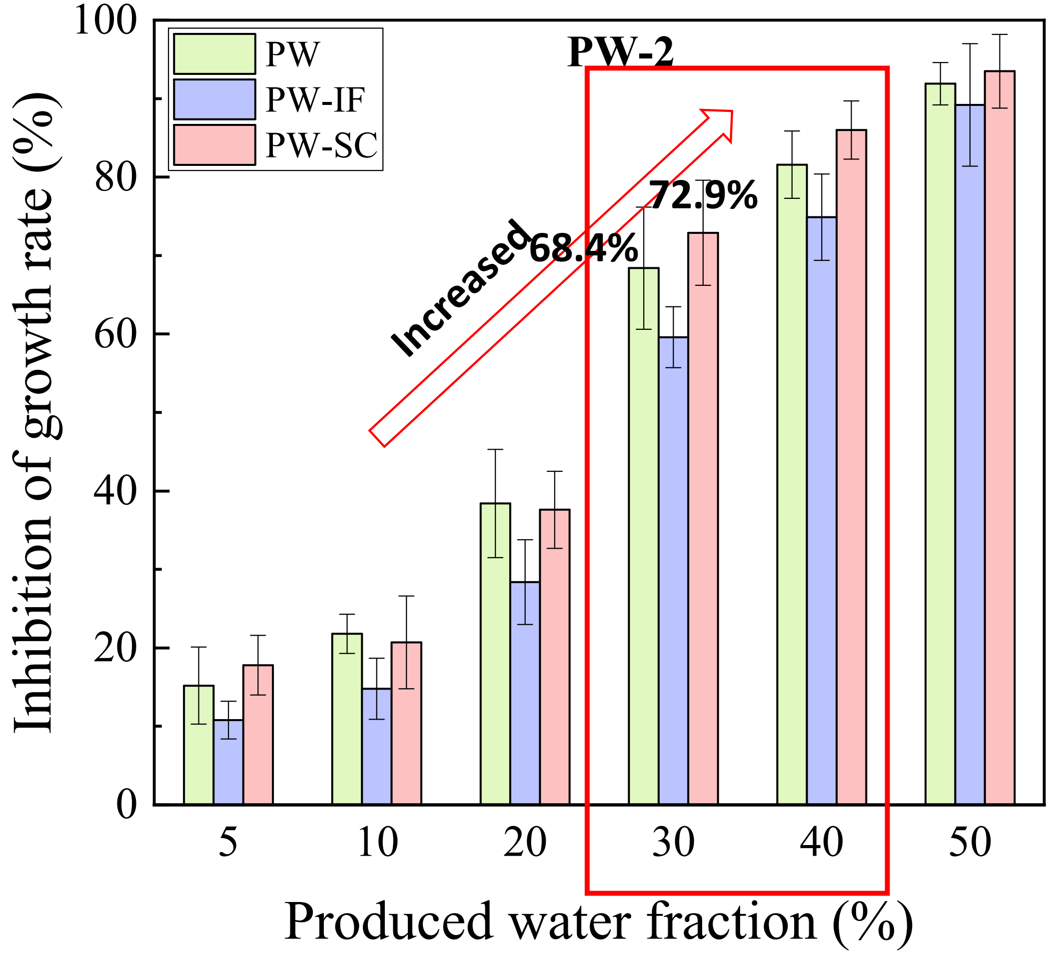
Cytotoxicity toxicity---LDH release assay



- **High salinity** was the **major contributor** to the cytotoxicity .
- The diversity and complexity of chemicals lead to **differences in the cytotoxic responses.**

Results

Aquatic ecotoxicity

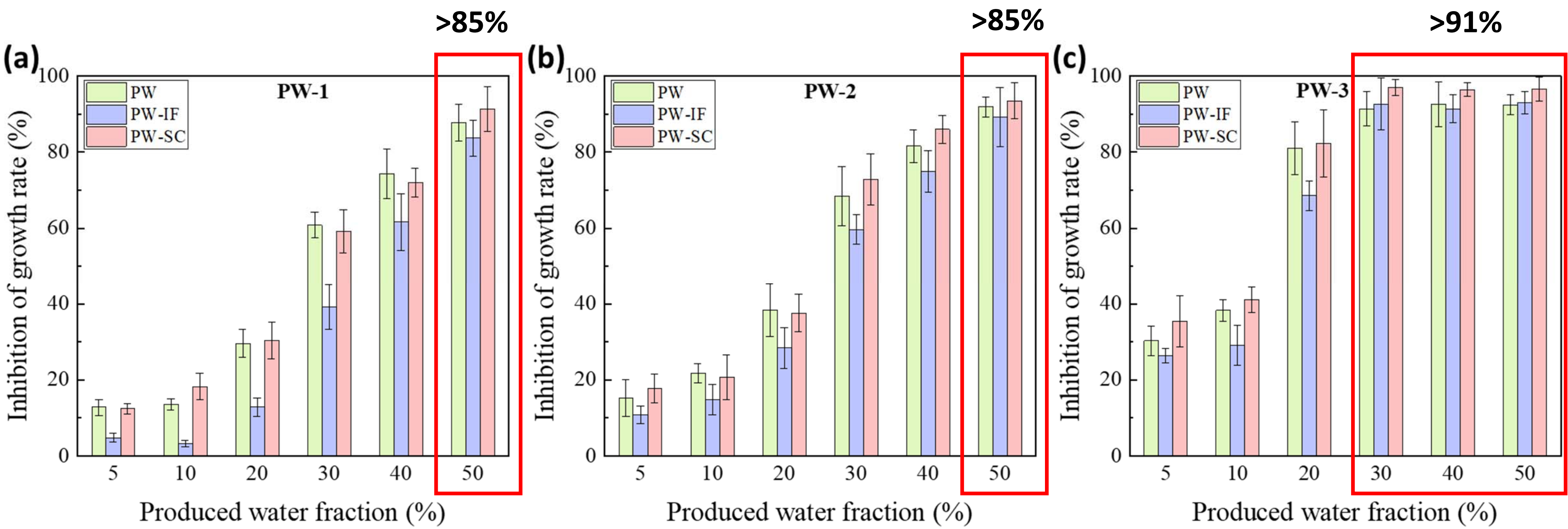


PW: produced water
PW-IF: produced water inorganic fraction
PW-SC: produced water salt control

- Dose-response relationship
- Aquatic ecotoxicity: **PW-SC > PW**.
- High **ammonium** can **promote the algal growth**.

Results

Aquatic ecotoxicity



	PW-1	PW-2	PW-3
TDS (g/L)	160.4	172.2	**219.6**

- Aquatic ecotoxicity assay was **more sensitive to salinity**

Results

Comparison of EC_{50}

EC_{50} ---the concentration that results in 50% of bioluminescence inhibition/mortality/growth rate inhibition

Organisms	Toxicity assay	Exposure time	EC_{50}		
			PW-1	PW-2	PW-3
Vibrio fischeri	Microtox®	15 min	25.9%	22.7%	**21.6%**
RTgill-W1	MTT	48 h	26.5%	23.1%	**20.3%**
	LDH	24 h	33.5%	31.2%	**27.5%**
S. obliquus	Growth inhibition	7 d	27.9%	25.3%	**11.5%**

Generally,

Higher TOC, TDS and NH_4^+

↓

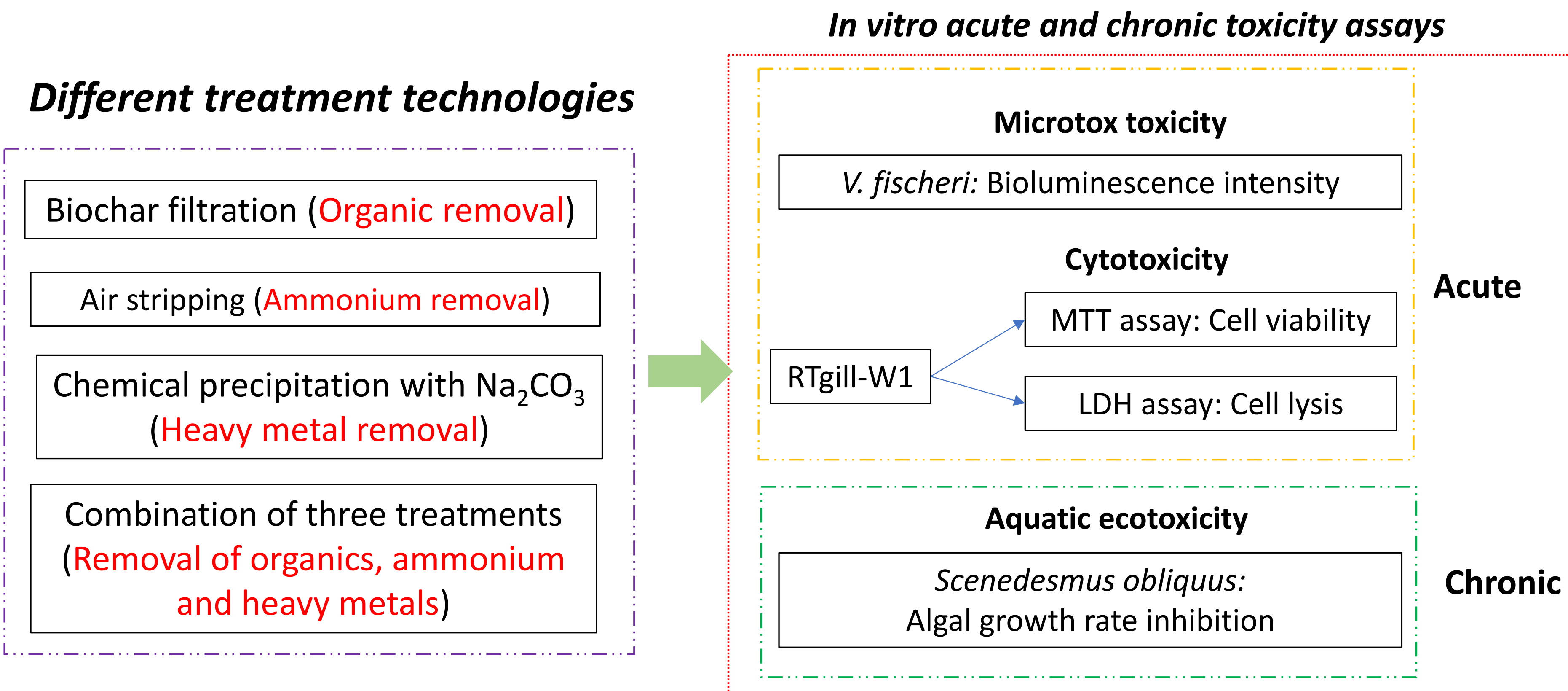
Lower EC_{50} (higher toxicity)

Water Quality Results

	PW-1	PW-2	PW-3
TOC (mg/L)	52.1	72.5	**139.7**
TDS (g/L)	160.4	172.2	**219.6**
NH_4^+ (mg/L)	483.4	654.4	**879.3**

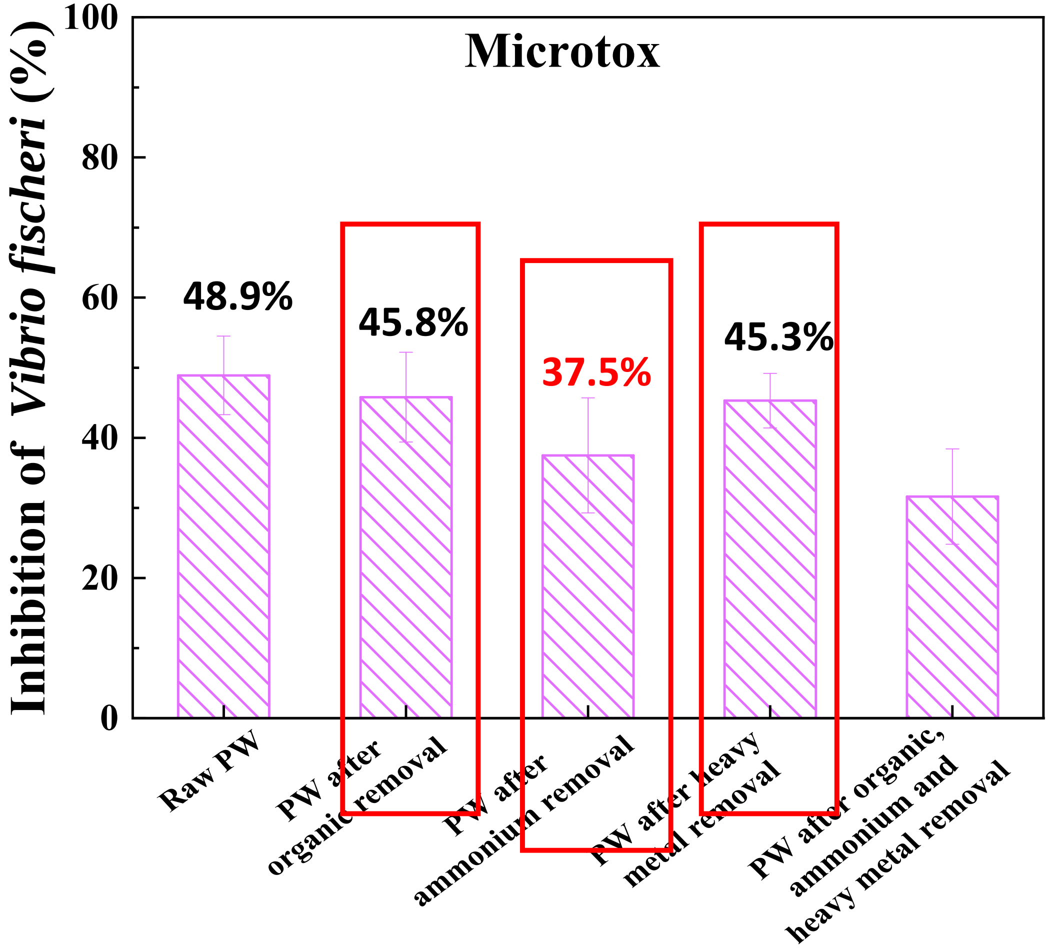
Research Methodology

Linking contaminant groups with toxicity of PWs



Results

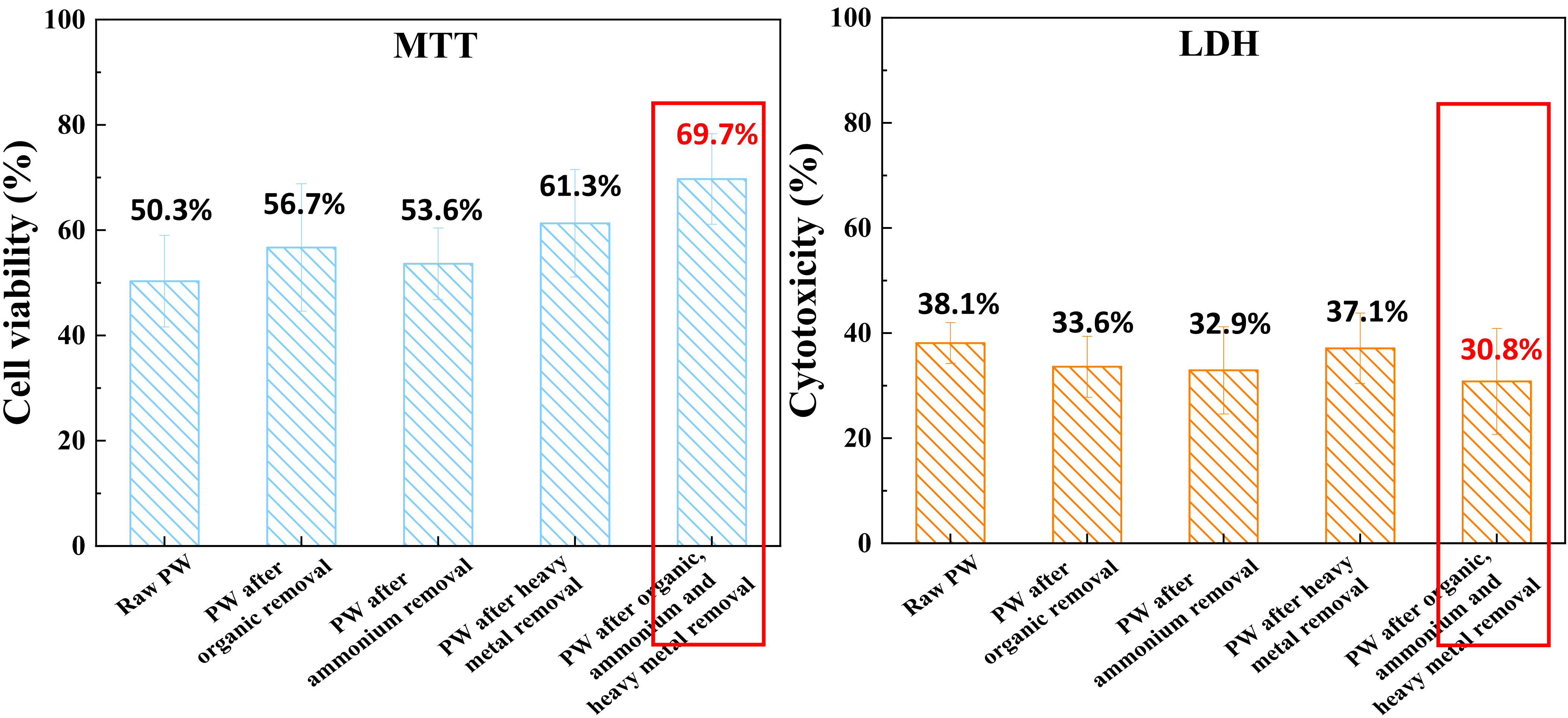
Effect of different pretreatments on the toxicity of PW



- **Ammonium** was one of the **main contributors** to the Microtox toxicity.

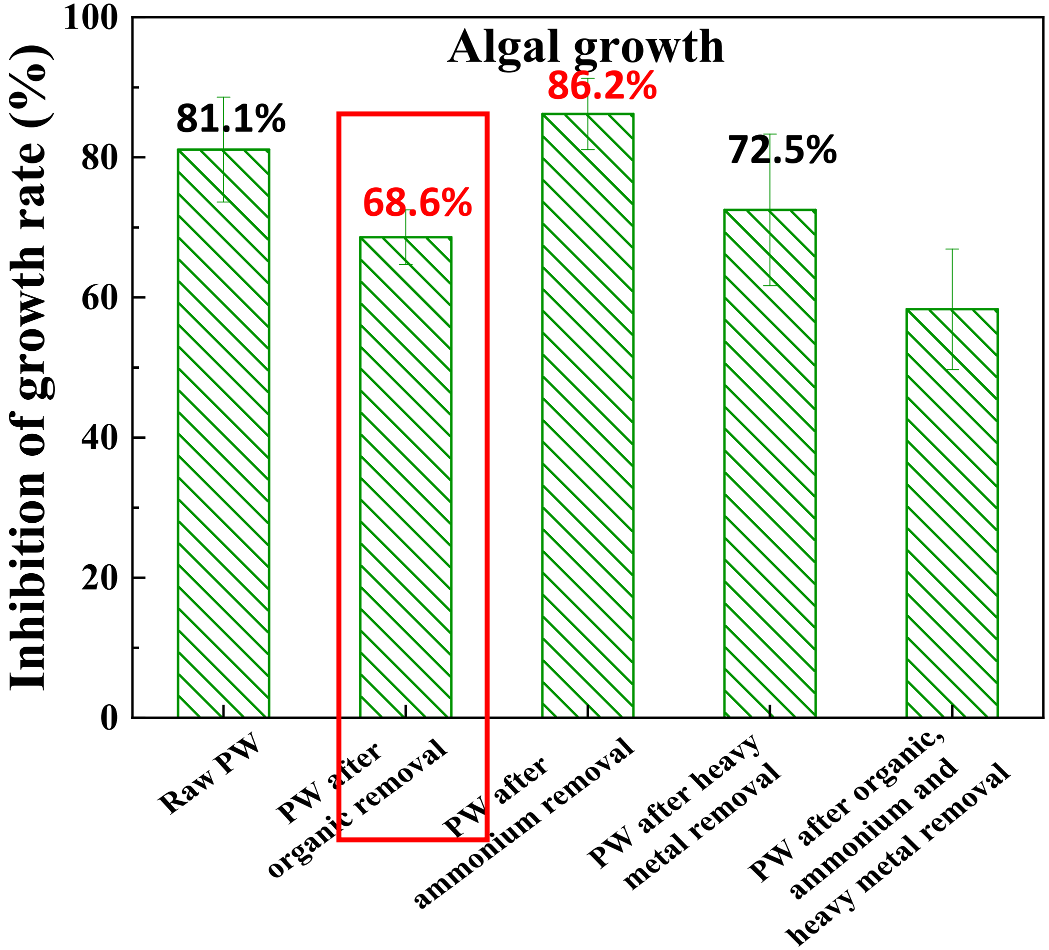
Results

Effect of different pretreatments on the toxicity of PW



Results

Effect of different pretreatments on the toxicity of PW



- In addition to salinity, **organics have the most significant impact.**

Summary

- High salinity was the predominant toxicological driver in PW.
- Organic contaminants had an important impact on the toxicity of PW.
- Heavy metals and ammonium in PW also contribute to toxicity.
- Strong correlations were found between chemical components and toxicity results.
- Toxicity assays should be selected based on the target compounds in PW.

Ongoing work

- Assessing the toxicity of PW after the advanced treatments, such as membrane distillation and thermal crystallizer
- Conducting more toxicity studies to further investigate species sensitivity and exposure scenarios

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