HEAVY METALS IN MINE EFFLUENTS AND POTENTIAL IMPACT ON THE GRAIN INDUSTRY

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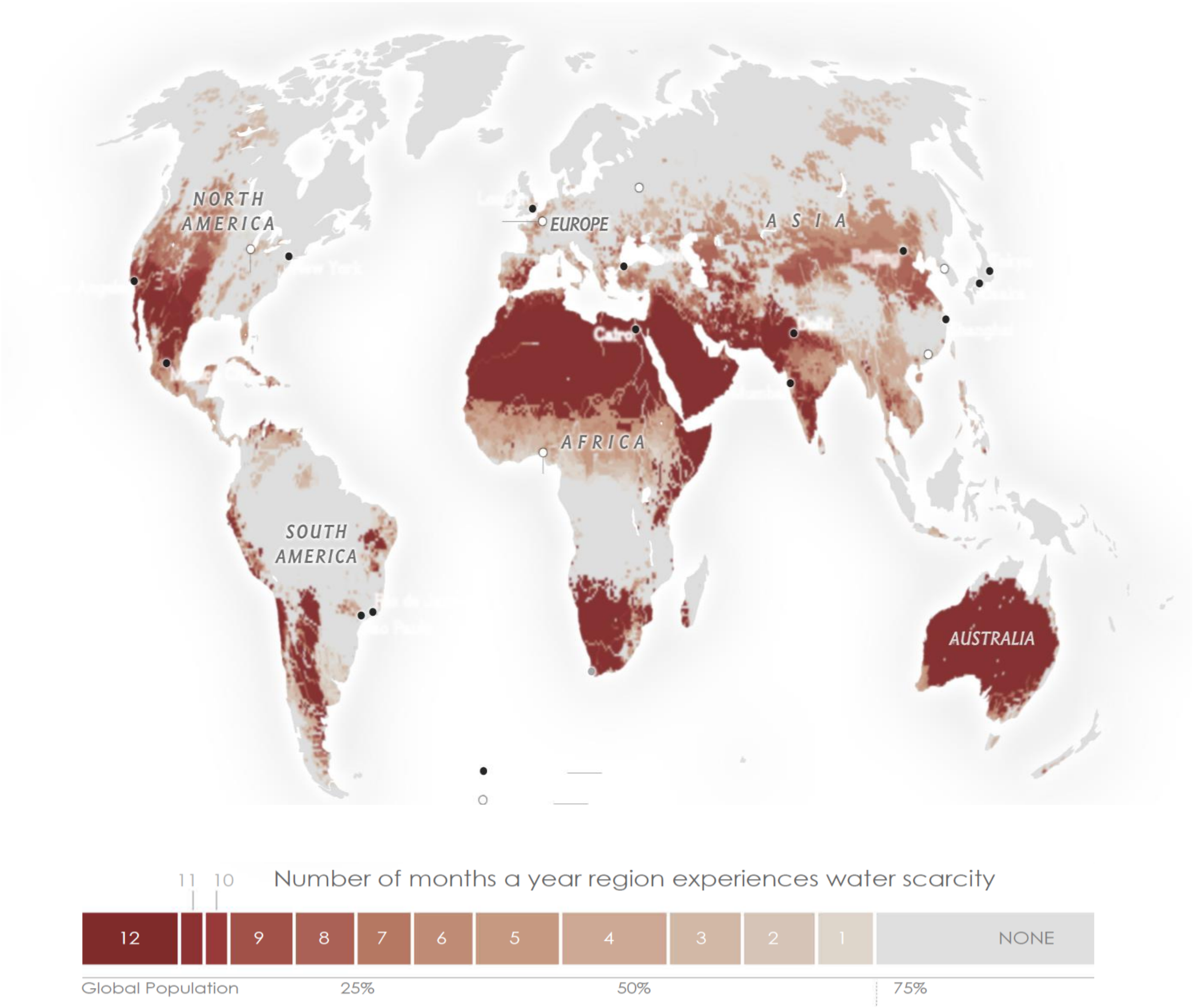
CONTENTS

GLOBAL WATER SCARCITY



GLOBAL WATER SCARCITY

- Two thirds of the world's population currently live in areas that experience water scarcity for at least one month a year (Mekonen and Hoekstra, 2016).
- Water scarcity will be exacerbated as rapidly growing urban areas place heavy pressure on neighboring water resources.
- Climate change and bioenergy demands are also expected to amplify the already complex relationship between world development and water demands.
- It is expected that by 2050, 4.8 to 5.7 billion of the world's population will be living in potential water scarce areas at least one month per year (Richey et al., 2015).
- Water scarcity can mean scarcity in availability due to physical shortage, or scarcity in access due to the failure of institutions to ensure a regular supply or due to a lack of adequate infrastructure (UN Water, 2015).

GLOBAL WATER SCARCITY

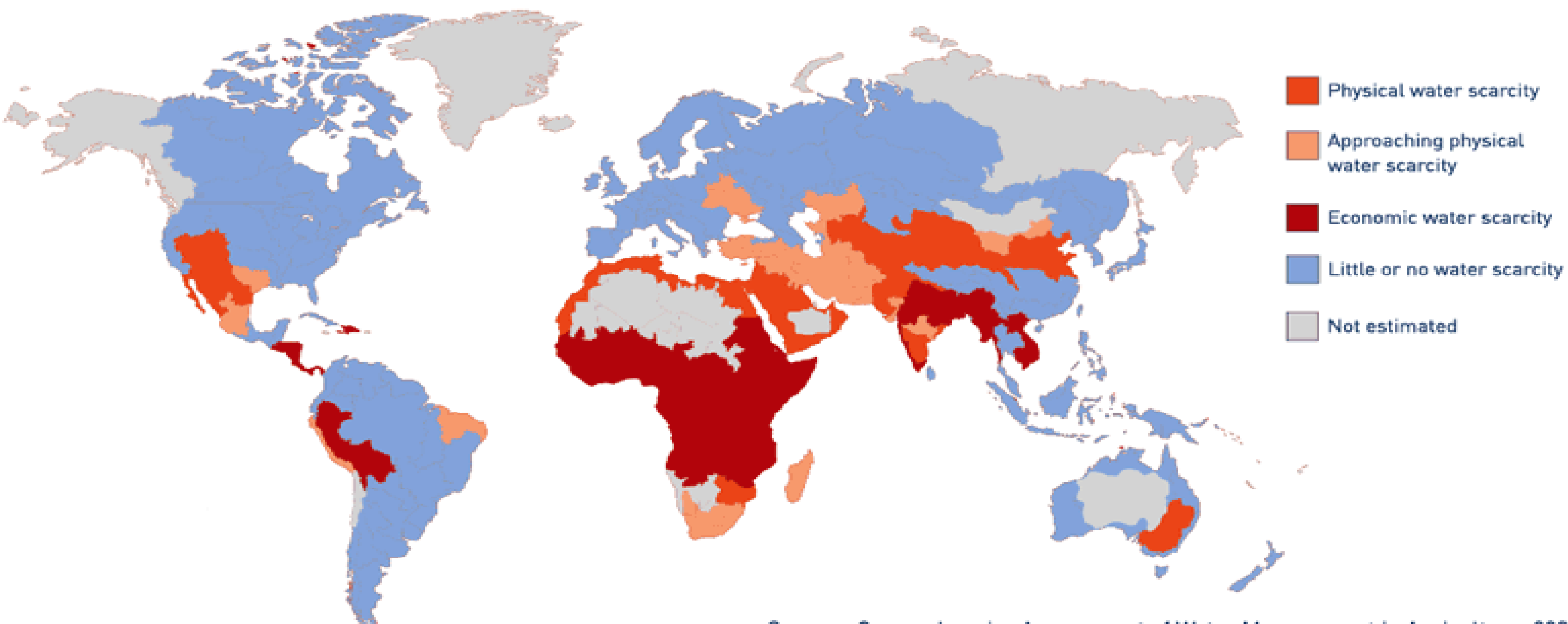
AREAS OF PHYSICAL AND ECONOMIC WATER SCARCITY

Physical water scarcity water resources development is approaching or has exceeded sustainable limits). More than 75% of the river flows are withdrawn for agriculture, industry, and domestic purposes (accounting for recycling of return flows). This definition—relating water availability to water demand—implies that dry areas are not necessarily water scarce.

Approaching physical water scarcity. More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.

Economic water scarcity (human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands). Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

Little or no water scarcity. Abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes.



Source: Comprehensive Assessment of Water Management in Agriculture, 2007

CONTENTS

1. WATER IN THE GLOBAL CONTEXT
   - Global agricultural water demand
2. WATER IN THE NATIONAL CONTEXT
3. METAL UPTAKE BY PLANTS
4. IMPACT OF METALS ON PLANTS
5. CONSUMERS EXPOSURE
6. IMPACT OF WATER QUALITY ON THE INDUSTRY
7. MITIGATION STRATEGIES
8. CONCLUSION

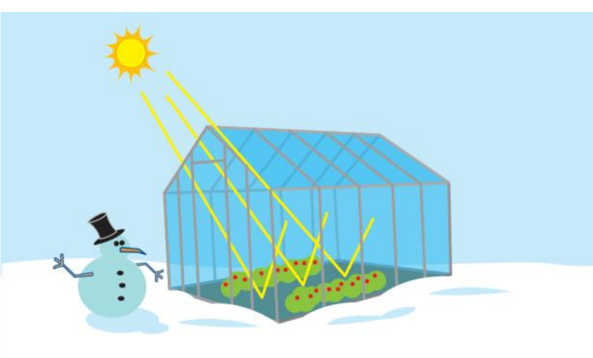
GLOBAL WATER SCARCITY

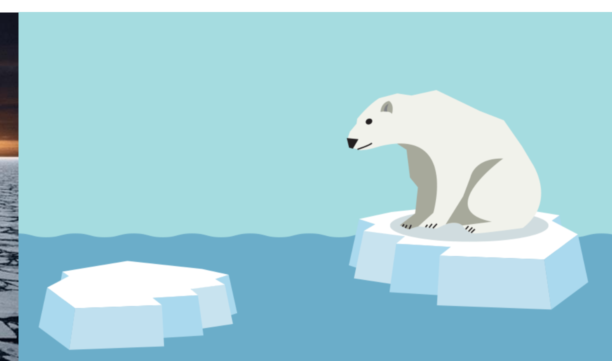
- Global agricultural water demand is estimated to around 70%, the competition with other sectors for water is therefore increasing.
- Water withdrawals grew at almost twice the rate of population increase in the twentieth century, and a 50 percent surge in food demand is expected by 2050.
- Climate change also affects freshwater resources negatively, in terms of both quantity and quality.
- More frequent and severe droughts impact agricultural production, while rising temperatures translate to increased water demand in agriculture sectors.
- It is therefore clear that there is an urgent need to address water scarcity.

Source: FAO, 2018

CLIMATE CHANGE

SIGNS OF CLIMATE CHANGE ARE EXPERIENCED WORLDWIDE WITH SIGNIFICANT IMPACT ON WATER AVAILABILITY

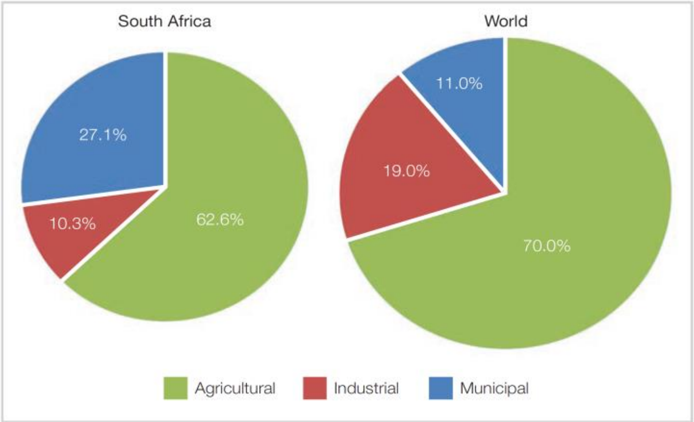




CONTENTS

WATER SCARCITY

- South Africa faces both physical and economic water scarcity
- **Physical water scarcity**
- "In such areas more than 60% of river flows are withdrawn"



Source: IFs v. 7.31 and FAO Aquastat data.

South Africa's water consumption is about 235 L/capita/day. The global average is 175 L/capita/day

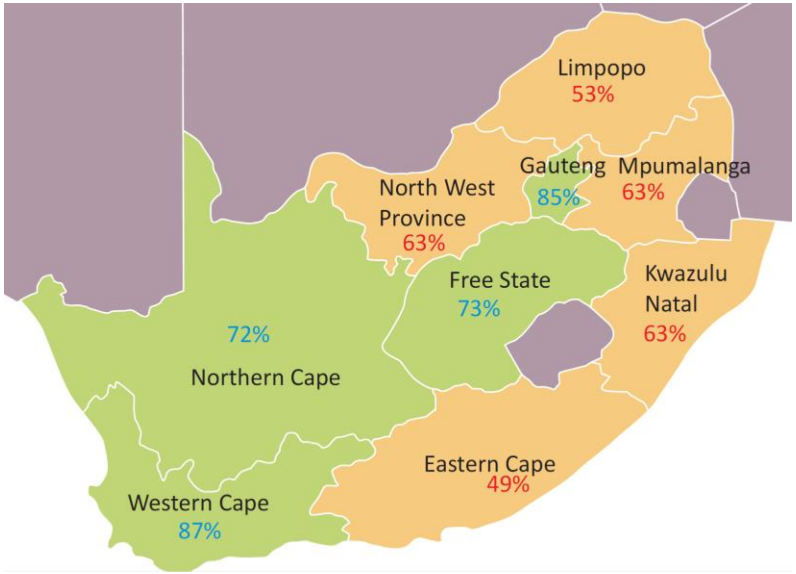
- South Africa is a semi-arid, water stressed country, with an average rainfall of about 450 mm, which is well below the world average of about 860 mm per year.

Water availability in the country is faced with three major challenges

- Uneven distribution and seasonality of rainfall
- Relatively low stream flow in rivers most of the time
- Points of use remote from the country's larger water courses

WATER SCARCITY

- **Economic water scarcity**
- "The scarcity in access to usable water could be due to the failure of institutions to ensure a regular supply or lack of adequate infrastructure"



Reliability on water services per province

- Of the 144 municipalities with water supply responsibilities, 33% are dysfunctional (WSA, January 2018).
- Nearly 25% of SA's wastewater treatment facilities are in "critical state".
- SA treats only 54% of its municipal wastewater (FAO, Aquastat 2018).

Aging, poor quality and poorly maintained infrastructure is contributing to high levels of water wastage and pollution of rivers and groundwater with sewage

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CONTENTS

1. WATER IN THE GLOBAL CONTEXT
2. WATER IN THE NATIONAL CONTEXT
   - Water scarcity
   - Water and Agriculture
   - Water pollution
3. METAL UPTAKE BY PLANTS
4. IMPACT OF METALS ON PLANTS
5. CONSUMERS EXPOSURE
6. IMPACT OF WATER QUALITY ON THE INDUSTRY
7. MITIGATION STRATEGIES
8. CONCLUSION

WATER AND AGRICULTURE IN SA

- The agricultural land of 96.8 million ha consists mostly of permanent meadows and pastures
- The cultivated area is estimated at 12.9 million ha in 2013 (FAO, 2016)
- 65 percent of the country does not receive enough rainfall for successful rainfed crop production and is used as grazing land. Crops grown in this area are grown under irrigation.
- Except for the Western Cape, with a Mediterranean climate and winter rainfall, the rest of the country has summer rainfall.
- The total water withdrawal in SA was estimated to 16 000 million m³ in 2013, with irrigation accounting for 62 percent.



WATER AND AGRICULTURE IN SA

- Irrigation is still the most important water user, while livestock and nature conservation uses 2.5 percent.
- Total groundwater withdrawal was estimated at 1 770 million m³ in 2010, of which 64 percent for irrigation (CSIR, 2010).
- Most commercial irrigation occurs in the Orange, Crocodile, Lower Vaal, Sundays & Fish rivers basins and in the Western Cape region (UNEP, 2000).
- About 80 to 90 percent of high-value crops such as potatoes, vegetables, grapes, fruits and tobacco are irrigated, and between 25 to 73 percent of industrial crops, such as sugarcane and cotton depending on the crops and years (Backeberg, 2005; DAFF, 2012).



WATER AND AGRICULTURE IN SA

- Irrigation farmers are estimated at 230 000 to 280 000, including 200 000 to 250 000 smallholders, most of which have very small plots for self-consumption, and less than 30 000 commercial farmers (WRC, 2011; DWA, 2013).



CONTENTS

1. WATER IN THE GLOBAL CONTEXT
2. WATER IN THE NATIONAL CONTEXT
   - Water scarcity
   - Water and Agriculture
   - Water pollution
3. METAL UPTAKE BY PLANTS
4. IMPACT OF METALS ON PLANTS
5. CONSUMERS EXPOSURE
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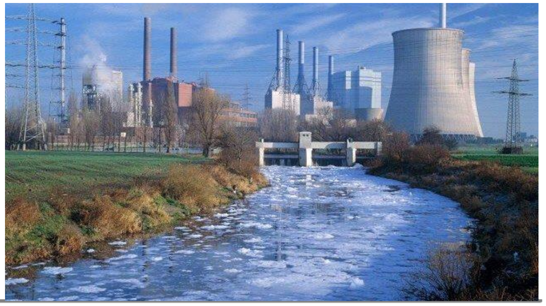
WATER POLLUTION

- The quality of raw water from rivers, dams, estuaries, wetlands and ground water, shows ongoing deterioration in many parameters.

- This water deterioration poses a major threat to the agricultural sector and therefore human health and wellbeing.

- Domestic waste, fertilizers, fuel combustion, minerals processing including mining are sources of toxic heavy metals in the water system.

- However, mining activities are the main contributors of toxic metals found in the environment.



WATER POLLUTION

- **Impact of mining activities on water system**
- Acid mine drainage (AMD) is one of the serious problems resulting from mining activities.
- The major sources of AMD include drainage from underground mine shafts, runoff and discharges from open pits and mine waste dumps, tailings and ore stockpiles.
- Serious cases of AMD have been reported in Witwatersrand area in Johannesburg and the Highveld area in Mpumalanga.
- Effluents contaminated by AMD, are very acidic, contain high concentrations of metals and sulphate and therefore not suitable for irrigation and many other human activities.



WATER POLLUTION

- Case study: AMD (Emalahleni, Mpumalanga)

Measured values of trace metals in water samples

Sampling sites	Concentration of ions in water (mg/L)							
	Ag	U	As	Cd	Cu	Ni	Pb	Zn
UDB	0	2.4	0	0.45	0	13.06	43.57	8.82
NDB	0.42	1.89	67.14	1.66	0.77	5.61	8.34	12.44
NDA	0	1.69	14.57	0	0.5	24.57	60.04	5.51
ID	0.38	4.57	0	0.79	0.18	30.38	38.68	12.41
IAD	0.08	1.85	31.64	0	0.19	8.47	10.89	11.44
IAD2	0.41	1.82	8.39	0	0	37.36	53.92	4.36
FD	**0.02**	**1.76**	**9.51**	**0.99**	**0**	**20.43**	**33.93**	**5.22**
DDU	**0**	**1.44**	**0**	**0.79**	**2.64**	**22.21**	**0**	**13.64**
DU	**0**	**1.59**	**6.42**	**0.18**	**0**	**33.8**	**29.7**	**1.53**

WATER POLLUTION

- **Case study: Non acidic mine effluent (North West Province)**
- Dispersion of metals in surface water in the vicinity of Potchefstroom

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WATER POLLUTION

- **Case study: Non acidic mine effluent (North West Province)**

Dispersion of metals along the Mooi and Vaal Rivers near Potchefstroom
1-Carletonville area
2-Boskop Dam
3-Potchefstroom Dam
4-Potchefstroom area
5-Okney and Klerksdop areas

WATER POLLUTION

Metals concentrations in surface waters around Potchefstroom

Sample	Heavy metals						
	Ag	Al	As	Ca	Cd	Cr	Fe
Number	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	0.00	0.00	0.00	38.43	0.00	0.00	0.00
2	0.00	0.00	0.57	37.60	0.17	0.00	0.00
3	0.00	0.63	5.00	102.92	0.07	0.00	0.00
4	0.00	0.14	2.07	102.25	0.09	0.00	0.00
5	0.00	0.30	4.84	78.26	0.05	0.00	0.00
6	0.00	0.00	3.51	71.40	0.15	0.00	0.00
7	0.00	0.00	4.61	68.45	0.09	0.00	0.00
8	0.00	0.00	2.30	68.40	0.01	0.00	0.00
9	0.00	0.03	0.84	218.50	0.15	0.00	5.71
10	0.01	0.05	0.00	216.60	0.11	0.00	0.10
11	0.07	3.85	0.00	217.30	0.14	0.00	11.34
12	0.01	0.05	0.00	213.40	0.09	0.02	0.65
13	0.00	0.00	0.31	212.50	0.25	0.03	6.90
14	0.00	0.05	0.26	210.30	0.08	0.00	0.39
15	0.00	0.09	0.95	211.40	0.14	0.00	8.29
16	0.00	0.00	2.20	44.35	0.00	0.06	0.00
17	0.00	0.00	2.10	45.48	0.24	0.03	0.00
18	0.00	0.00	0.00	48.75	0.03	0.00	0.00
19	0.00	1.60	0.00	52.80	0.14	0.06	9.45
20	0.04	0.10	2.35	51.22	0.03	0.00	8.47
21	0.01	0.30	1.43	208.70	0.15	0.00	0.47
22	0.02	0.40	0.00	208.40	0.15	0.00	0.68
23	0.02	0.06	0.00	210.10	0.09	0.00	0.20
24	0.00	0.11	0.00	210.20	0.08	0.00	0.34
25	0.00	0.14	0.00	212.00	0.13	0.00	0.69
26	0.12	0.21	4.53	48.43	0.20	0.06	22.00
27	0.05	0.16	3.67	48.64	0.70	0.06	36.00
28	0.59	0.13	2.06	48.73	0.09	0.01	17.80
29	0.00	0.09	2.25	66.15	0.15	0.00	7.69
30	0.00	0.00	0.97	53.36	0.00	0.02	0.66
31	0.01	0.43	1.38	49.88	0.21	0.09	6.95
32	0.00	0.00	0.00	38.69	0.00	0.00	0.00
33	0.01	0.14	0.00	185.80	0.10	0.03	15.60
34	0.02	0.04	1.76	48.89	0.02	0.00	8.48
35	0.05	0.04	1.08	49.26	0.20	0.00	14.00

Sample	Heavy metals						
	K	Mg	Mo	Ni	Pb	U	Zn
Number	mg/l	mg/l	mg/l	mg/l	mg/l	mg/	mg/l
1	1.43	28.39	0.51	0.00	0.72	0.01	0.00
2	9.75	27.67	0.29	0.00	0.32	0.06	0.00
3	1.22	72.00	0.10	0.00	0.00	0.04	0.16
4	5.38	71.00	0.00	0.15	0.00	0.07	0.00
5	5.08	42.02	0.17	0.06	0.21	0.00	0.00
6	20.17	38.25	0.00	0.00	0.25	0.00	0.00
7	13.14	37.33	0.00	0.00	0.22	0.00	0.00
8	12.79	39.85	0.00	0.00	0.00	0.00	0.00
9	2.38	195.60	1.10	0.00	0.39	0.05	0.30
10	4.93	199.90	0.91	0.00	0.44	0.01	0.07
11	13.24	202.00	0.88	0.00	0.70	0.03	0.08
12	13.48	199.50	0.62	0.00	1.25	0.00	0.16
13	13.02	199.20	1.07	0.00	0.73	0.00	0.56
14	16.72	198.00	0.35	0.00	0.67	0.00	0.24
15	12.88	198.80	0.65	0.00	0.21	0.00	0.29
16	12.98	41.07	0.14	0.00	0.00	0.01	0.00
17	12.94	42.09	0.25	0.00	0.00	0.00	0.03
18	12.89	39.65	0.00	0.00	0.00	0.00	0.00
19	13.11	43.09	0.00	0.32	0.00	0.05	0.56
20	3.17	36.56	0.58	0.28	0.00	0.01	0.25
21	3.37	188.80	0.65	0.00	0.30	0.00	0.28
22	3.54	191.30	0.60	0.00	1.21	0.00	0.10
23	2.87	195.00	0.38	0.00	0.89	0.00	0.29
24	2.32	199.00	0.54	0.00	0.59	0.00	0.21
25	2.07	199.70	0.69	0.00	1.01	0.04	0.09
26	11.67	40.37	23.50	0.00	5.13	0.00	0.25
27	9.34	39.89	0.41	0.51	0.13	0.00	0.33
28	6.85	39.52	0.13	0.00	0.00	0.00	0.00
29	39.41	50.53	0.38	0.03	0.00	0.03	0.09
30	25.88	20.00	0.13	0.00	1.01	0.00	0.00
31	27.93	40.19	0.31	0.28	0.00	0.00	0.00
32	0.00	28.33	0.80	0.31	0.00	0.00	0.00
33	0.99	124.10	0.99	0.13	0.00	0.00	0.00
34	0.95	35.94	0.17	0.13	0.00	0.00	0.01
35	2.56	35.38	0.04	0.00	0.00	0.00	0.00

WATER POLLUTION

- Case study: Non acidic mine effluent (North West Province)

Range of highest percentages of speciated forms of metals measured in surface water of the vicinity of Potchefstroom

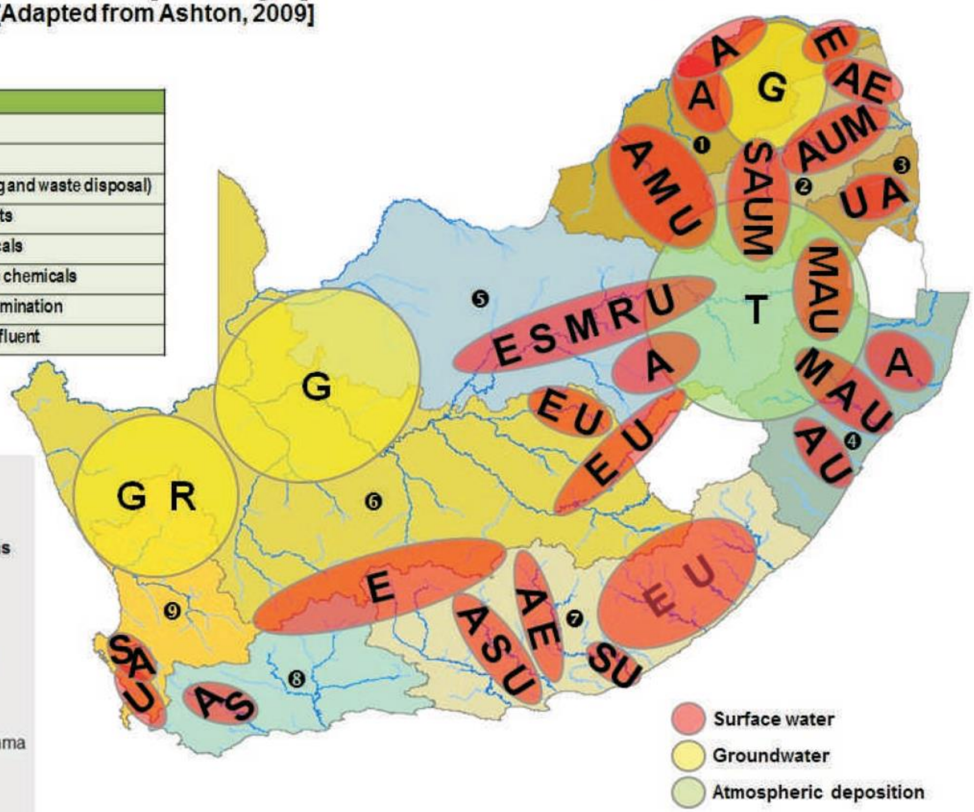
Element	Speciated forms	Wet season % Range	Dry season % Range
Ca	Ca^{+2}	57.87 -88.95	68.69 - 87.66
	$CaHCO_3^+$	1.88 - 11.64	0.06 - 3.07
	$CaCO_3$	0.25 - 20.92	0.24 - 9.43
	$CaOH^+$	< 1	-
	$CaSO_4$	3.10 - 30.61	6.62 - 29.8
Mg	Mg^{+2}	63.15 - 90.15	70.58 - 90.48
	$MgSO_4$	2.66 - 26.35	5.56 - 27.44
	$MgHCO_3^+$	1.21 - 8.39	1.10 - 3.62
	$MgCO_3$	0.14 - 8.92	0.33 - 2.38
	$MgOH^+$	< 1	-
Pb	$PbCO_3$	20.99 - 37.49	39.48 - 47.68
	$Pb(CO_3)_2^{-2}$	1.37 - 18.42	0.89 - 3.77
	$PbHCO_3^+$	0.28 - 5.42	-
	Pb^{+2}	-	0.45 - 2.27

WATER POLLUTION

Water quality problems across South Africa

[Adapted from Ashton, 2009]

CODE	DESCRIPTION
S	Salinity
R	Radioactivity
M	Metals (from mining and waste disposal)
E	Excessive sediments
A	Agricultural chemicals
T	Acidic atmospheric chemicals
G	Groundwater contamination
U	Urban/ industrial effluent

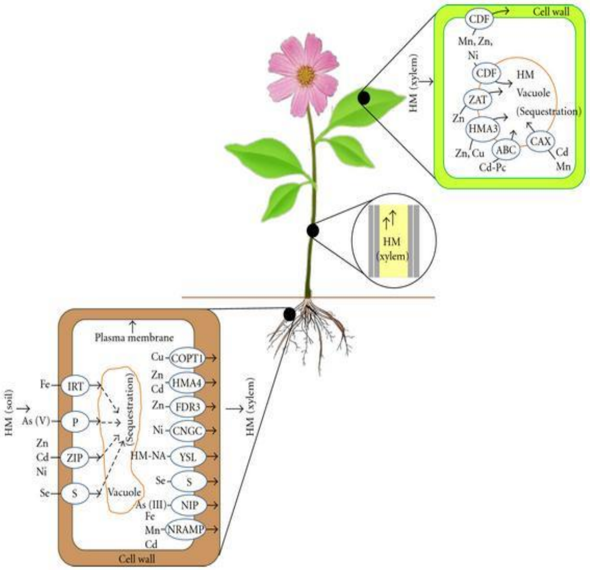


Rivers are contaminated by metals in at least four provinces

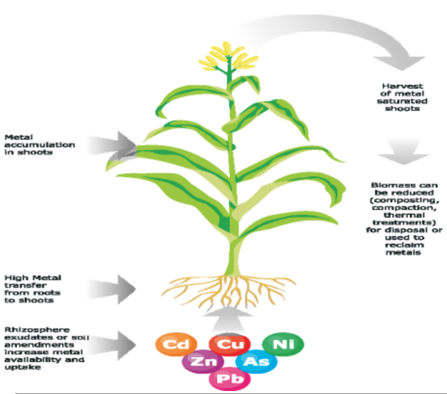
CONTENTS

1. WATER IN THE GLOBAL CONTEXT
2. WATER IN THE NATIONAL CONTEXT
3. METAL UPTAKE BY PLANTS
4. IMPACT OF METALS ON PLANTS
5. CONSUMERS EXPOSURE
6. IMPACT OF WATER QUALITY ON THE INDUSTRY
7. MITIGATION STRATEGIES
8. CONCLUSION

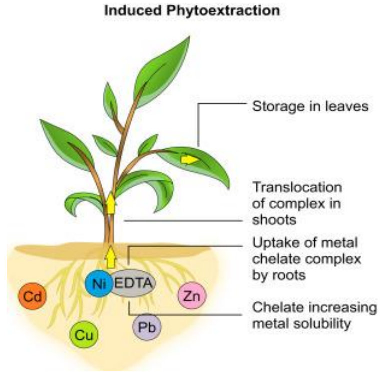
METALS UPTAKE BY PLANTS



- The shortage of fresh water for irrigation has compelled some farmers around the world to use sewage or industrial effluents.
- The use of such waters on agricultural lands will result to the build-up of high levels of metals in the soils.
- Metals in the soil exist as a variety of chemical species which affects their bioavailability and uptake by plant roots.
- Metals such as Zn and Cd primarily occur in soil as soluble while others such as Pb occur as insoluble precipitates.

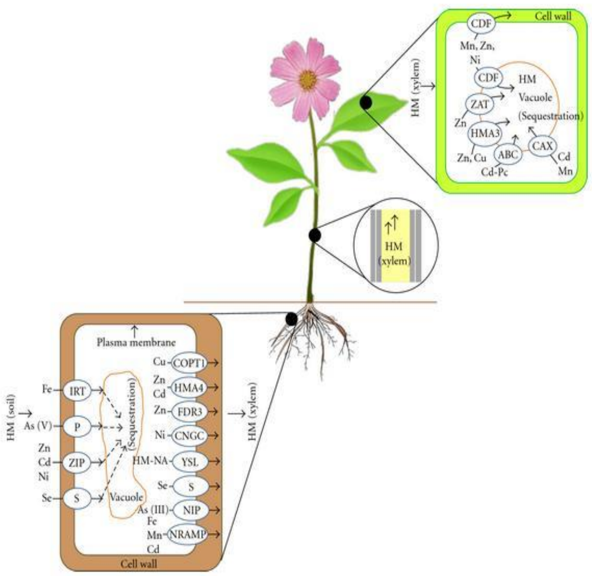


Do Nascimento & Xing, 2006

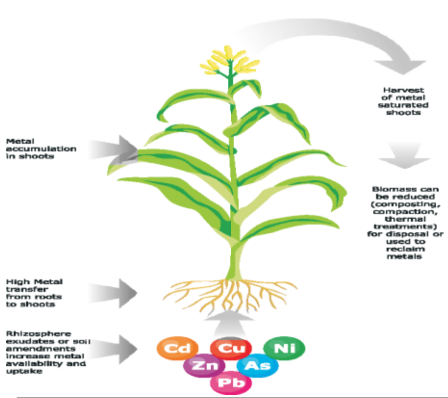


Ghori et al., 2016

METALS UPTAKE BY PLANTS



- Plants possess highly specialized mechanisms to stimulate metal bioavailability in the rhizosphere, and to enhance uptake into roots.
- Transport of metals across the root cellular membrane is an important process which initiates metal absorption into plant tissues.
- Metal ion transport into cells is mediated by membrane proteins with transport function.
- Excessive accumulation of heavy metals in agricultural soils through wastewater irrigation may lead to elevated heavy metal uptake by crops, which will affect food quality and safety.



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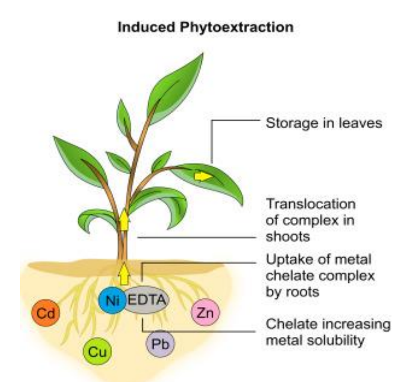
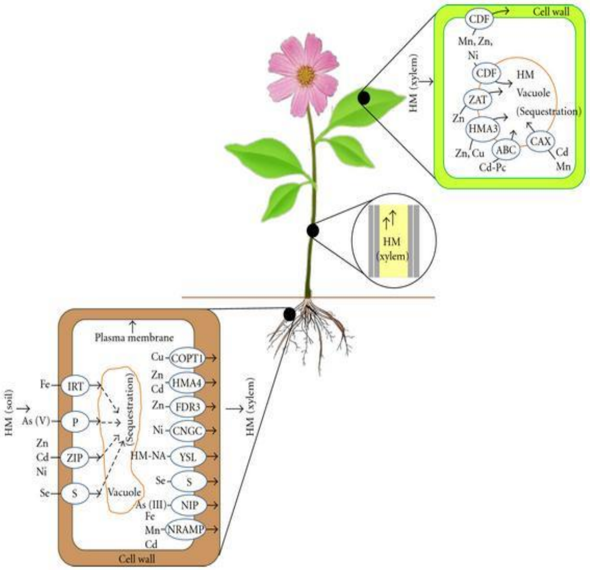
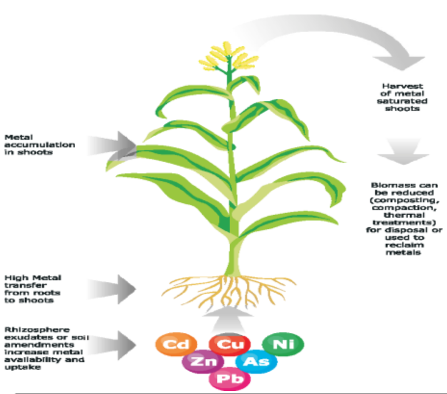


CONTENTS

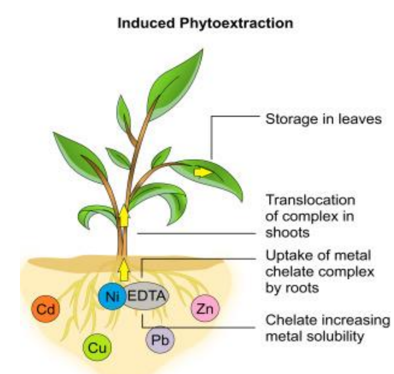
IMPACT OF METALS ON PLANTS



- Some heavy metals are essential micronutrients required for plants growth.
- However, excessive amount of these metals can become toxic for plants just as the non-essential metals.
- Although the phytotoxicity effects of heavy metals may differ, high concentration of metals in general cause the inhibition of cytoplasmic enzymes and damage to cell structures due to oxidative stress.
- The phytotoxicity of Zn and Cd is indicated by decrease in growth and development, metabolism and an induction of oxidative damage to various plant species.



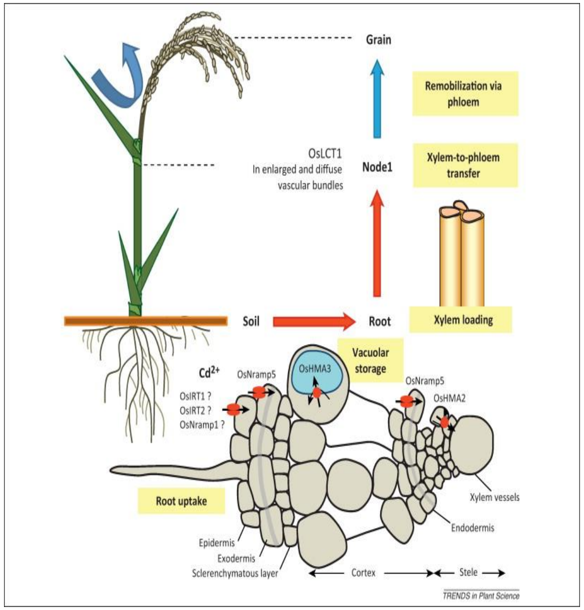
Do Nascimento & Xing, 2006



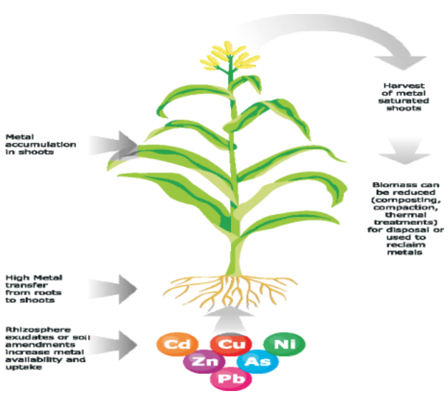
Ghori et al., 2016

CONTENTS

CONSUMERS EXPOSURE



- Chronic level intake of toxic metals has adverse effects on humans and the associated harmful impacts become apparent only after several years of exposure.
- Therefore, heavy metals accumulation in soils and plants is of increasing concern because of the potential human health risks.
- The food chain contaminations is one of the important pathways for the entry of toxic heavy metals into the human body.
- The consumption of heavy metal contaminated food can affect immunological defenses and cause upper gastrointestinal cancer.



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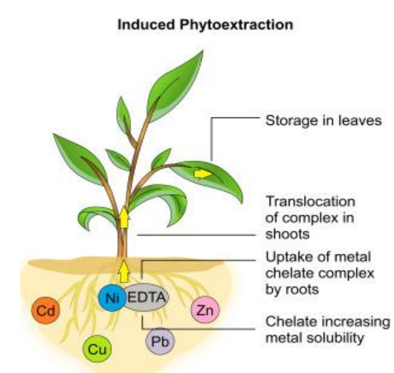
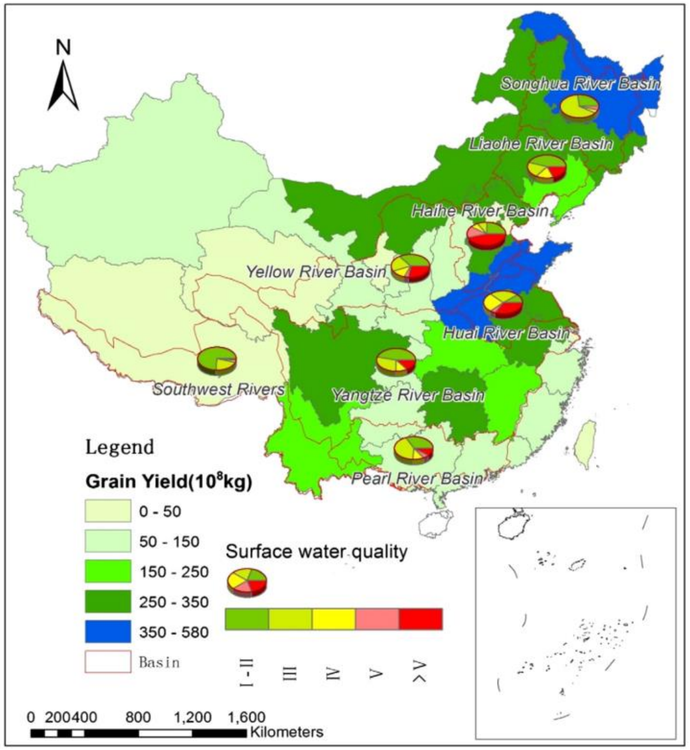


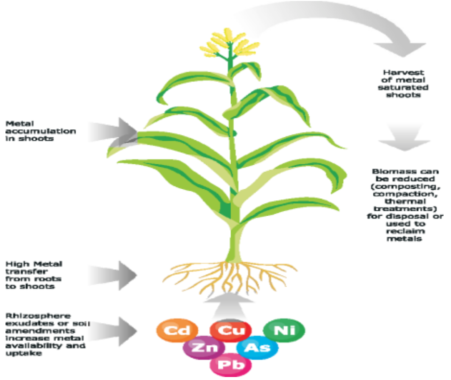
Ghori et al., 2016

CONTENTS

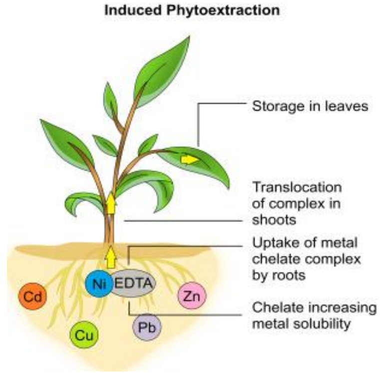
IMPACT OF WATER QUALITY ON THE INDUSTRY



- 6.24% of soils in Europe are contaminated and need remediation actions.
- In 2006 the Chinese government reported a decrease of grain yields by 10 million tons due to soil contamination.
- On the other hand, 12 million tons of food were found to contain high residues of pollutants resulting in more than 20 billion RMB Yuan of direct economic loss.



Do Nascimento & Xing, 2006

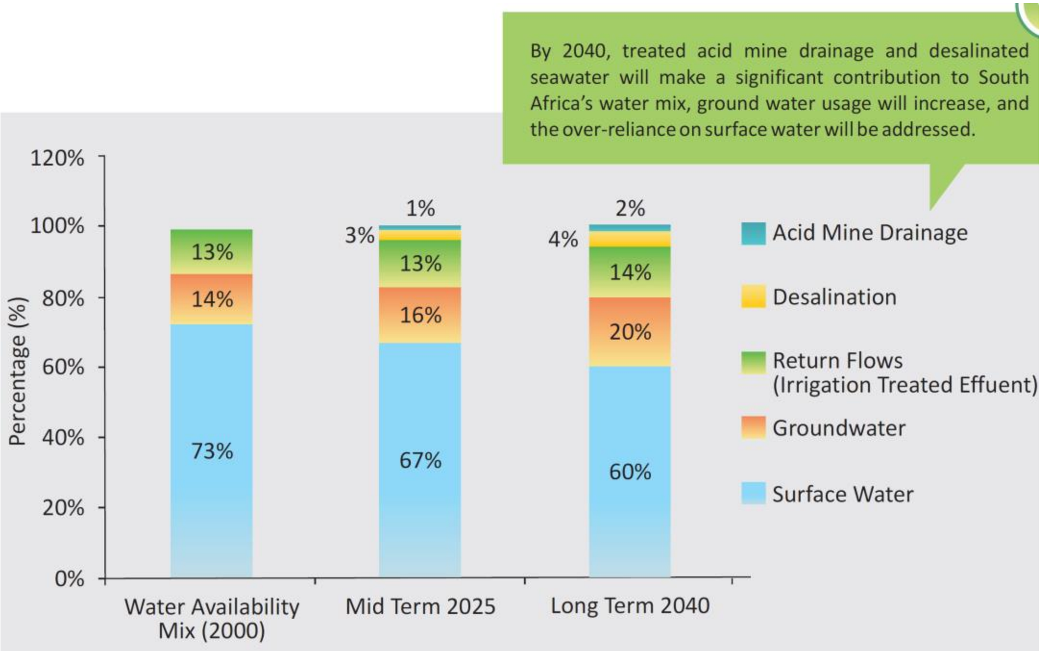


Ghori et al., 2016

CONTENTS

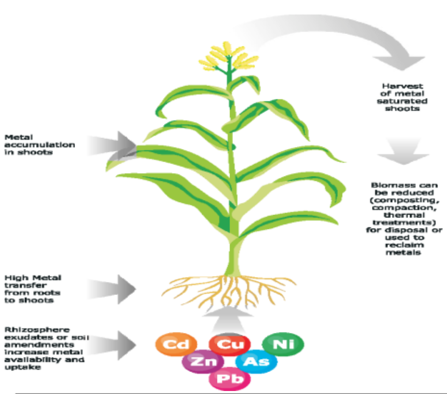
MITIGATION STRATEGIES

- South Africa must reduce water demand and increase supply in order to ensure a balance between the supply and the demand.
- Water demand must be reduced by improving efficiency, adopting new technologies and reducing losses through water awareness, strict regulation and incentives.
- To increase the supply, by considering a water mix that increases ground water use, re-use of effluents from waste water treatment plants, water reclamation, as well as desalination and treated acid mine drainage.

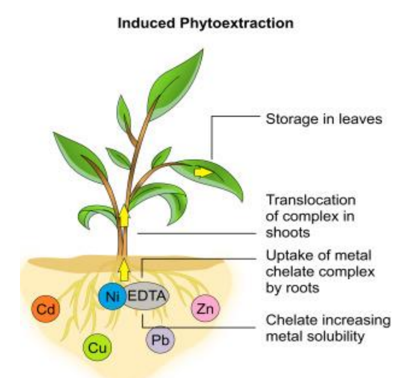


WSA, 2018

CONTENTS



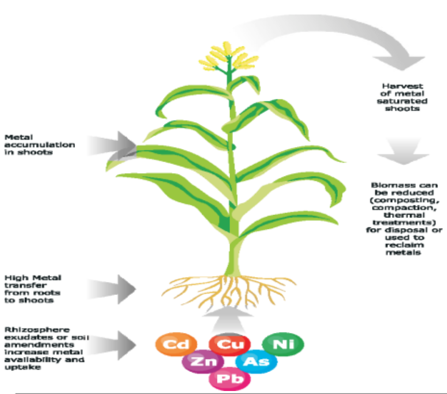
Do Nascimento & Xing, 2006



Ghori et al., 2016

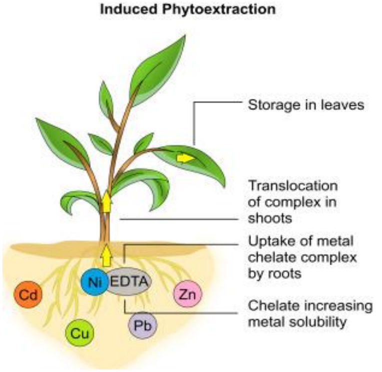
CONCLUSION

- Water scarcity is a worldwide concern and is expected to worsen in the near future. South Africa is already experiencing water shortage in many provinces.
- The agricultural sector depends heavily (around 60%) on water for irrigation.
- Pollution from the industries and mostly mining contributes to the deterioration of the quality of limited surface and ground waters posing a serious threat to the agricultural sector.
- Heavy metals mobilized from mining areas are released in surface waters which are eventually used for irrigation and may not only affect crops yields, but also have a negative impact on consumers' health.
- To continuously ensure food security it is important to improve the water management, by reducing pollution, prioritize demand and seriously consider other sources than surface water.



Do Nascimento & Xing, 2006

Ghori et al., 2016



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Thank you