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Isotopic and geochemical evidence of anthropogenic recharge to the Thiaroye Urban aquifer of Dakar, Senegal

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INTERNATIONAL ATOMIC ENERGY AGENCY

International Symposium on Isotope Hydrology : Advancing the Understanding of Water Cycle Processes

IAEA Headquarters Vienna, Austria

20 -24 May 2019

GW and UN SDGs in Urban Africa

Thiaroye suburb Quickbird view (2005)

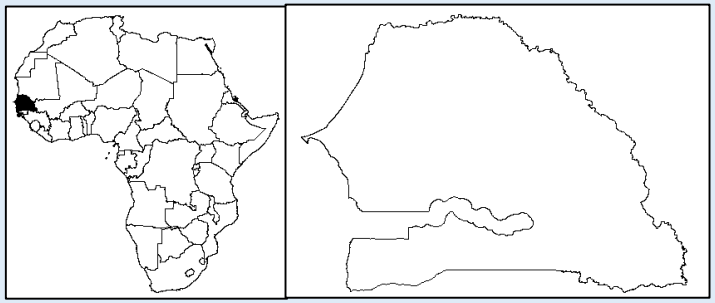
- Rapid, unplanned urban growth and inadequacies in urban planning constrain provision of universal access to safe water and sanitation by 2030 – United Nations' Sustainable Development Goal (UN SDG) 6

- Urban groundwater represents a substantial, strategic freshwater resource to meet rising demand under accelerating rates of urbanisation and reduced river-intake security due to pollution and climate change (Foster et al., 2018)

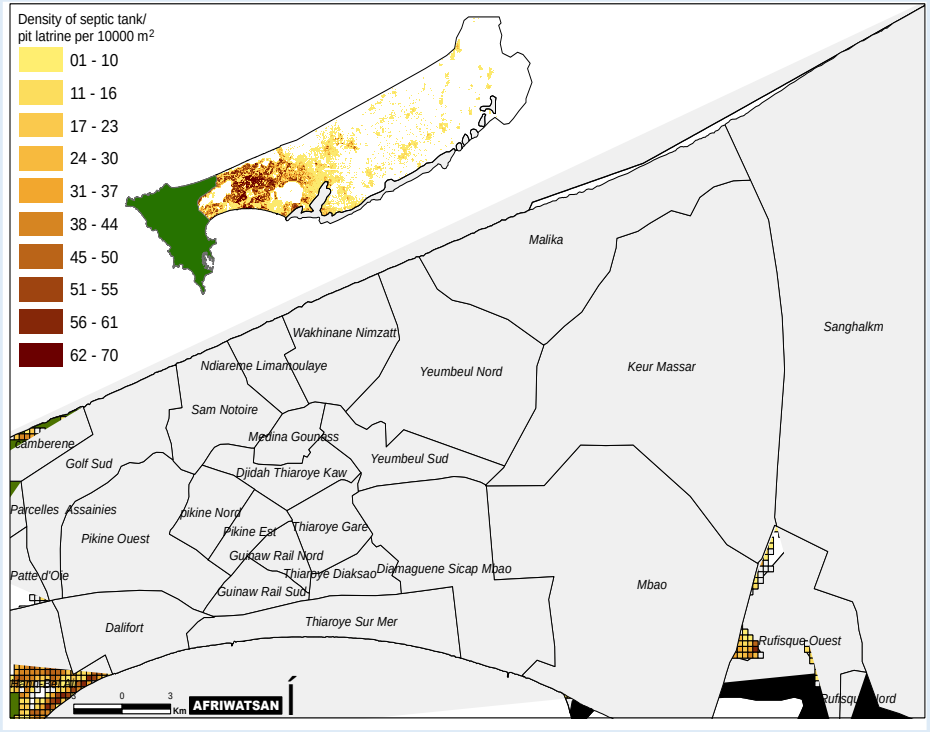
- Risk of pollution from on-site and centralised sanitation systems as well as uncontained faecal waste remains key constraint to the sustainability of urban groundwater use

Natural and anthropogenic recharge in the Thiaroye Urban aquifer

- understanding groundwater recharge and flow systems in Dakar is vital to assessing the sustainability of groundwater use and the contribution of groundwater to flooding



- in the Thiaroye aquifer of Dakar, evidence from piezometry, stable-isotope ratios of O and H, and tritium (^3H) shows that shallow groundwaters to be modern and from monsoonal rainfall

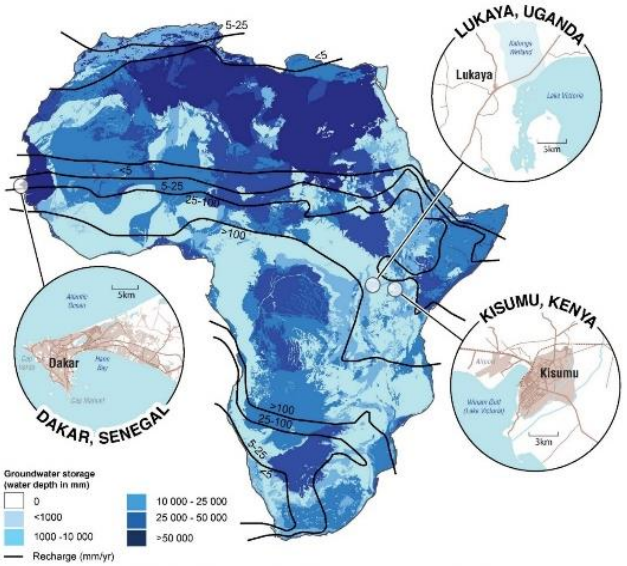


- urban recharge is supplemented by effectively diffuse flows from on-site sanitation facilities (*i.e.* 234 000 septic tanks draining to the Thiaroye aquifer)

Dakar Research: pan-African study *AfriWatSan*

1. to develop scientific evidence required to inform policies and practices that sustain the quantity and quality of low-cost, urban water supply and sanitation systems exploiting the sub-surface in Sub-Saharan Africa; and

2. to strengthen the capacity of individuals and institutions to conduct this vital research.



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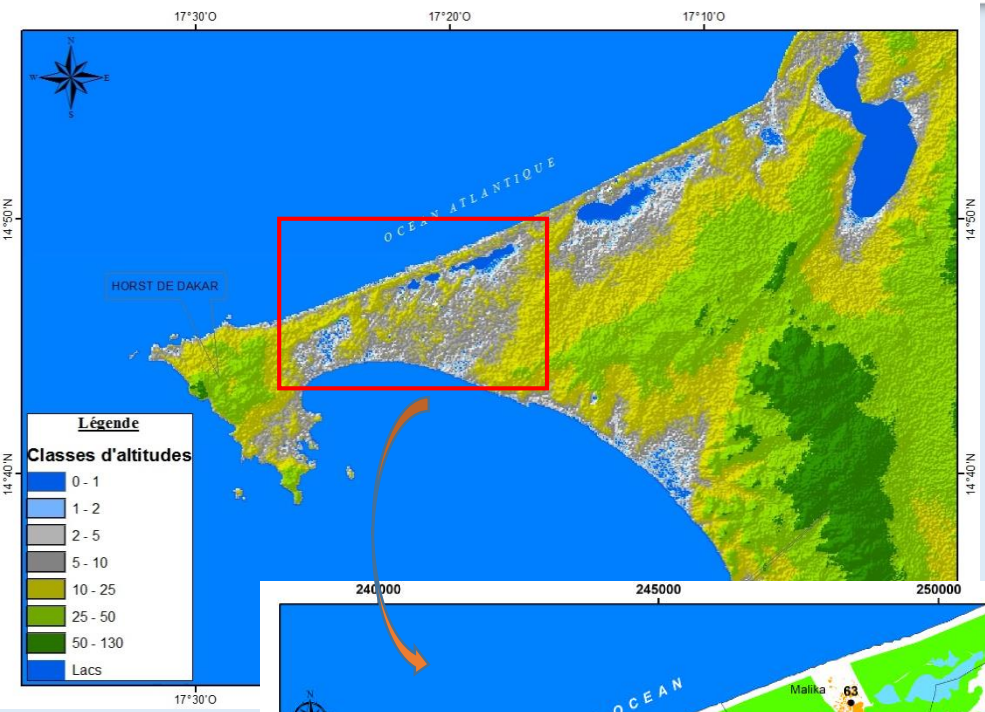
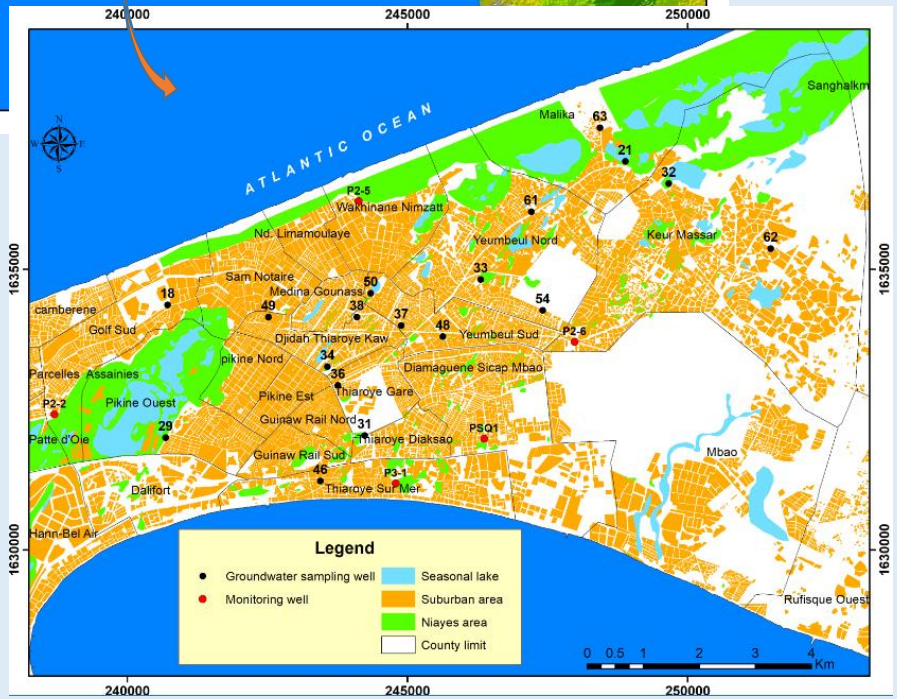
Urban Thiaroye Aquifer of Dakar





Geology / Geomorphology

Low-lying area between westward peninsula with an uplift of the sedimentary deposits (105m) and eastern cliff of Ndiass (127m)

Hydrogeology / Hydrology

shallow, unconfined quaternary sand aquifer occupying a low-lying area of ~300 km^2 that is prone to flooding

Dakar and its suburb represent 54% of the total urban population of Senegal

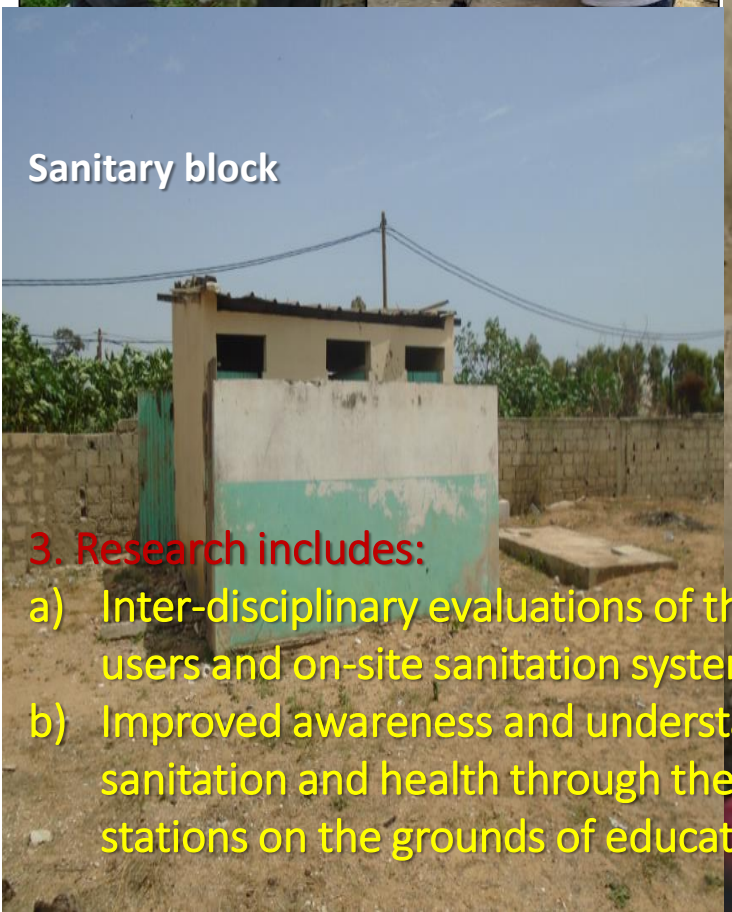
AUTOMATED DATALOGGERS FOR GW LEVELS AND SALINITY MONITORING

1. Installation of probes for continuous high-frequency monitoring

2. Seasonal monitoring:

a) Tracing groundwater movement from piezometry, hand-pumped wells, and production boreholes that enable sampling of $\delta^{18}O$, $\delta^{2}H$ and residence-time indicators

b) Impact of on-site sanitation systems on groundwater quality using chemical tracers and microbiological parameters (*Escherichia coli*, TTCs)



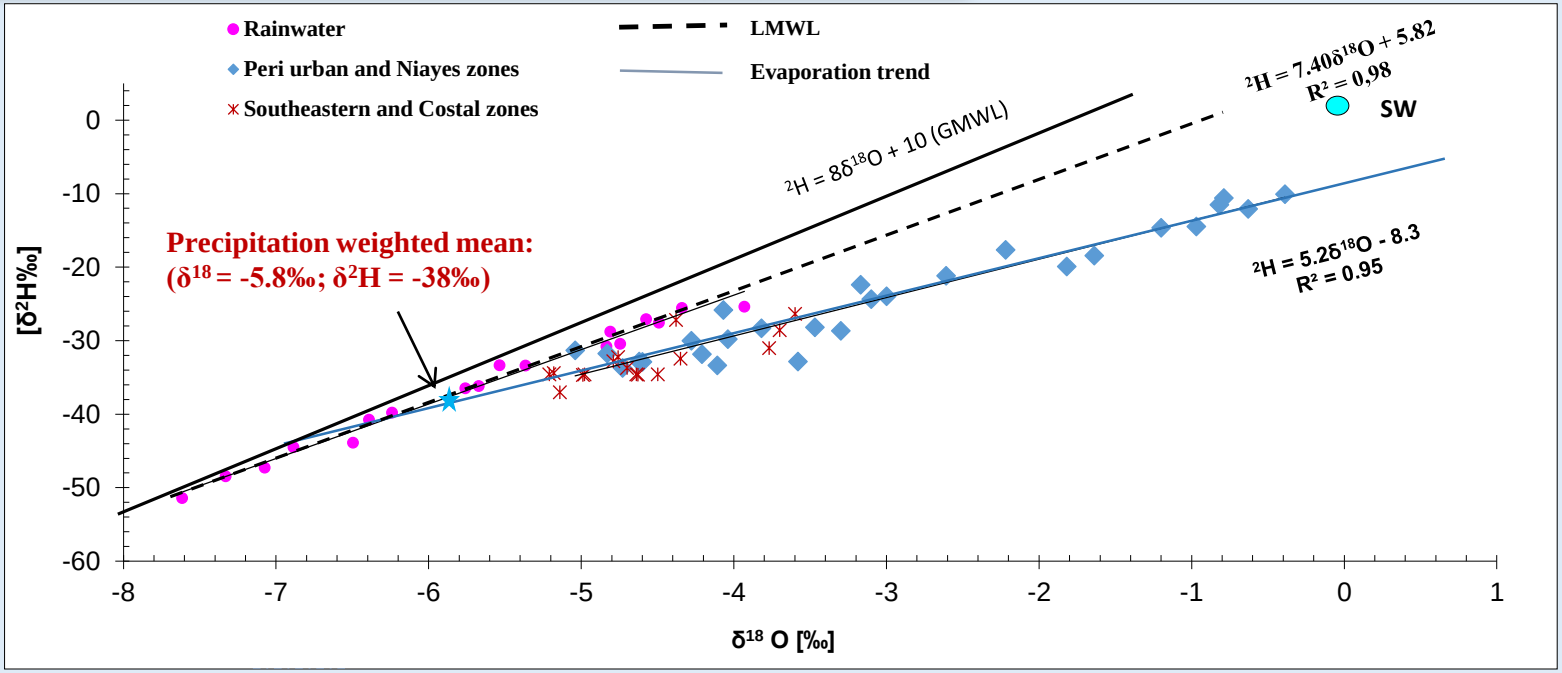
Sanitary block

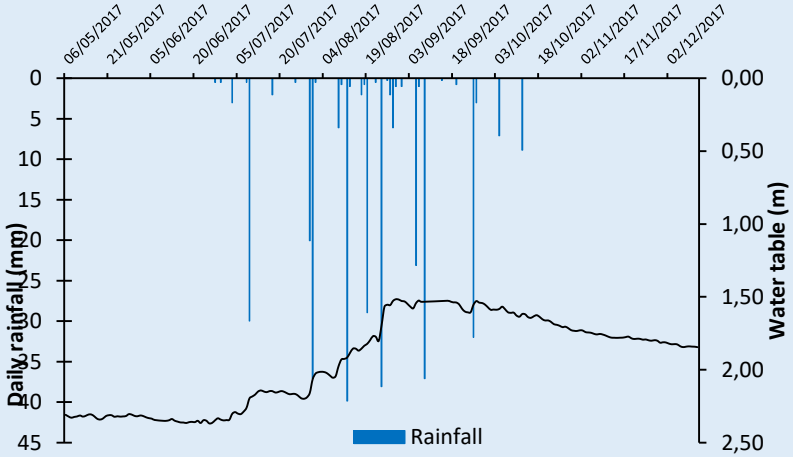
leaky septic tank

3. Research includes:

a) Inter-disciplinary evaluations of the characteristics of water users and on-site sanitation systems on human health; and
b) Improved awareness and understanding of linkages among sanitation and health through the establishment of monitoring stations on the grounds of educational institutions.

RESULTS – TRACING SOURCES OF GROUNDWATER

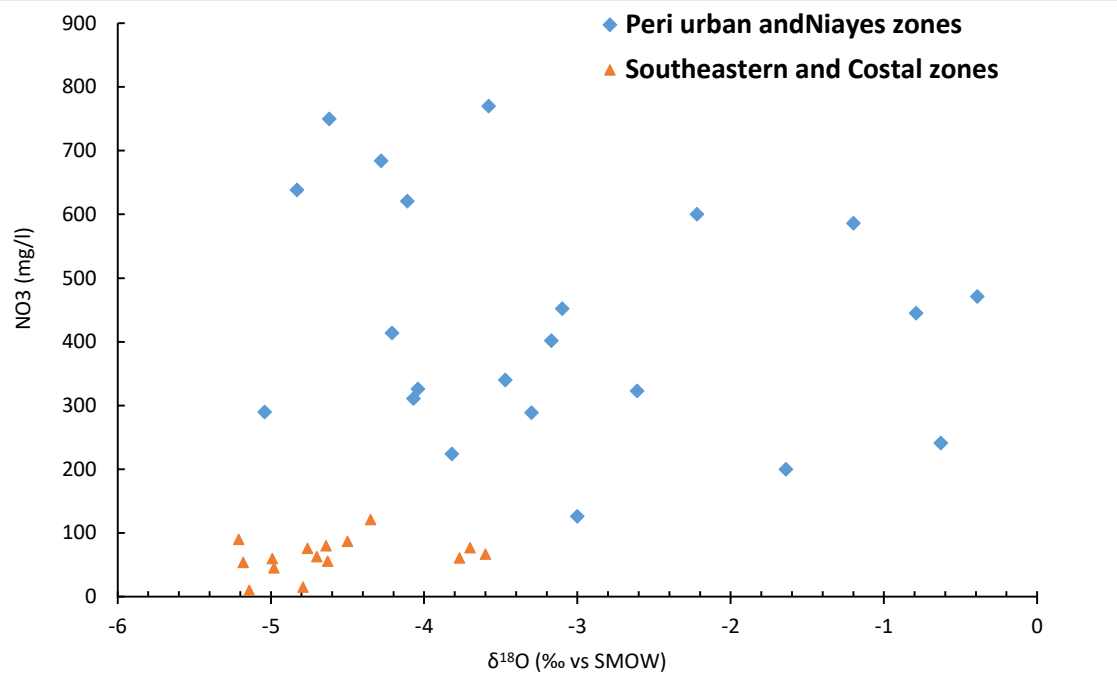




Daily water table fluctuations and rainfall from May to December 2017

- GWs regress along a slope of 5.2 consistent with evaporative enrichment in the heavy isotope of O and H
- GWs intercept LMWL at ($\delta^{18}O$ = -6.3, depleted relative to weighted mean composition of rainfall ($\delta^{18}O$: -5.8) suggesting bias to heavy, isotopically depleted rainfalls
- Diffuse recharge to a shallow water table, indicated by piezometry, reveals the vulnerability of shallow, unconfined aquifer and risk of groundwater flooding

RESULTS – SOURCE OF GW

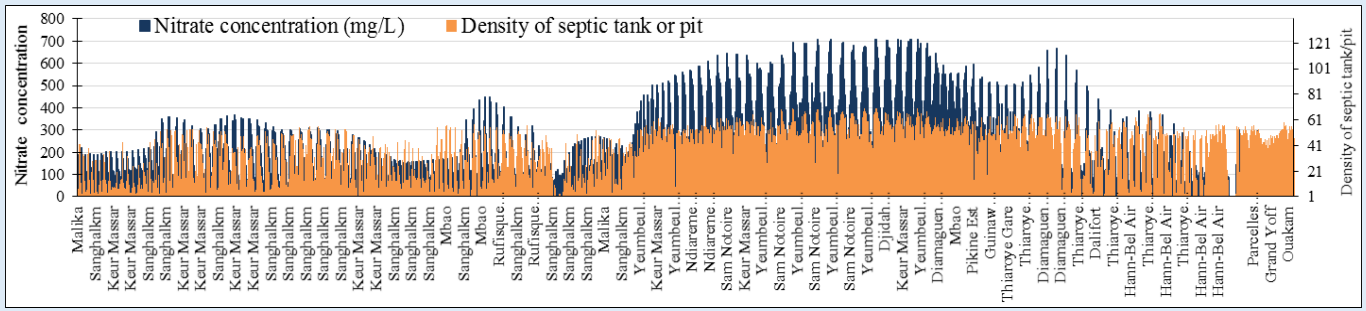


δ18O vs. Nitrate in groundwater

Groundwater samples from suburban and "Niayes" zones enriched in stable isotopes $\delta^{18}O$ and $\delta^{2}H$ compared to the rest of the system

Variation in isotopes suggests contribution of recharge traced to leakage from septic tanks to shallow groundwater

$^{15}N/^{14}N$ ratios in NO_3^- range from + 9 to +22‰ , indicative of *faecal sources of N* found in 87% of sampled groundwaters *(Re et al., 2010; Diedhou et al., 2012)*

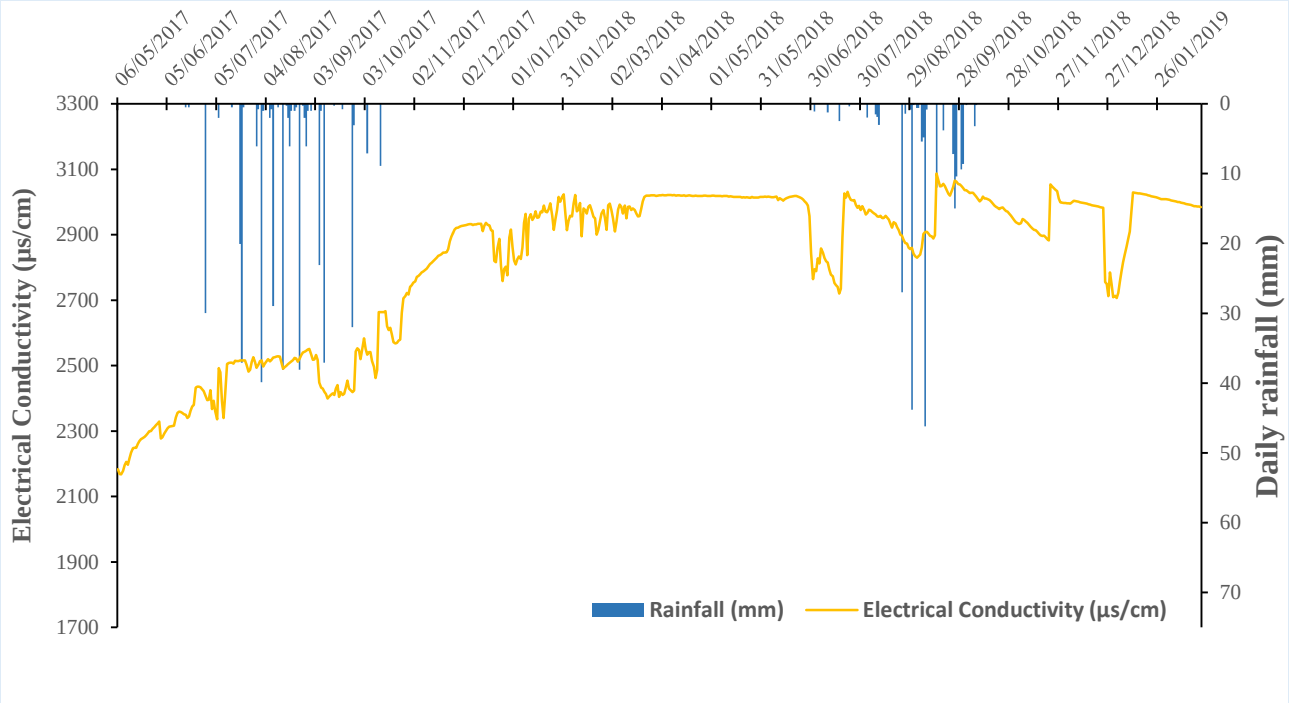


Density of on-site sanitation directly correlated to concentration of faecal chemical pollutants (nitrate) Thiaroye aquifer

RECENT OBSERVATIONS

T (°C)	pH	EC (µS/cm)	DOC	Cl	NO3	P	K	Na	Br	Na/K	Cl/Br
26.7	7.1	1930	18.5	237	327	1.7	25	199	0.5	7.8	480

Mean chemistry of GW in the peri-urban Thiaroye aquifer; all concentrations are given in mg/L

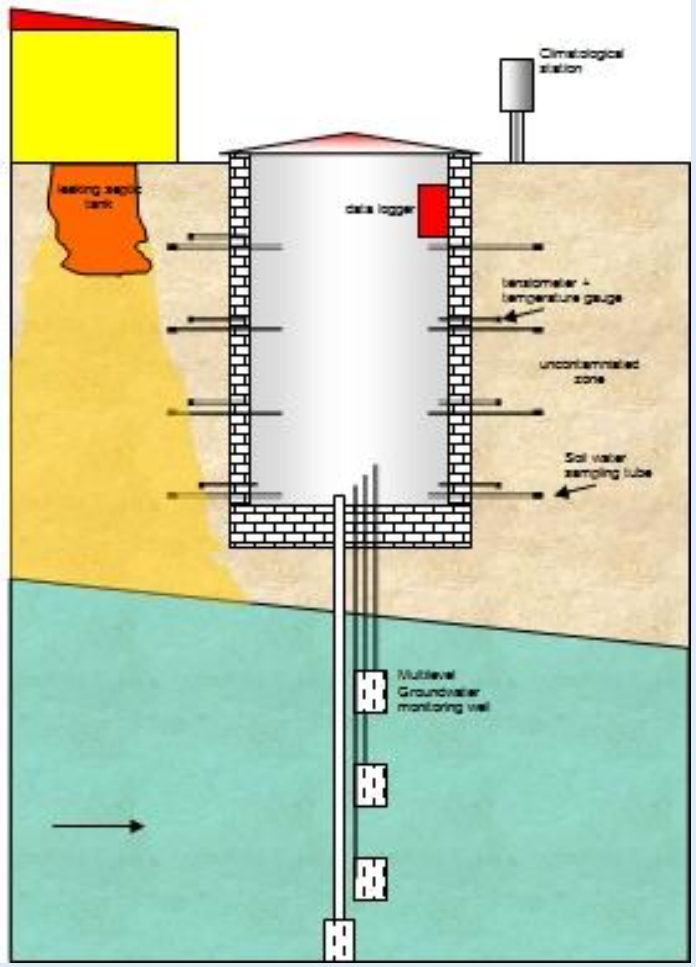


EC of GW and daily rainfall from May 2017 to February 2019

Rainfall stabilises trend toward increase salinity measured by EC

extent of leaching surface and near-surface contamination from uncontained and contained faecal waste (on-site sanitation) is the subject of on-going research

NEW OBSERVATORIES



Urban groundwater observatories monitor effluent migration from septic tank to shallow groundwater

Constructed to inform:

- degree of access, in hydraulic terms provided for penetration of contaminants and;
- assess attenuation capacity of the unconsolidated sand aquifer
- quantify recharge
- assess viability of urban groundwater abstraction to irrigate peri-urban agriculture

SUMMARY - CONCLUSIONS & PERSPECTIVES

- combined use of isotopic and bacteriological tracers provides new insight into sources of recharge to the Thiaroye aquifer of Dakar;
- groundwater derives from diffuse recharge and faecal effluent from a vast network of septic tanks (on-site sanitation);
- pathways by which faecal effluent causing nitrate concentrations exceeding 500 mg/L examined using newly constructed field observatories to monitor pollutant migration through thin unsaturated zone from septic tanks to shallow groundwater;
- seasonal rain-fed recharge and perennial anthropogenic recharge via septic tank effluent exacerbate frequency and duration of groundwater flooding in Dakar.

SUMMARY - CONCLUSIONS & PERSPECTIVES

Outstanding uncertainties in tracing the hydrology & hydrogeology of the Cap Vert Peninsula in Senegal using stable-isotope ratios of O and H include:

- inadequate resolution of seasonal variability in and controls on $\delta^{18}O$ and $\delta^{2}H$ in rainfall; and

- lack of measurements on $\delta^{18}O$ and $\delta^{2}H$ in perennial and seasonal surface waters (Niayes).

=> need to resurrect & sustain observatories.

THANK YOU FOR YOUR KIND ATTENTION

Acknowledgments to :

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Africa Capacity Building Initiative