


The relationship between on-site sanitation density and shallow groundwater quality: evidence from remote sensing and in situ observations in Dakar, Senegal

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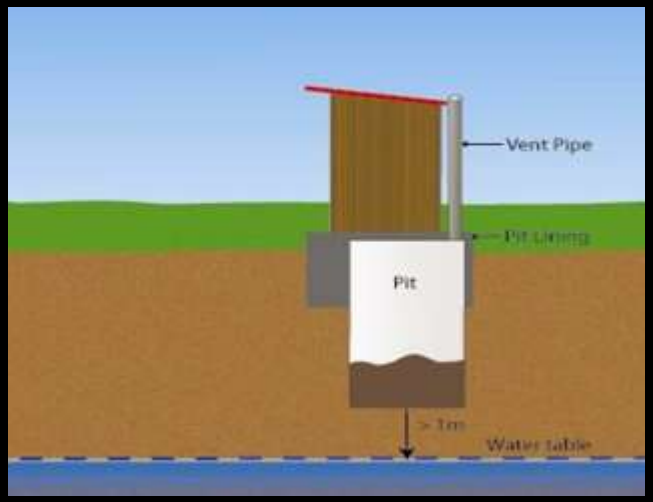
BACKGROUND TO THE RESEARCH

Water management in Senegal is experiencing multiple issues : Degradation of water quality **by on-site sanitation systems failure…**



on-site sanitation (pit latrines, septic tanks) most widely system in low-income cities of Africa

sewered sanitation systems serve a minority of urban dwellers in most low-income cities of Africa

- **Planning or readjustment of improved supply sources & low cost on-site sanitation**

achieving UN SDG 6 of universal access to safe water and sanitation by 2030 in African cities relies upon on-site solutions

OBJECTIVE AND METHODOLOGY OF OUR STUDY

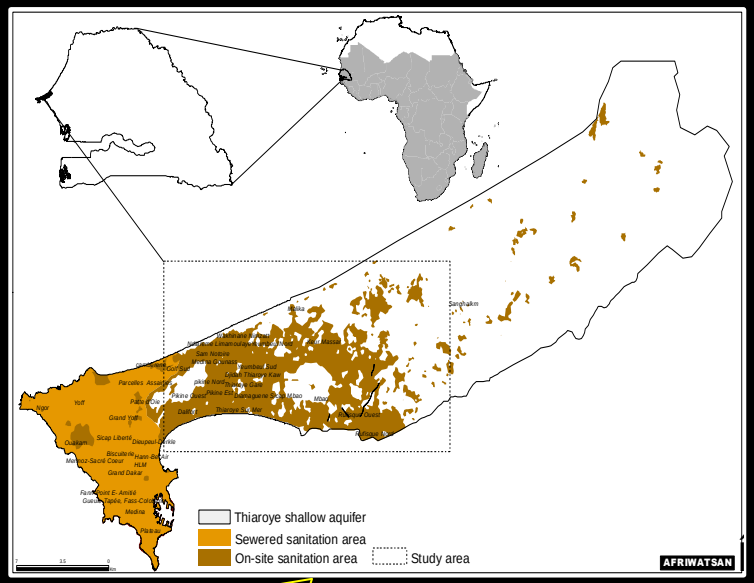
✓ OBJECTIVE

Evaluate the density of on-site sanitation facilities associated with faecal contamination of groundwater below WHO guidelines for safe water

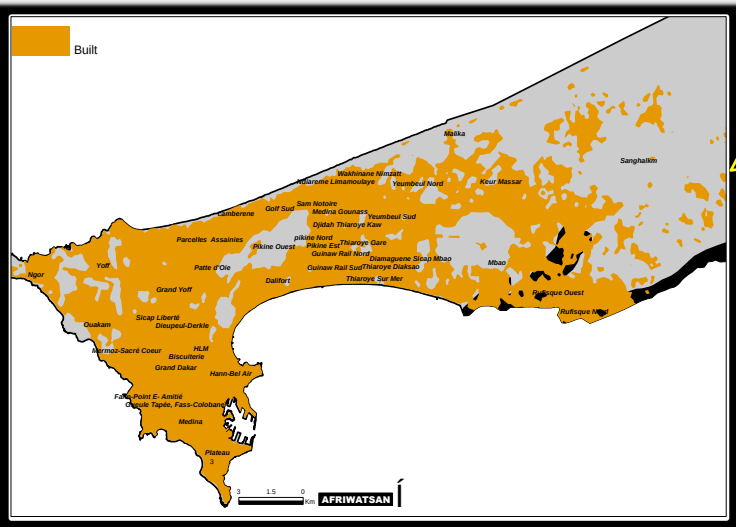
✓ METHODOLOGY

- **City-scale mapping of on-site sanitation fafilities (*i.e.*, septic tanks, pit latrines)**
- **Sampling of shallow groundwater sources for faecal contaminants**
- **Statistical modeling (Chi-squared tests, Spearman correlation ….)**
- **Validation of statistical models**
- **Implied outcomes**

SHALLOW AQUIFER AND ON-SITE SANITATION AREA

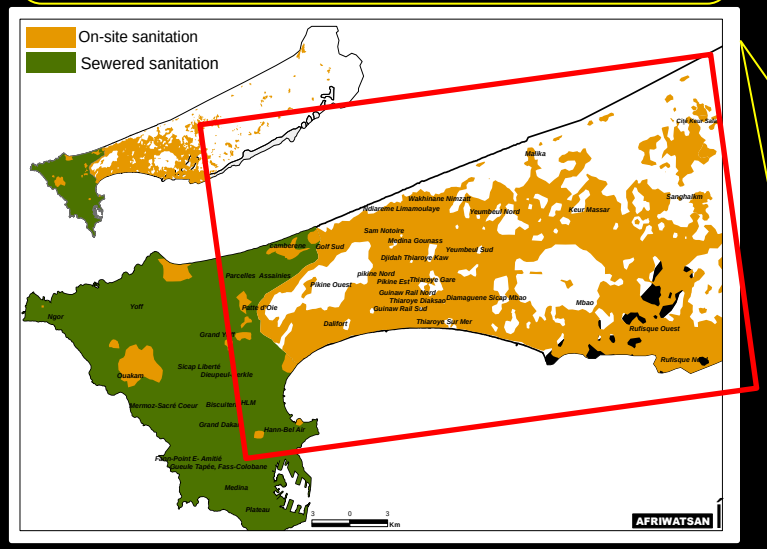


shallow aquifer of Quaternary sands on peninsular Senegal

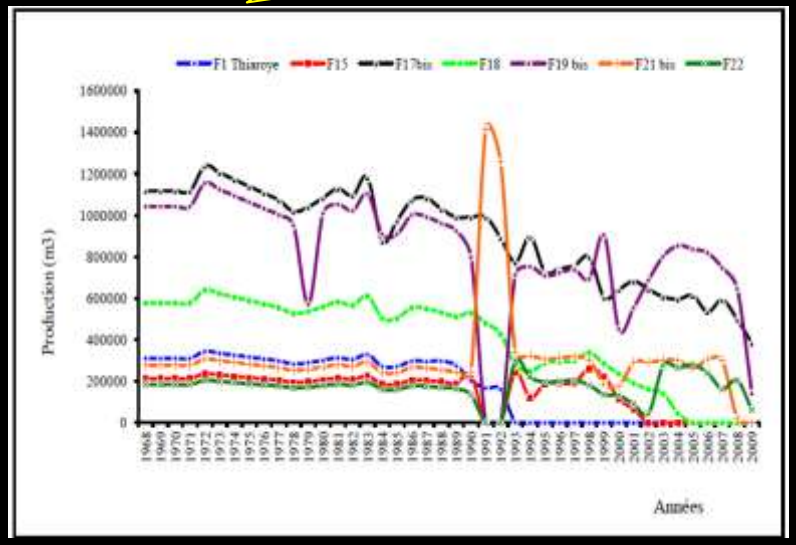


Built area: ~80% of the total study area

- Urban aquifer provided 10% of the water supply until excessive nitrate concentrations – traced to faecal sources using $^{15}N/^{14}N$ (Diediou, 2012), restricted further use of urban wells in 2008

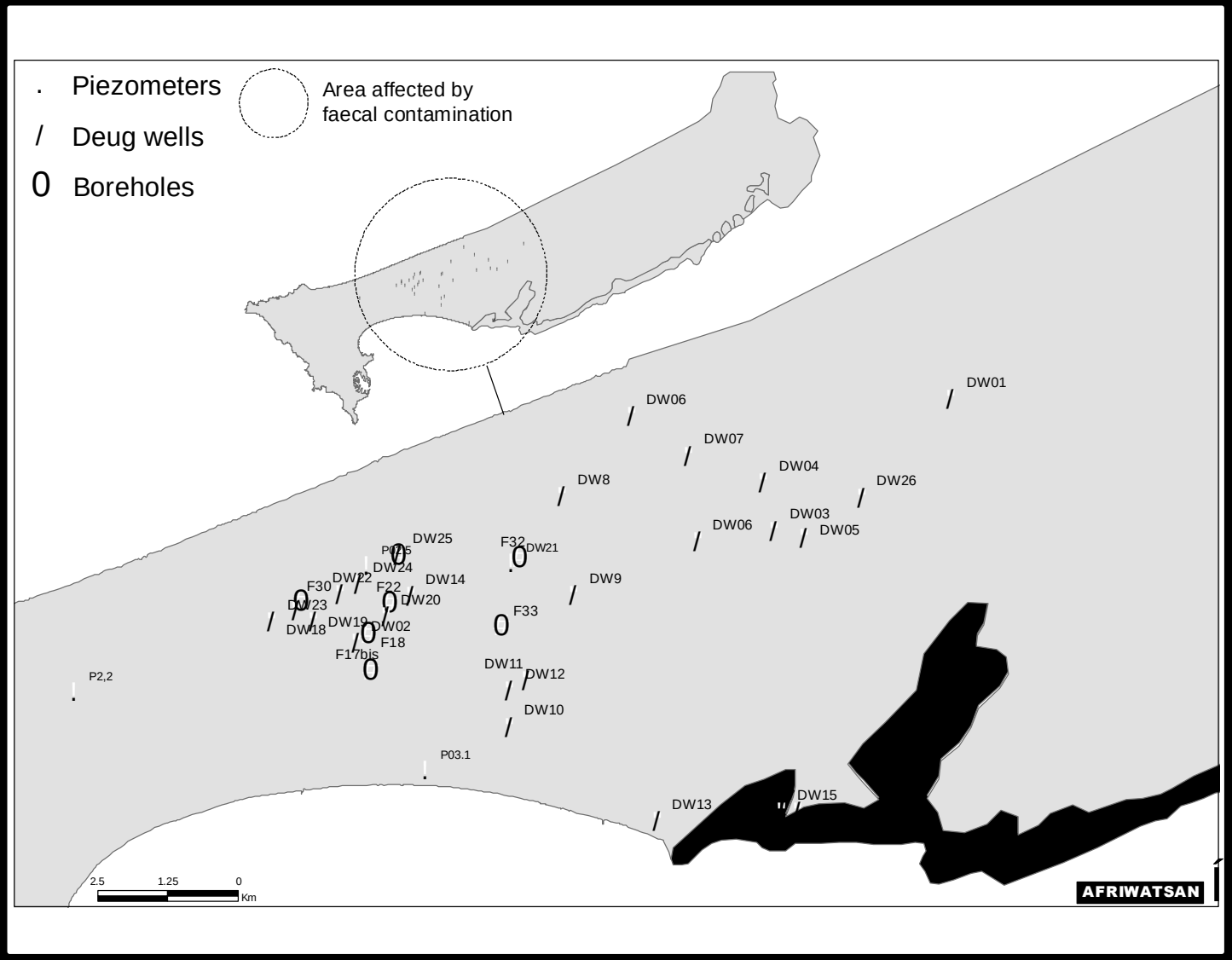


On-site sanitation systems (septic tanks or pit latrines): *coverage rate* (90 - 95%)



COLLECTION AND ANALYSIS OF FAECAL CONTAMINATION INDICATORS

A network of 48 sampling wells consisting of dug-wells, piezometers and boreholes



(37) ➡ 1st campaign
(19) ➡ 2nd campaign
(25) ➡ 3rd campaign

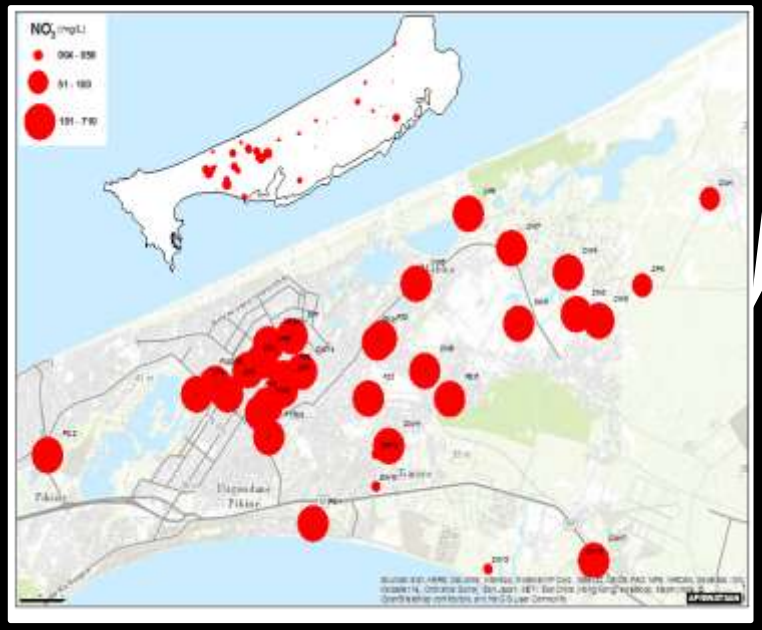
Faecal indicators

- $[NO_3^-]$ (laboratory)
- *E. coli* counts (laboratory)

Analyses

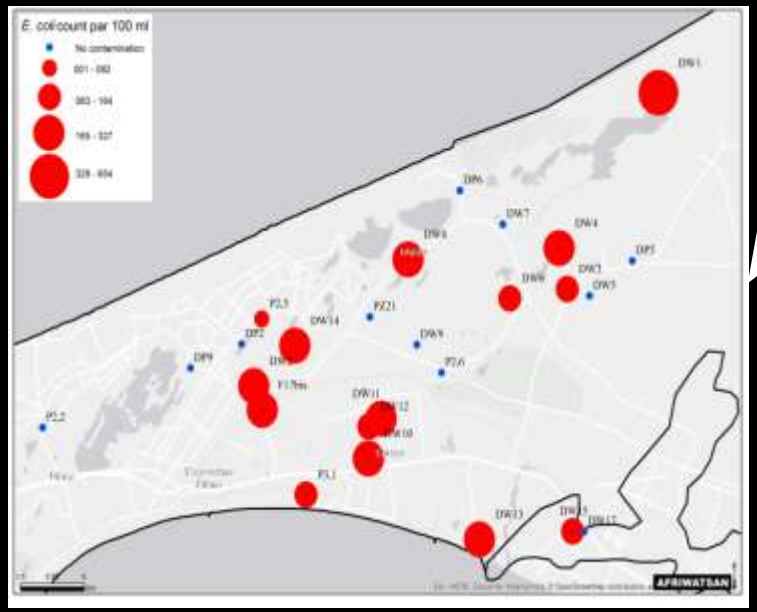
- $[NO_3^-]$ Cd reduction and photometry
- [- E. Coli counts FISH

RESULTS FROM SPOT SAMPLING OF GROUNDWATER



53 % of Sampling wells > 50 mg/L

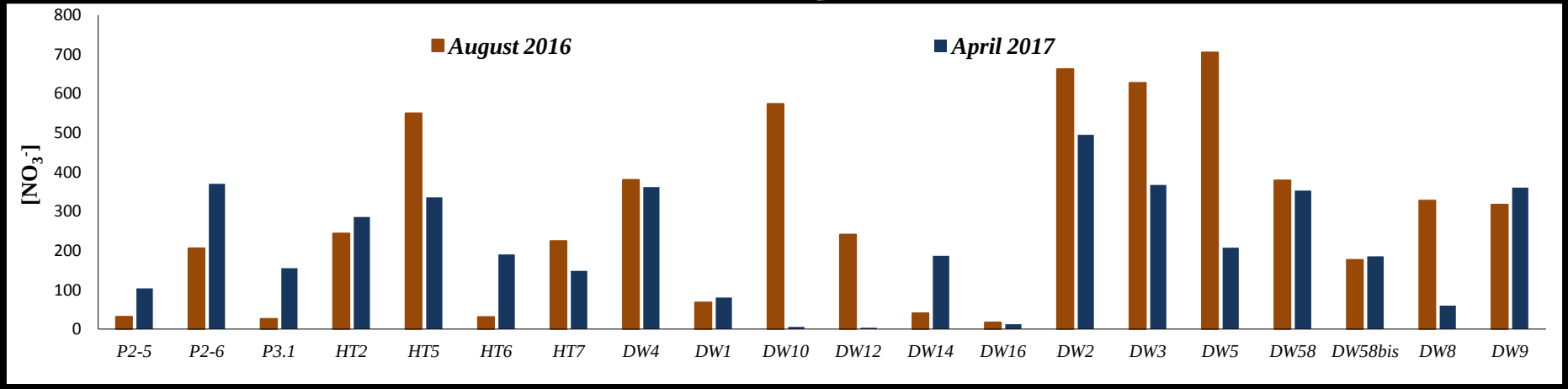
Max[NO3-] = 710 mg/L



70 % of wells > 0 E.coli /100ml ;

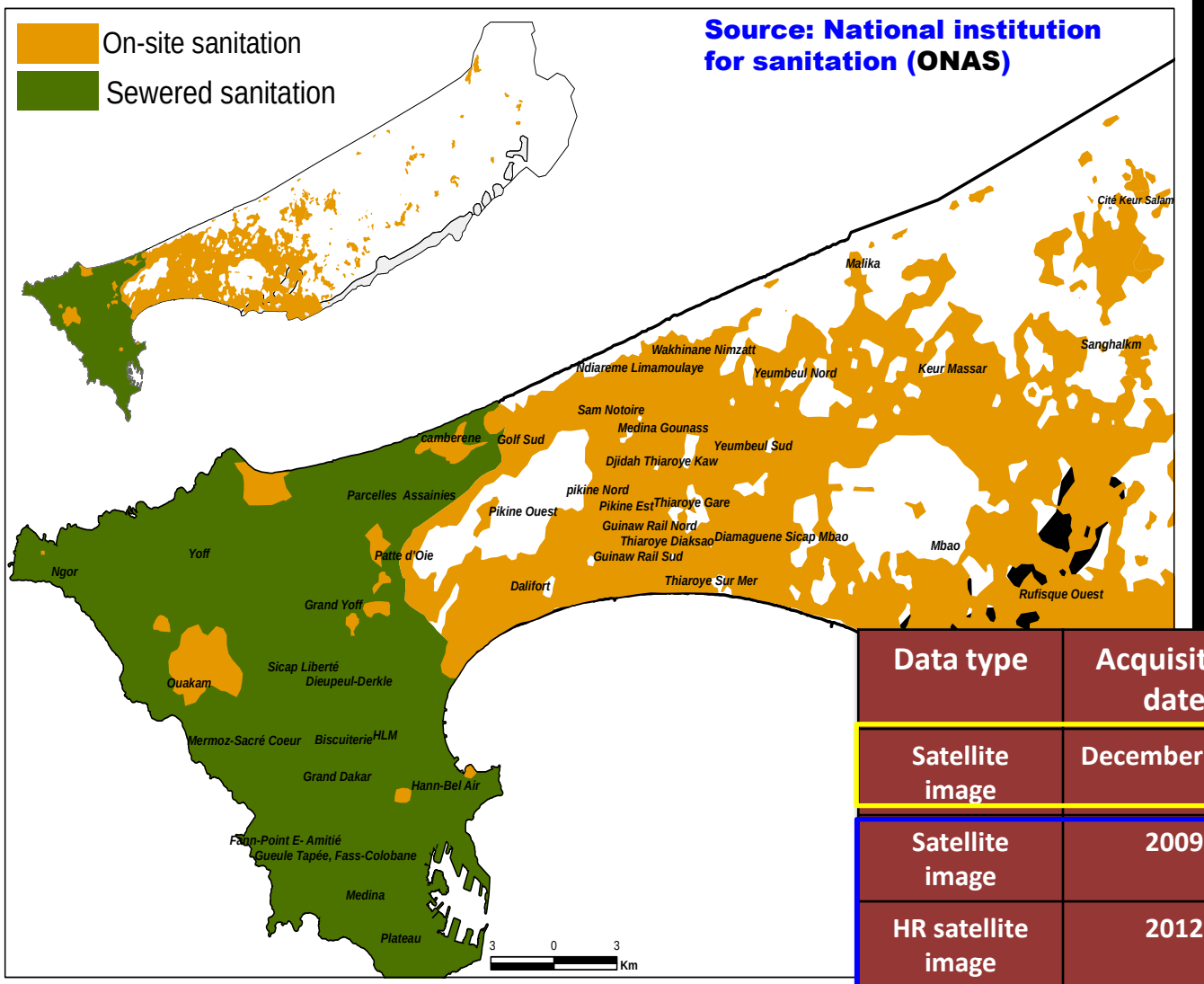
Max[E. coli count] = 654 E. coli/100 ml

Post-monsoon sampling (Aug 2016) shows both increased contamination (Injection rate of septic tanks or pit latrines) and reduced contamination (dilution from recharge rain-fed) relative pre-monsoon (Apr 2017)



MAPPING OF ON-SITE SANITATION FACILITIES 1

❑ DISTRIBUTION OF SANITATION TYPE / HIGH RESOLUTION SATELLITE IMAGE USED



- western zone, 74 km² (sewered sanitation)

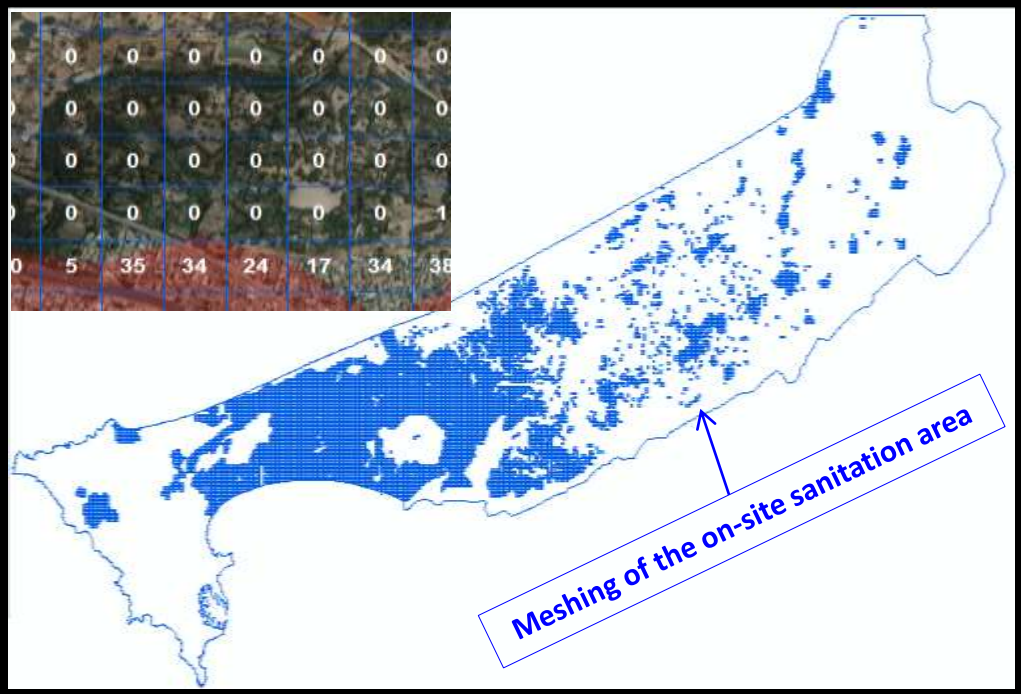
- eastern zone, 99 km² (on-site sanitation)

❑ High resolution Satellite image used

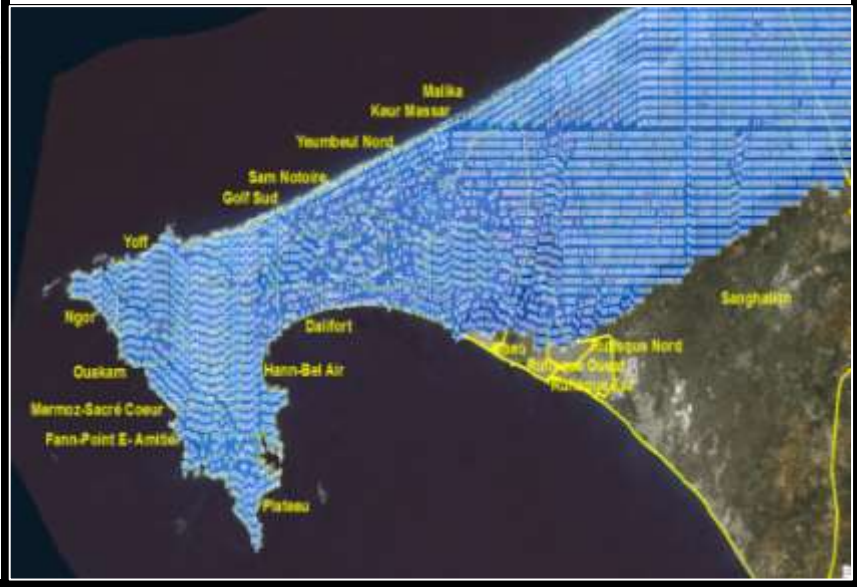
Data type	Acquisition date	Source	Resolution (m)
Satellite image	December 2016	QuickBird	1
Satellite image	2009	Orbview	1.60
HR satellite image	2012	Geoeye	0.60

MAPPING OF ON-SITE SANITATION FACILITIES 2

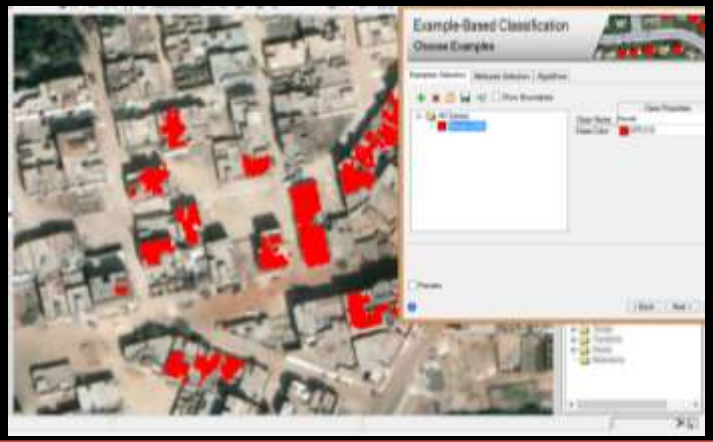
❑ Meshing / Object-oriented classification of high resolution satellite image

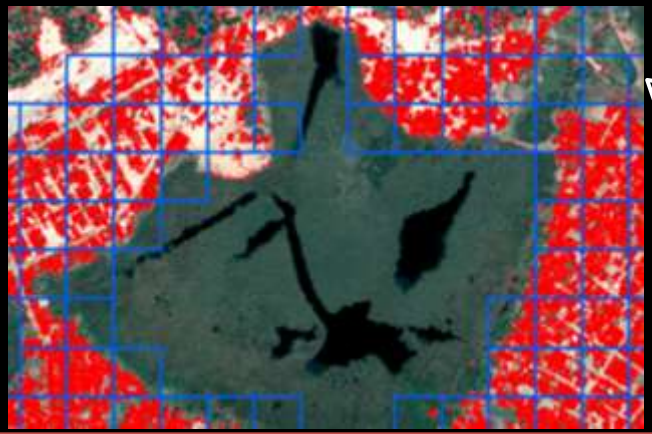


Meshing of 100/100 m at the scale unsaturated zone of the shallow aquifer



✓ **Object-oriented classification** (Spectral values and morphological parameters)



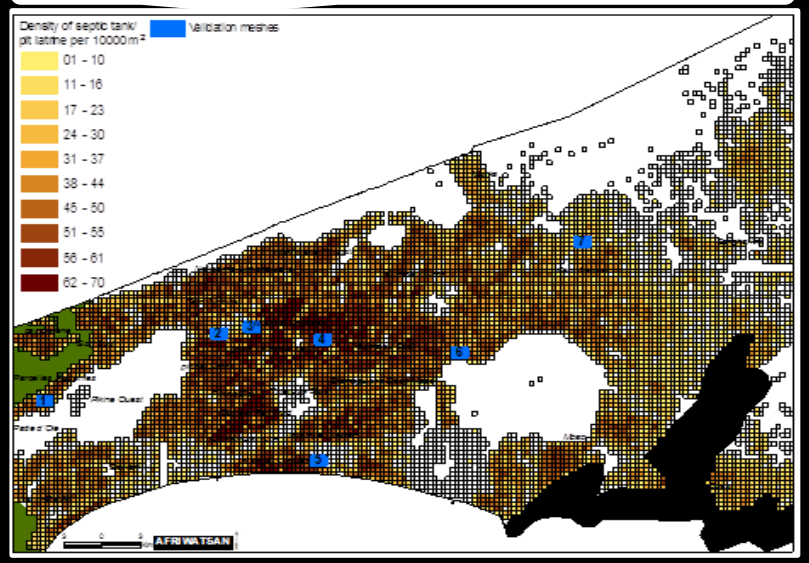


✓ A rough estimation of surfaces occupied by the houses on 100/100 m

MAPPING OF ON-SITE SANITATION FACILITIES 3

❑ REFINED AND VALIDATED BY PHOTO-INTERPRETTION AND TRUTHING SURVEYS

DISTRIBUTION OF VALIDATION MESHES

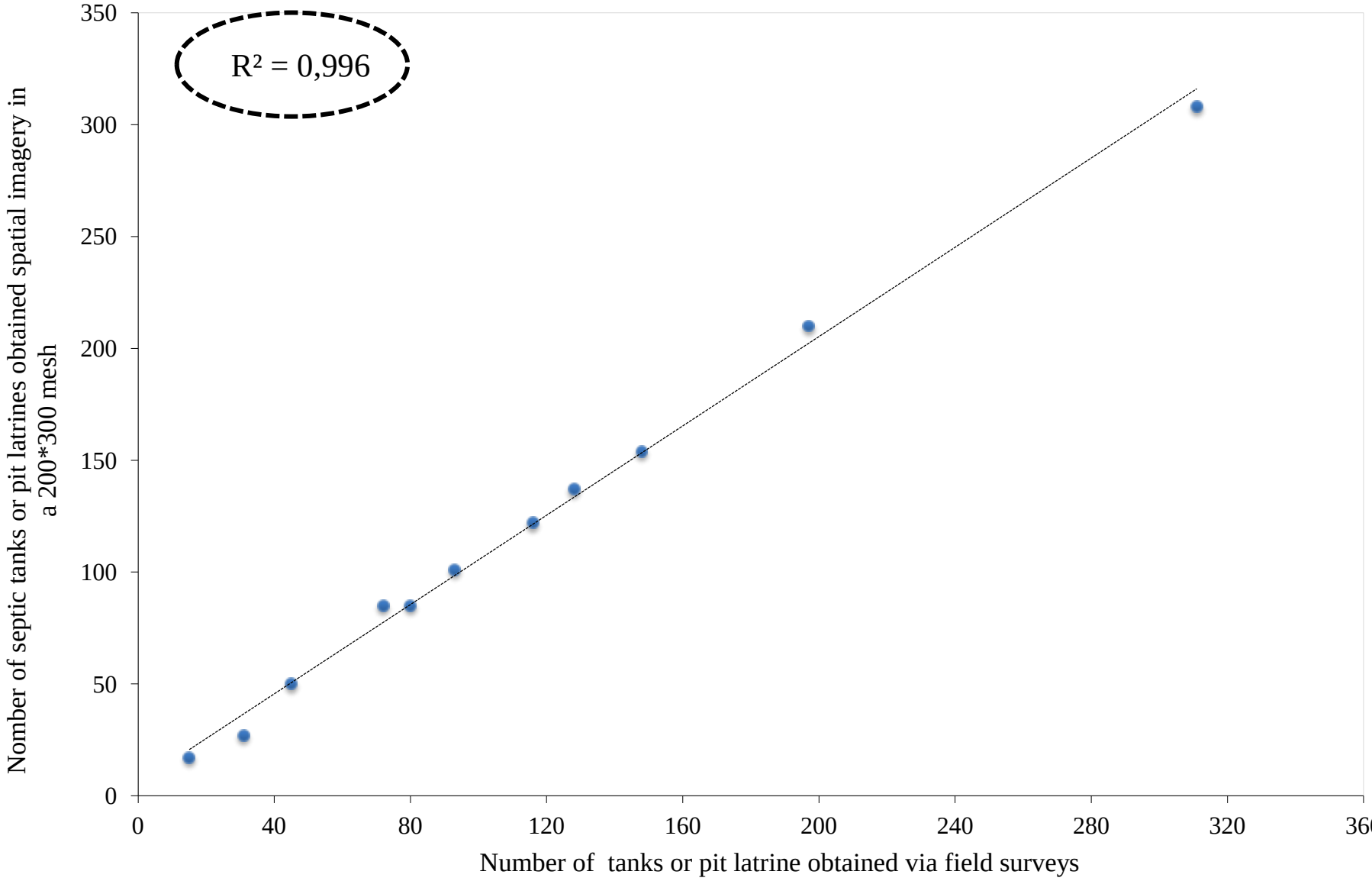


VISUALIZATION OF A VALIDATION MESH OF 200/300 m

Validation mesh	Center of the mesh (well identifier)	X (m)	Y (m)	Size of the validation mesh	Number of tanks or pit latrines obtained in 200/300 m mesh via satellite imagery	Number of tanks or pit latrines obtained in 200/300 m mesh through truthing surveys
Mesh 01	P.2.2	238560	1632570	200/300	031	027
Mesh 02	F30	242530	1634140	200/300	128	137
Mesh 03	DW18	242790	1633795	200/300	197	205
Mesh 04	F19	244890	1634001	200/300	311	308
Mesh 05	P.3.1	244793	1631188	200/300	093	101
Mesh 06	P.2.6	248000	1633700	200/300	148	154
Mesh 07	DW4	242790	1633795	200/300	116	122
Mesh 08	DW202	257326	1632464	200/300	045	050
Mesh 09	DW109	257203	1638571	200/300	072	078
Mesh 10	DW234	257203	1638571	200/300	083	085

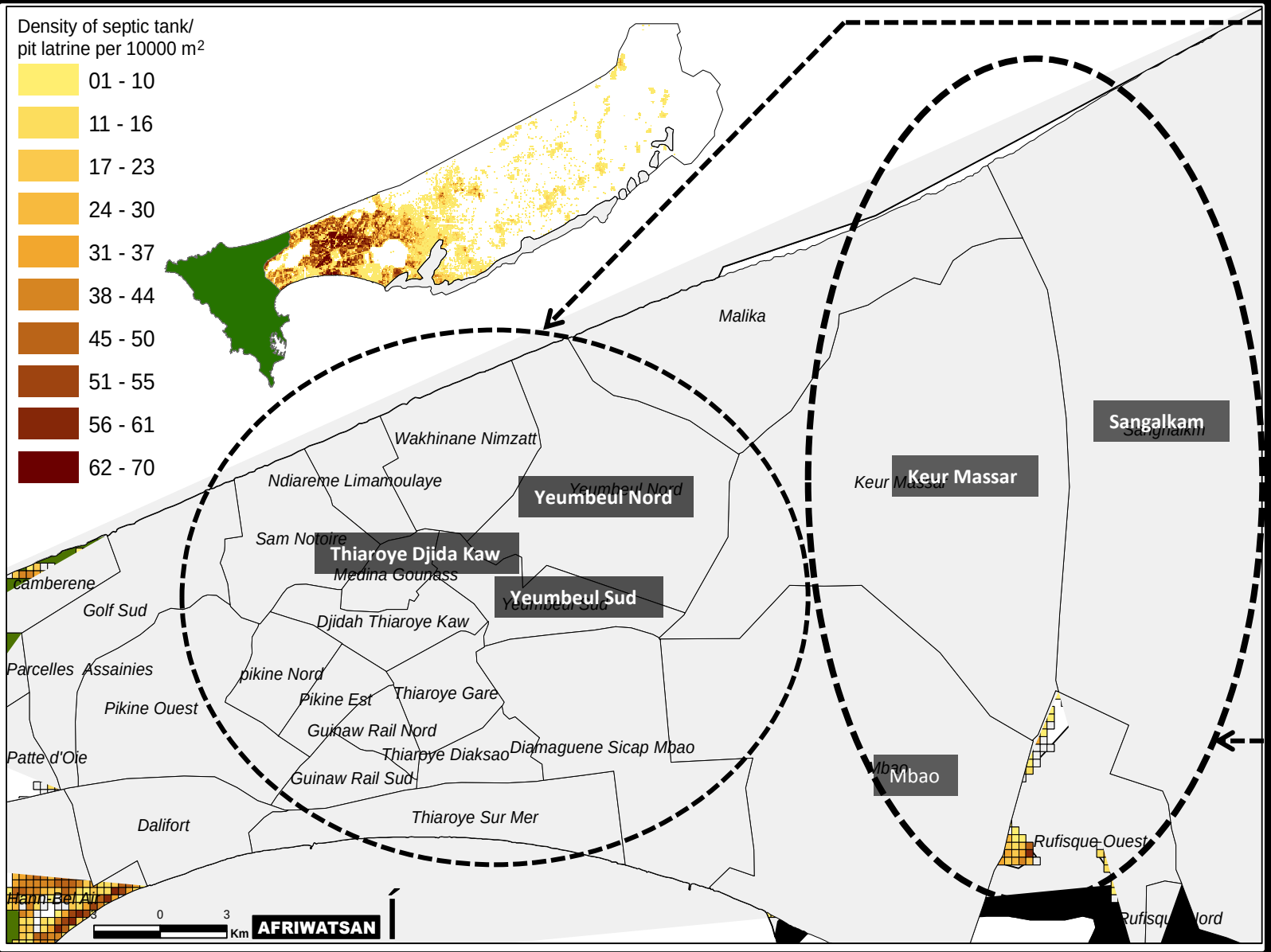
MAPPING OF ON-SITE SANITATION FACILITIES 5

❑ RS analysis strongly correlated to ground-truthing surveys



MAPPING OF ON-SITE SANITATION FACILITIES 4

❑ Results of advanced on-site sanitation / Density of of tanks or pit latrines



High septic tank density in the urban area

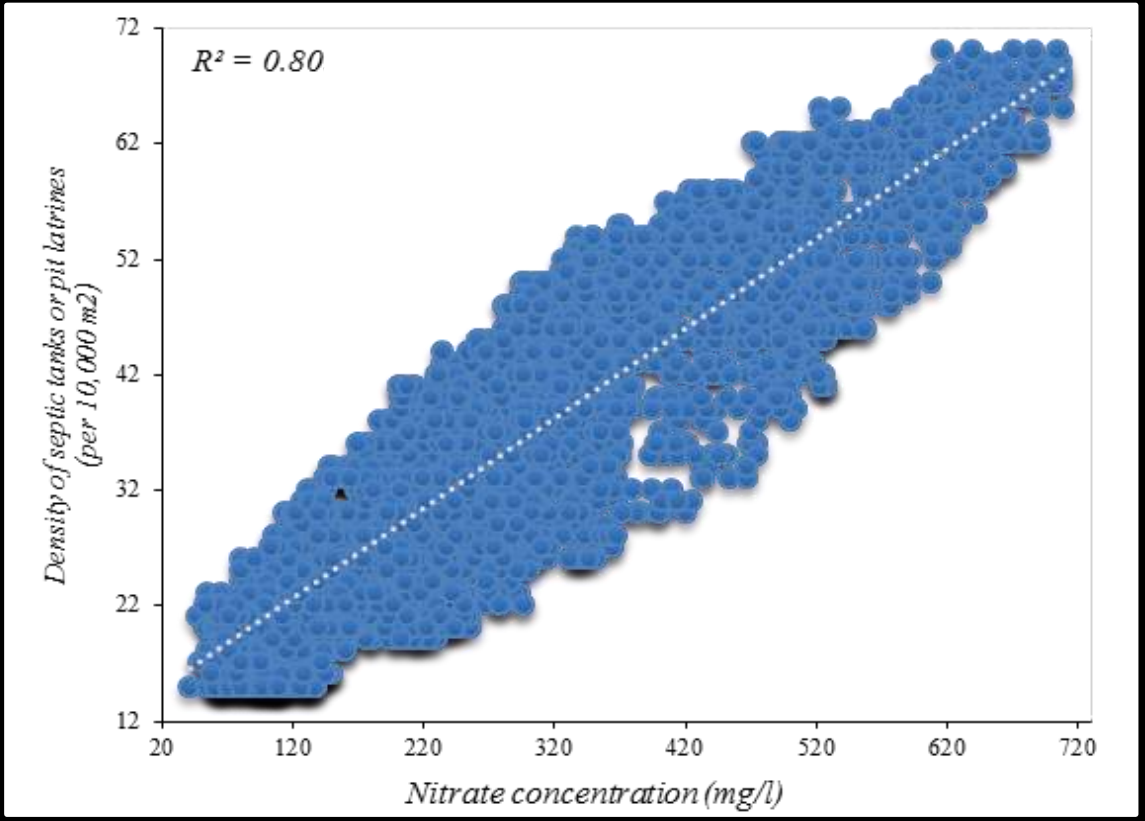
Density max = 70 tanks or pit latines /hectare

Low septic tank density in the peri urban area

RESULTS GENERATED BY STATISTICAL MODELS

❑ Correlation coefficients of between faecal contaminants and density of tanks/pit

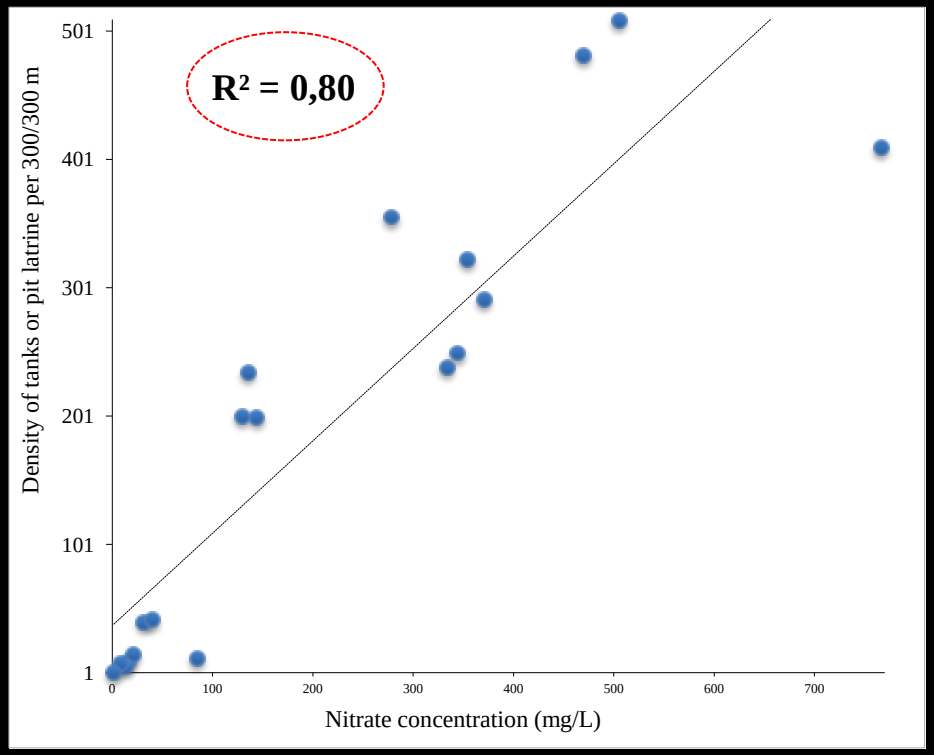
Minimum number of meshes observed in the study area	Correlation coefficient (R^2) / P-value	Kendall tau-C (τ) / P-value	Gamma Coefficient ($_\Upsilon$)/ P-value	Spearman correlation (ρ)/ P-value	Chi-square (X^2) / P-value
3,325 meshes	$R^2 = 0.80$ 0.000	$\tau = 0.78$ 0.000	$_\Upsilon = 0.78$ 0.000	$\rho = 0.93$ 0.000	$X^2 = 65.550$ 0.0001

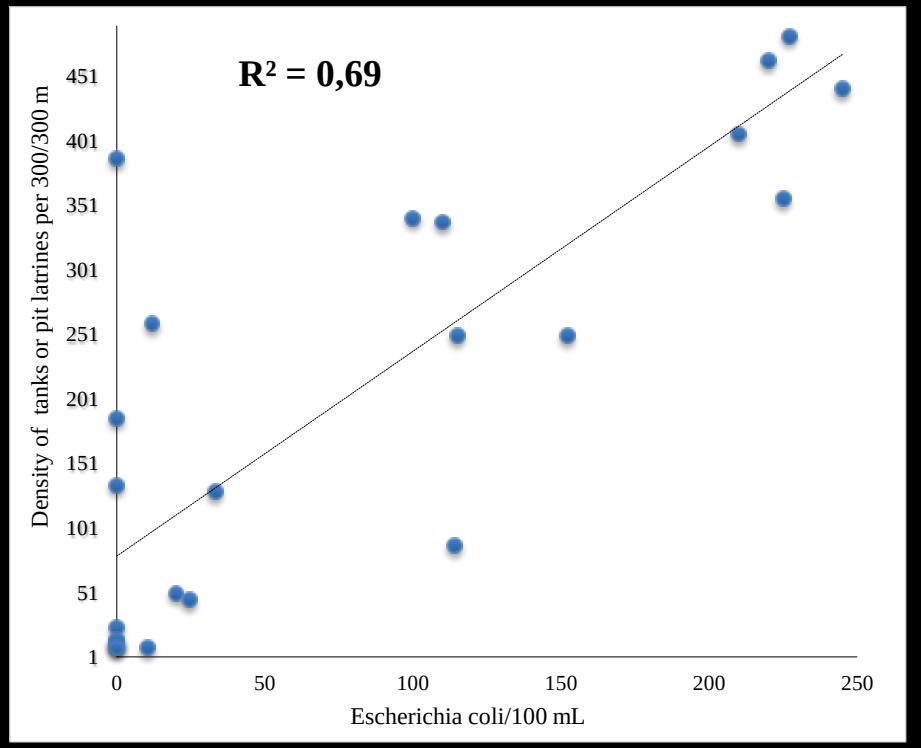


Faecal contaminants	Nitrate concentration [NO3] : dependant variable)
Linear regression:	ρ on-site sanitation = 0.08 * [NO3]+ 14 ; ρ: Independant variable

REVERSE VALIDATION OF THE STATISTICAL MODELS 2

❑ **A very significant association between faecal contaminants and on-site sanitation density**





Use WHO guideline value for nitrate (< 50 mg/L) as a criterion for safe/unsafe water representing the ability of the shallow aquifer to attenuate faecal contamination through dilution and degradation.

Exceeding densities ranging from 18 to 24 on-site sanitation facilities (septic tanks) per hectare in the Thiaroye aquifer pose a serious risk to human health

CONCLUSIONS

- ✓ density of on-site sanitation facilities has been successfully mapped in a low-income area (99 km^2) of Dakar (Senegal) using an object-oriented classification of optical imagery (QuickBird, GeoEye, OrbView) and photo-interpretation, validated by ground-truthing surveys
- ✓ density of on-site sanitation facilities, comprising primarily septic tanks, is strongly correlated to the magnitude of faecal contamination (nitrate, *E. Coli*) observed in shallow groundwater within unconsolidated Quaternary sands
- ✓ Exceeding densities ranging from 18 to 24 per hectare is associated with nitrate contamination exceeding the WHO guideline value of 50 mg/l
- ✓ analysis highlights the capacity of an unconfined shallow sand aquifer to attenuate untreated faecal effluent from on-site sanitation
- ✓ replication of these analyses in other conurbations in Sub-Saharan Africa is required to better understand the attenuation capacity of urban aquifer systems in different contexts and to inform use of low-cost sanitation systems to contain faecal effluent

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Thank you for your listening

Afriwatsan team

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