Methodology for Groundwater Resiliency Indicators and Mapping

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Groundwater resiliency

- Groundwater resiliency: It is an ability to absorb the stress on the aquifer and adopt to the changes in the system.
- Stress on groundwater mainly due to groundwater pumping for different uses
- Aquifer characteristics and properties directly related to the recovery process
- The recovery time higher in low transmissivity aquifer systems
- Unsustainable pumping yield to reduced groundwater resiliency in such systems

Driving factors for resiliency concept

- Population: increasing population and demand for reliable and safe water supply for drinking purpose affect the resilience of the groundwater system
  - Reliable supply mostly obtained from groundwater reserves
  - Groundwater relatively less contaminated than surface water
- Land use: land use/land cover changes alter the consumptive water use rates
  - Intensive cropping in low rainfall region heavily depend on groundwater supplies
- Climate change: climate variability and changes also affects the resilience of the groundwater systems
  - Shifting the peaks of rainfall events within the inter annual scale affect the groundwater usage and so resiliency

Importance for resiliency studies

- It is expected that two third of world's population will live in urban cities by 2050
  - Safe drinking water and sanitation to meet the demand from surface water resources critical
  - Supplementing groundwater most easily available alternative
- Agricultural produce and food demand must comply with increasing population
  - Irrigated agriculture – the solution for increased produce but met from reliable water sources
- Understanding groundwater system and its response to various pumping stresses critical to manage the system
- Uncertain climatic variability and consequences of over exploitation must be minimized from studying the resilience

Objectives of this presentation

- The objectives of this presentation:

1. To explain the methods that we have proposed to calculate the resiliency index and resiliency mapping criteria in the background paper
2. To get the valuable comments from the participants to improve our methodological framework to address the resiliency issue in effective manner

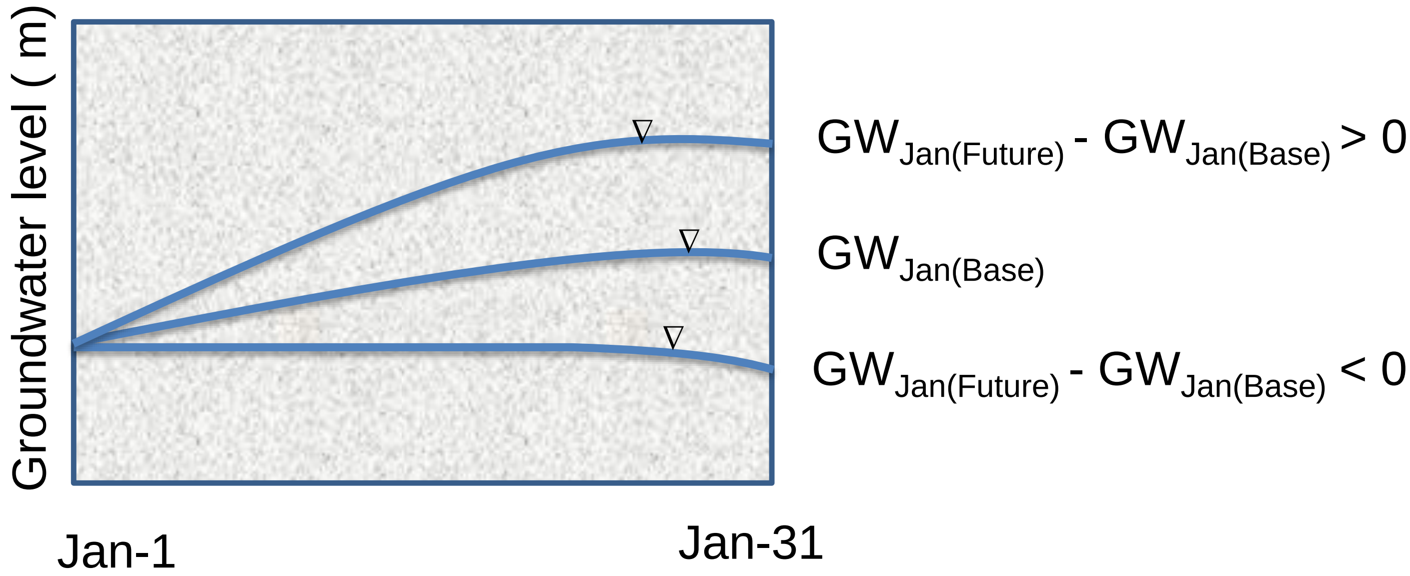
Resiliency indicators

- Resiliency indicator measures the magnitude of groundwater resiliency under different scenarios
- Resiliency indicator calculates the difference in the value based on the base line period values
- Base line period: base line period in general the historical period from which the mean values derived
- Resiliency indicator values calculated over future time series segments for different scenarios
- The value of resiliency indicator can be either positive, zero or negative

Resiliency indicator: Method-1

- Based on groundwater level data

Change in groundwater level (Δ_{GW}) = ($GW_{t(Future)}$ - $GW_{t(Base)}$)



- t(Future), t(Base) corresponds to time steps in future and base line periods
- Change in groundwater level computed between future and base line changes

Resiliency indicator: Method-1 contd.,

- Groundwater flow simulation in MODFLOW

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+Q_s^{'}=SS\frac{\partial h}{\partial t}$$

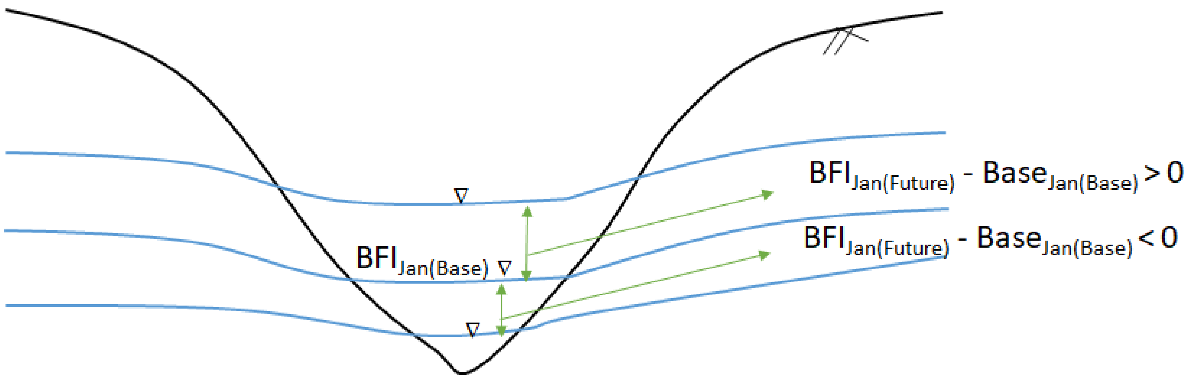
  - K – hydraulic conductivity tensor at x, y and z directions (L/T)
  - h – potentiometric head (L)
  - Q'_s = volumetric flux per unit volume representing source/sinks (T^{-1})
  - SS – specific storage of the porous material (L^{-1})
  - t – time (T)
- Solved using control volume finite difference method
- Newton-Raphson equation method of iteration for solution
- Groundwater level or potentiometric levels obtained at the end of each time steps

Resiliency indicator: Method-1 contd.,

- Data required for solving groundwater levels
  - Groundwater recharge
  - Boundary conditions
  - Hydrogeological properties
  - Observed groundwater levels
  - Groundwater abstraction
  - River properties
  - Top and bottom elevation of each layers
  - Initial conditions
- Solved groundwater level values used for calculating the change in groundwater levels
- The magnitude of change in groundwater levels related to resilience

Resiliency indicator: Method-2

- Based on streamflow data
- Base flow index = base flow / stream flow
- Base flow can be approximated to base recharge
- The difference in base recharge values can be used to identify the dynamics of an aquifer



Resiliency indicator: Method-2 cont.,

- Separating baseflow from streamflow: recursive digital filters (RDF)
- RDF tools used to remove high frequency quickflow signal to derive low frequency baseflow signals
- RDF filters sensitive to the filter parameters and needs calibration

$$q_{b(i)} = \frac{(1 - BFI_{max})\, a\, q_{b(i-1)} + (1-a) BFI_{max} q_i}{1 - a\, BFI_{max}}$$

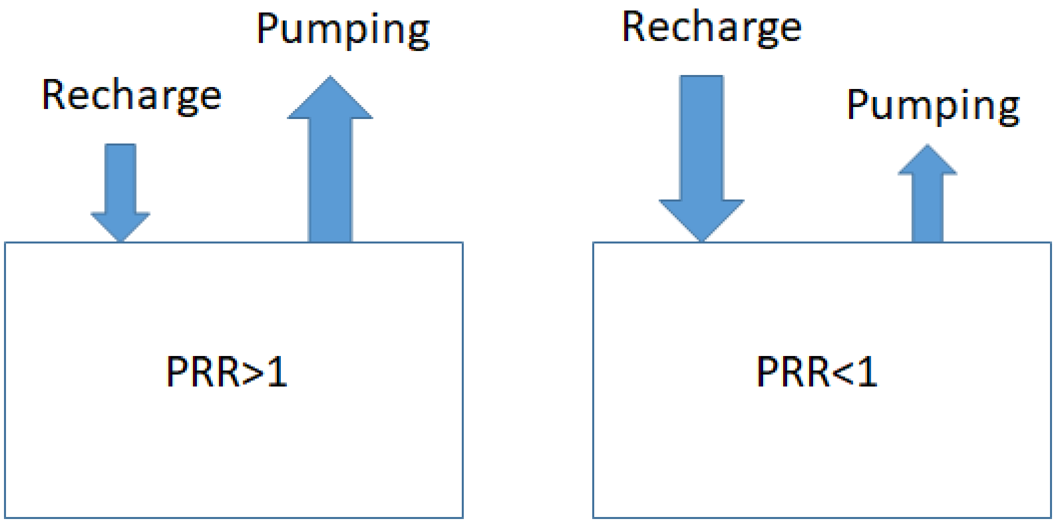
- $q_{b(i)}$ = baseflow at time step i
- $q_{b(i-1)}$ = baseflow at time step i-1
- q_i = streamflow at step I
- a – recession constant
- BFI_{max} = Maximum BFI measured

Resiliency indicator: Method-2 cont.,

- Data requirements for streamflow prediction
  - Precipitation
  - Temperature
  - Wind speed
  - Solar radiation
  - Relative humidity
  - DEM
  - Landuse map
  - Soil map
- Data requirements for baseflow separation
  - Predicted streamflow
  - RDF parameters
  - Discharge measurements
  - BFI

Resiliency indicator: Method-3

- Pumping to recharge ratio (PRR) = pumped volume / recharge volume
- The balance between recharge and pumping into and from aquifer assessed
- Aquifer stable when PRR<1 and non-resilient when PRR>1



Resiliency indicator: Method-3 cont.,

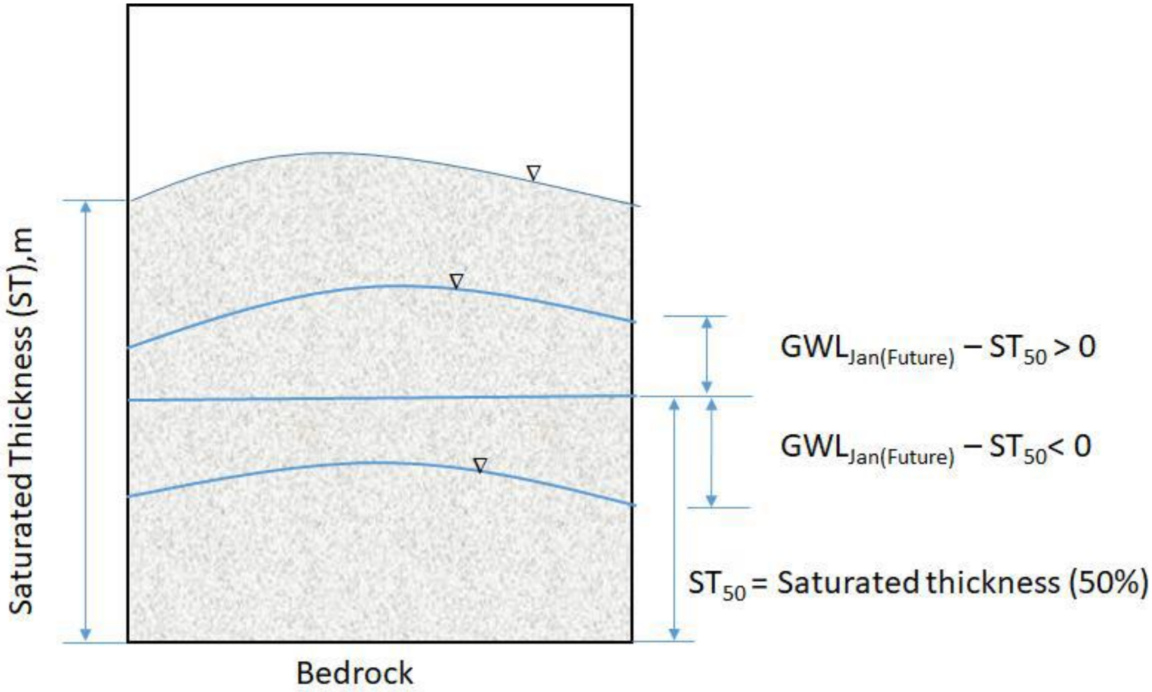
- Recharge estimation: SWAT model simulates the recharge from soil, slope and land use and climatic parameters
- Future climate data obtained from RCM's
- Change in land use modelled using Dyna-CLUE model
- Future recharge volume simulated using SWAT model with the projected climatic and land use parameters
- The volume of recharge compared with volume of draft from aquifer

Resiliency indicator: Method-3 cont.,

- Pumped volume: groundwater pumping for different sectors such as municipal, industrial and agriculture to be estimated
- Municipal demand: population projection and corresponding per capita water consumption as a percentage of groundwater supply
- Agricultural demand: crop water demands based on projected land use changes practices to be calculated as a percentage of groundwater supply
- Industrial growth water demand to be calculated based on projected data

Resiliency indicator: Method-4

- Saturated thickness : Fluctuation of water level about with respect to 50% of the saturated thickness
- Aquifer assumed to be resilient when water level stays above ST_{50} and non-resilient it falls below ST_{50}



Resiliency indicator: Method-4 cont.,

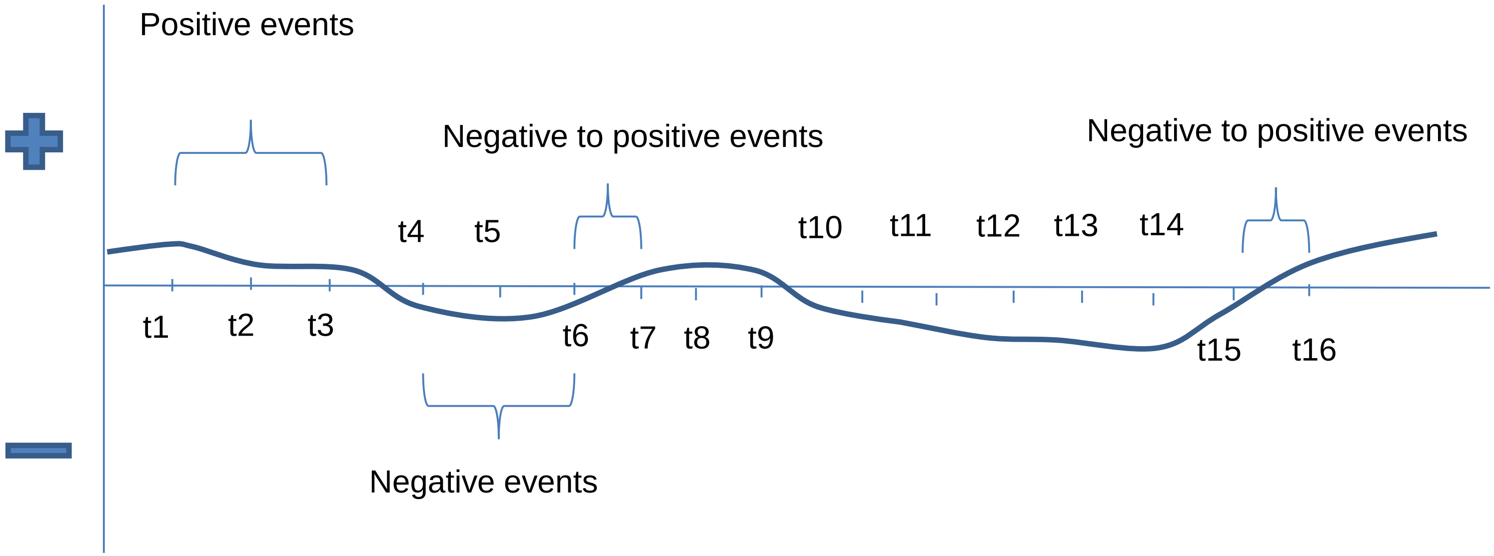
- Baseline saturated thickness: historical period groundwater levels to be analyzed for calculating the saturated thickness
- Mean monthly ST_{50} values derived from the historical data analysis
- Mean monthly ST_{50} values act as the base line standards for comparison
- Future water levels from the bedrock compared with the Mean monthly ST_{50} values
- Non – resilient aquifers show negative values consistently

Resiliency indicator: Method-4 cont.,

- Saturated thickness data: based on geological settings of the study area
- Groundwater level data: modelled from MODFLOW
  - Groundwater recharge
  - Initial condition
  - Boundary conditions
  - Hydrogeological properties
  - Groundwater abstraction
  - River stage and conductance
- The base line ST_{50} values compared with the projected water levels for calculating resilience

Resilient index

- Resilient index (RI): it is an ability of the system to recover from the negative events



$$RI = \frac{Negative\,to\,Positive\,events}{Negative\,events} = \frac{2}{9} = 0.22 = 22\%$$

Resiliency classification

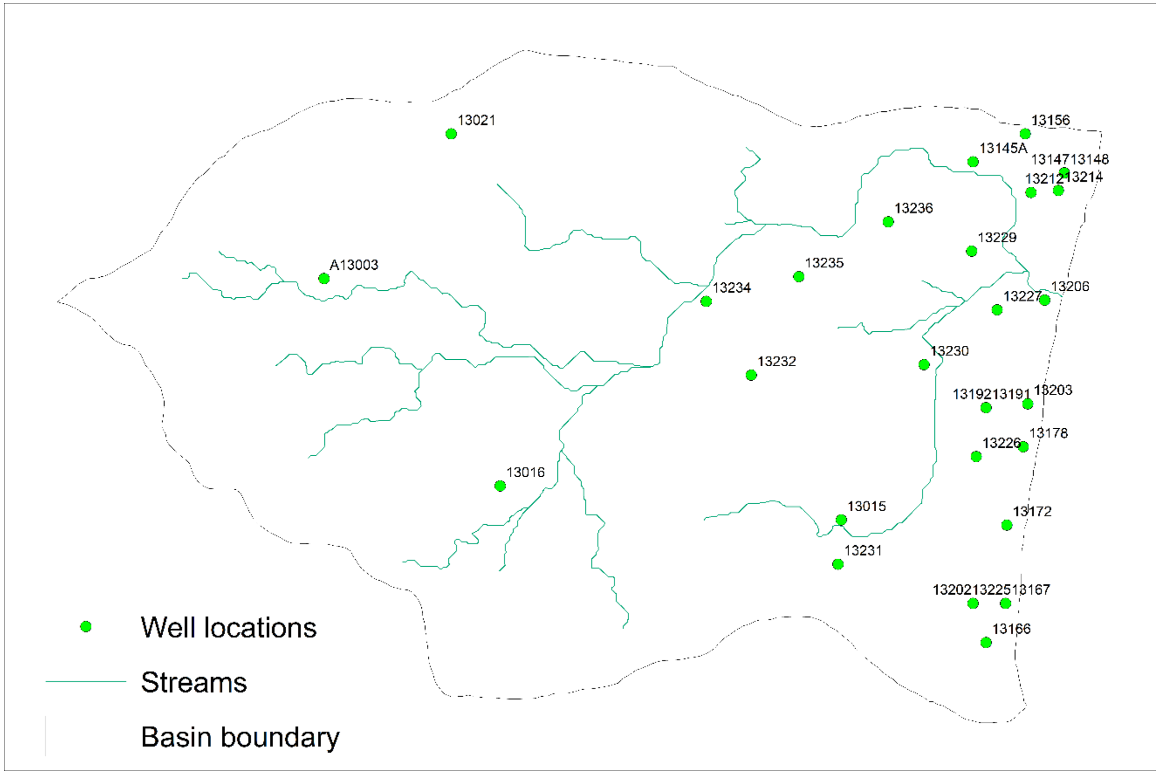
- Resiliency classification: Equally dividing the resiliency index range

Resiliency classes		
RI(%)	75-100	Highly resilient
	50-75	Moderately resilient
	25-50	Less resilient
	0-25	Very less resilient

Example study: Adyar basin, India

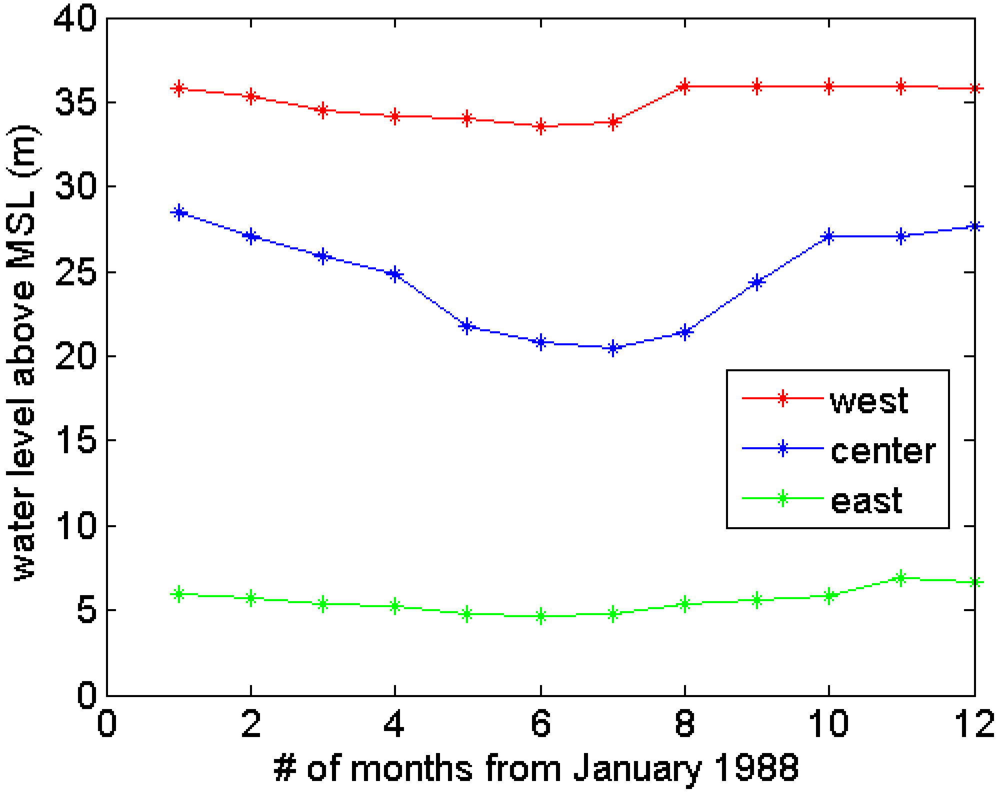
- Groundwater level data from Chennai basin (Adyar sub basin)
- 29 observation wells

- Elevation increases from 0 m in the east to 150 m in west
- Monthly groundwater levels
- 1988 January to 2007 January
- Base line period: January 1988 - December 1988



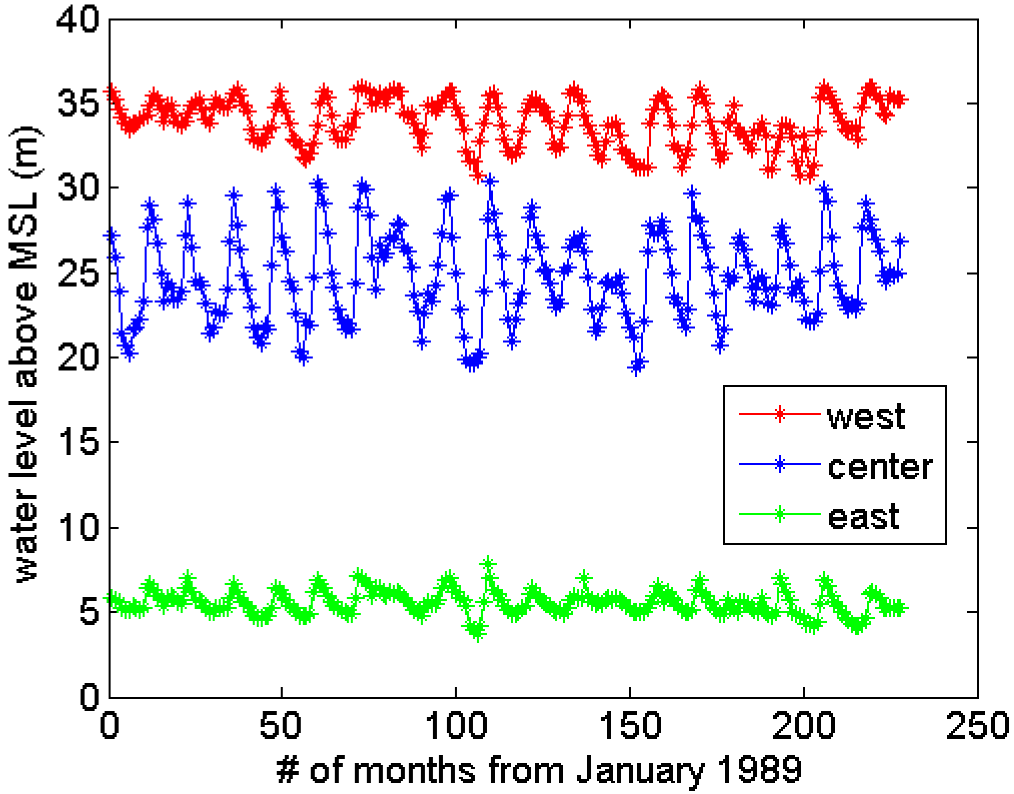
Baseline water levels

- Base line water levels at western, central and eastern wells in Adyar basin
- Western side at higher elevation then eastern side



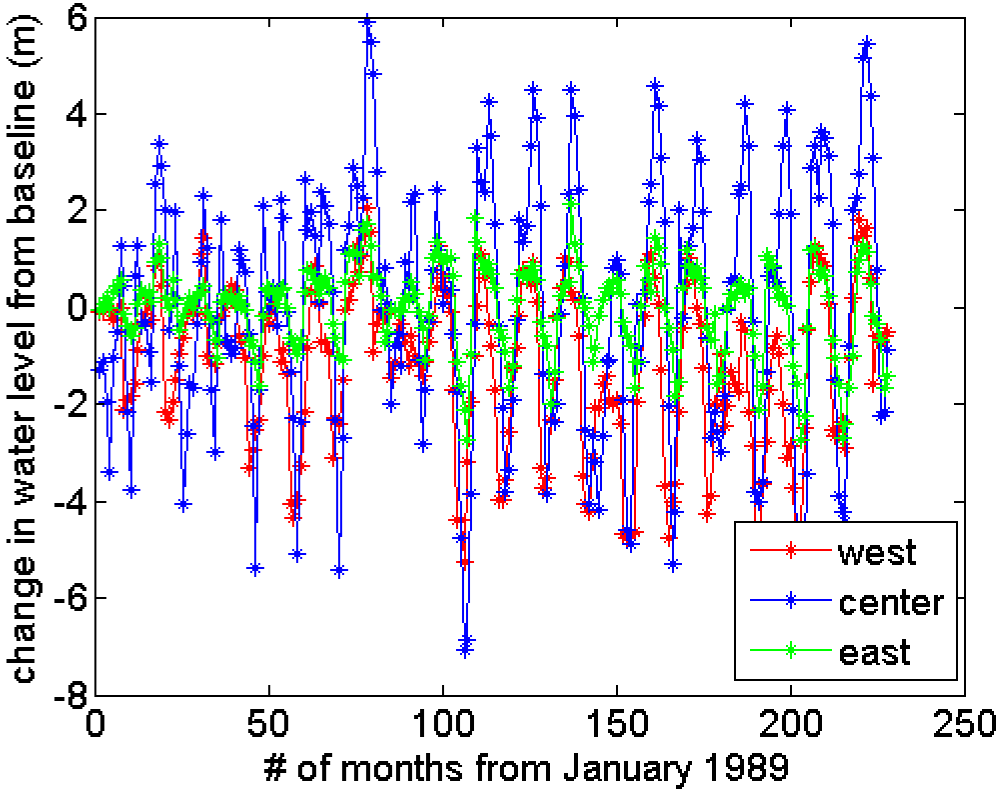
Time series water levels

- Water level from 1989 January to 2007 December plotted
- Huge variability in the central part of the well as the geological formation consists of fractured formations



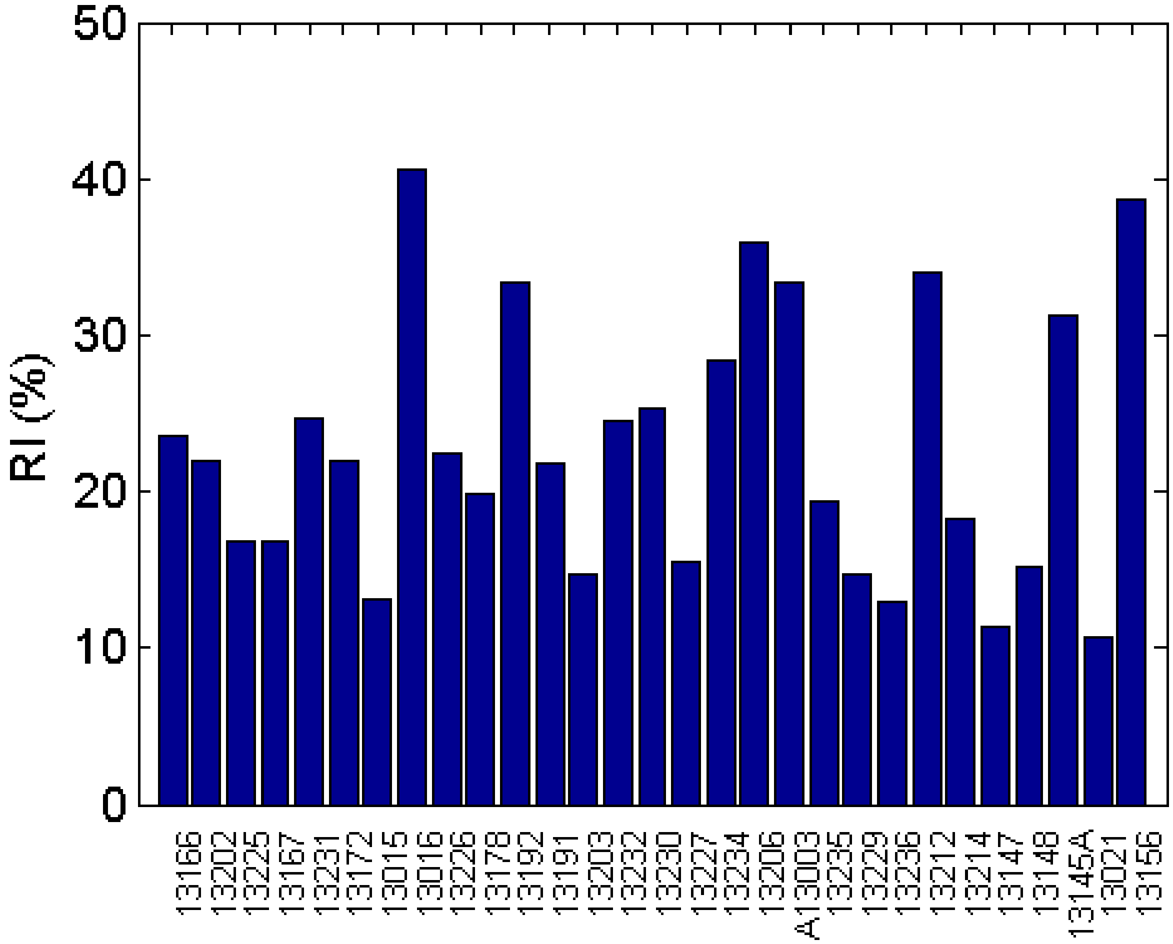
Resilience of the aquifer

- Response of aquifer signal with respect to baseline signals in Adyar basin



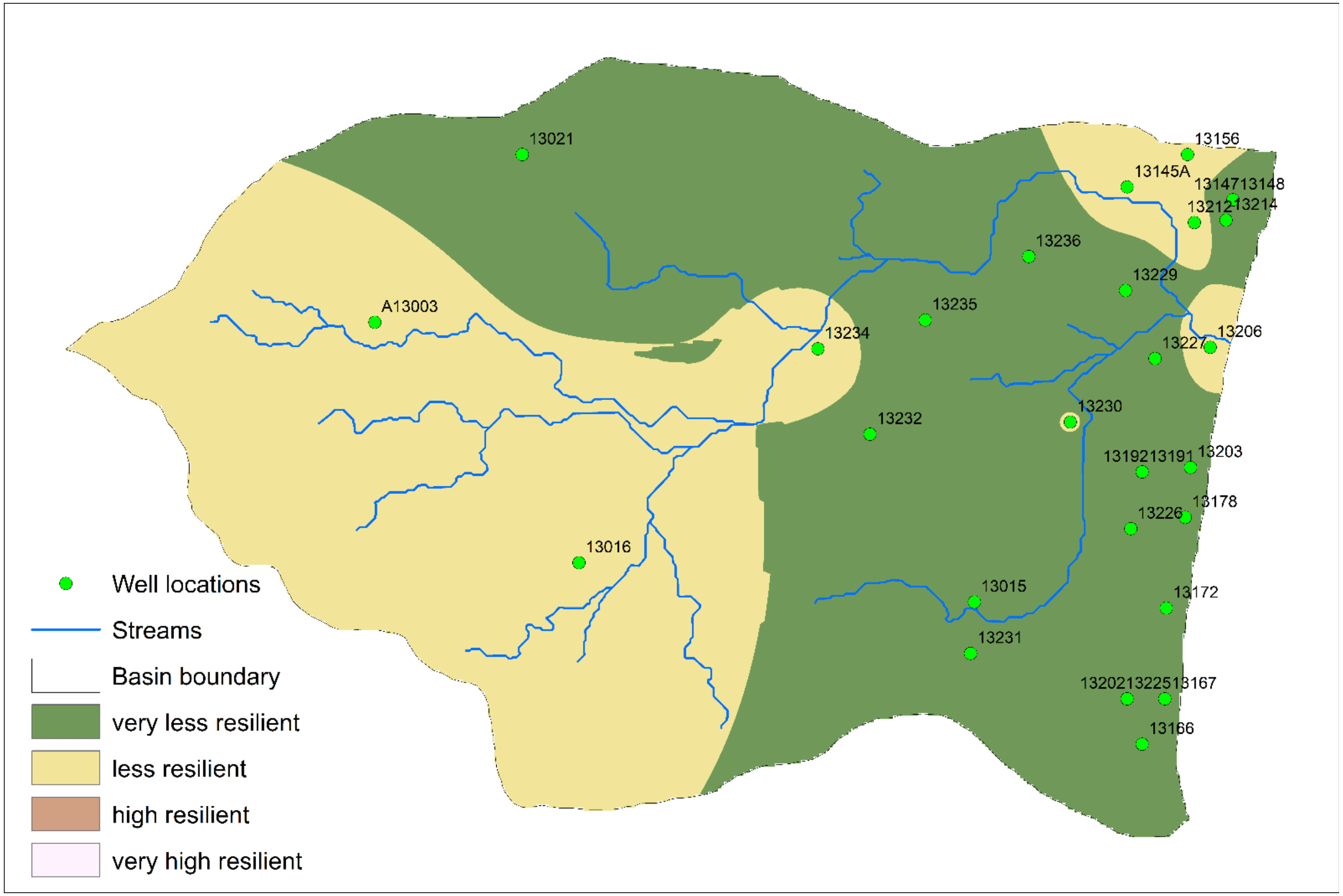
Resiliency index

- Calculated resiliency index values at the observation wells



Resiliency Mapping

- Interpolated resiliency index values over the study location in Adyar basin



Thank you