Spatial and Temporal Analysis of Water Quality in the Greater Houston Area

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Introduction and Objectives

- The city of Houston is one of the largest cities in the United States, with its rapid growth throughout the decades.
- Regions with significant economic growth, population expansion, and urbanization development are expected to prioritize water quality preservation to sustain local communities.
- Greater Houston Area(GHA) worked to meet federal and state water quality standards, such as obtaining NPDES(National Pollutant Discharge Elimination System permits for stormwater discharge, upgrading its wastewater treatment plants to reduce nutrient pollution.
- This study's main purpose is to examine how rapid population growth and land use has influenced water quality in the Greater Houston Area (GHA).
- This study analyzed spatial and temporal patterns of surface water quality, specifically focusing on nutrient-related parameters in the Greater Houston Area (GHA), Texas.
- **It addressed two key questions:**

(1) How have population growth and changes in land use over the past four decades influenced water quality over time and across space?

(2) Have ongoing pollution control efforts effectively maintained water quality over the past 40 years?

Study Area

- The greater Houston area (GHA) includes nine counties: Austin, Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller. Land cover throughout this area varies from developed high, medium, and low intensity, developed open space, barren land, forest/shrubs, pasture/grasslands, cultivated crops, and wetlands.
- Urban land cover mostly of Harris County, the most populated county of the GHA. It was reported to have a population of approximately 4.73 million in 2020.
- 19 sites were selected for water quality analysis. These sites are widely distributed and cover most of the counties.

County	Area (mi²)	County Population Estimate (2020)	Population Density (people/ mi²)
Austin	656	30,032	45.78
Chambers	871	43,837	50.33
Fort Bend	885	811,688	917.16
Galveston	874	342,139	391.46
Harris	1,777	4,713,325	2652.41
Liberty	1,176	88,219	75.02
Montgomery	1,077	607,391	563.97
Waller	518	55,246	106.65

- Nutrient-related parameters show different long-term patterns
- NIT remains stable or increasing trend
- PO4 remains stable at most of the stations.
- There is a strong correlation between population density between NIT and PO4.

Materials and Methods

- The data used in this study was obtained from TCEQ(From a total of 19 monitoring stations across 9 counties of the Greater Houston Area that were selected for 40 years of records.
- Parameters include: Nitrates, phosphorus, dissolved oxygen, total solids, fecal coliform, and pH levels.
- Mann-kendall (MK) and Sen's slope estimator were used to detect long-term trend of water quality parameters.
- The Sen's Slope method proposed by Sen (1968) is a nonparametric method to obtain a slope estimate (Equation 7).

$$Q_i = (x_j - x_k)/(j - k) \quad (i=1, \ldots\ldots\ldots\ldots N).$$

- x_j and x_k are data values at time j and k ($j > k$); Q_i is the Sen's slope; and N is the number of the data points. A positive Q_{median} values means an increasing trend, whereas a decreasing trend is shown with a negative Q_{median} value.
- The Mann-Kendall Test determines the direction of a trend for a time series.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign}(x_j - x_i)$$

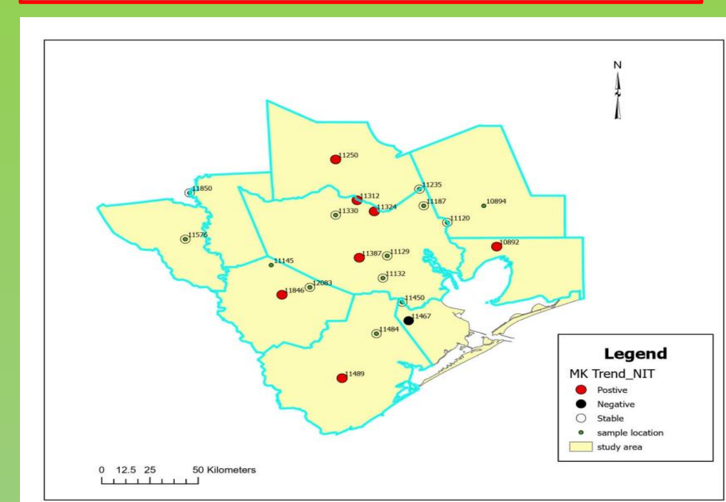
- Where the sign (x_j - x_i) is +1 if (x_j - x_i)>0; 0 if (x_j - x_i) =0, -1 if (x_j - x_i) <0; S represents the number of positive differences minus the number of negative differences.
- $Var(S)$ is the variance of S. The Z value is used to represent the trend. If the Z value is positive, it indicates a positive trend, while a negative Z value means a decreasing trend.

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i (t_i - 1)(2t_i + 5)\right]$$

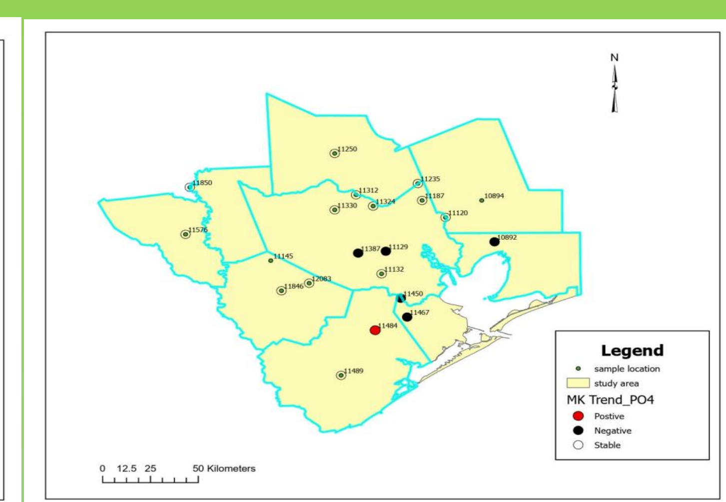
$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0, \\ 0 & \text{if } S = 0, \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0. \end{cases}$$

Results and Discussion

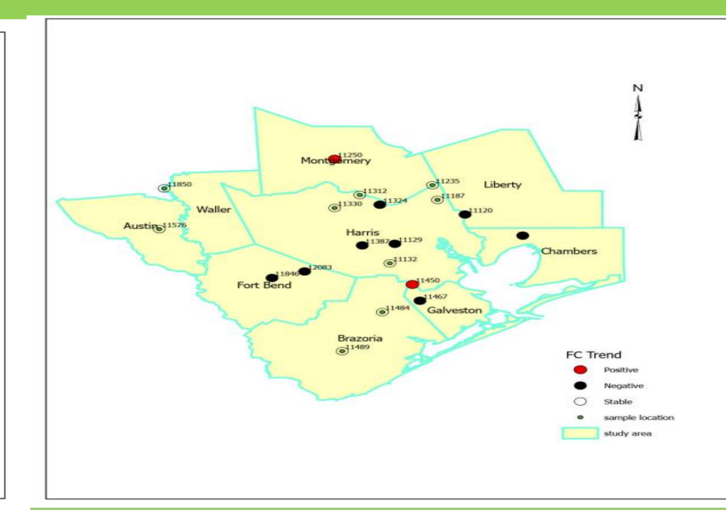
Long-term trend analysis



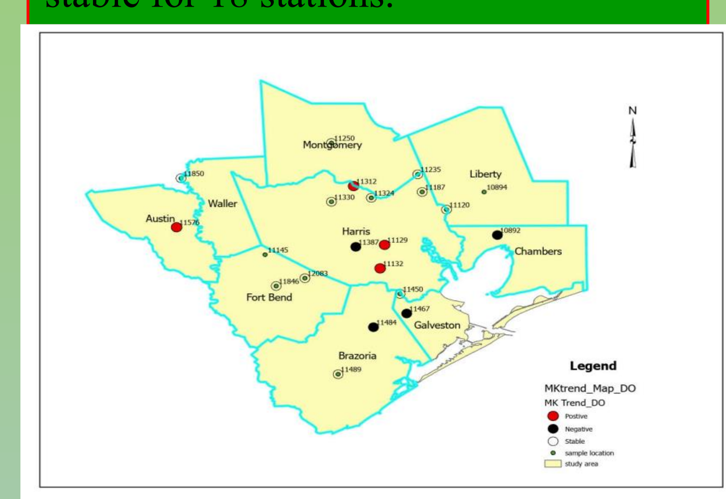
NIT concentration increases or remains stable for 18 stations.



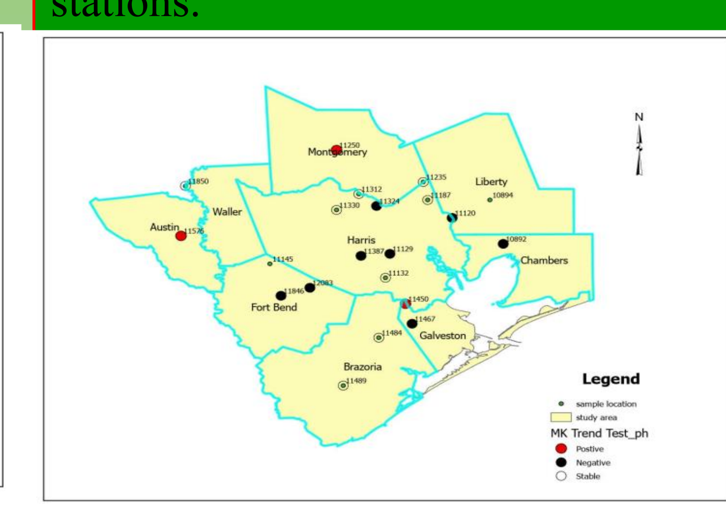
PO4 remains stable for most of the stations.



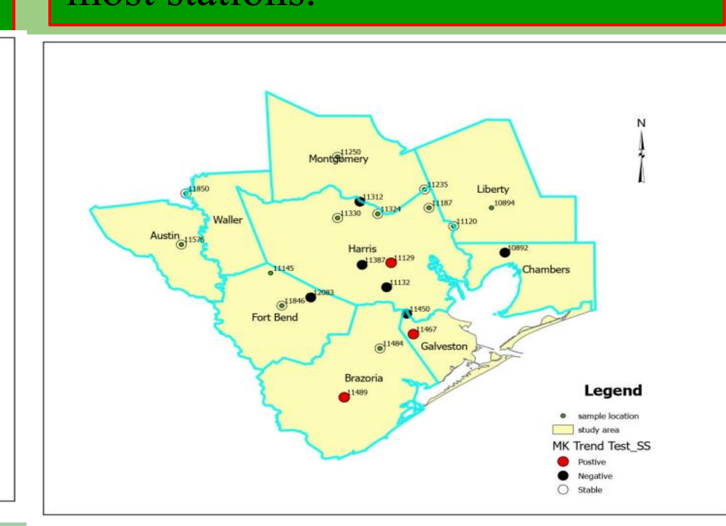
FC decreases or remains stable for most stations.



DO shows different trends. Half of the stations remain stable.

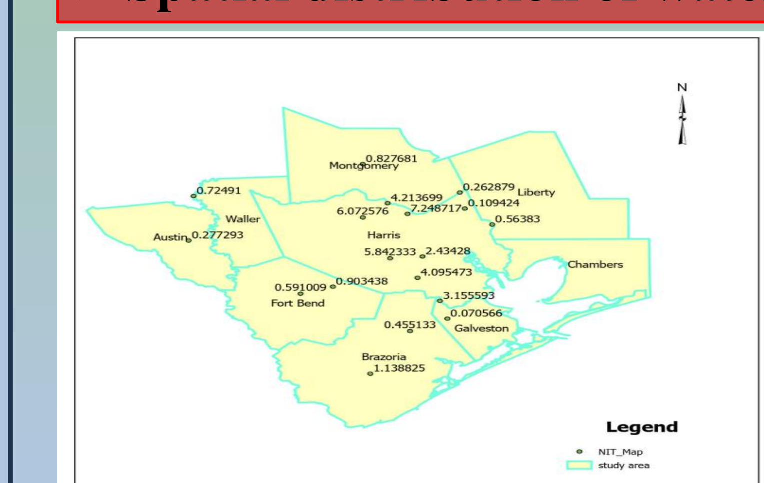


Ph shows different trends. Half of the stations remain stable.

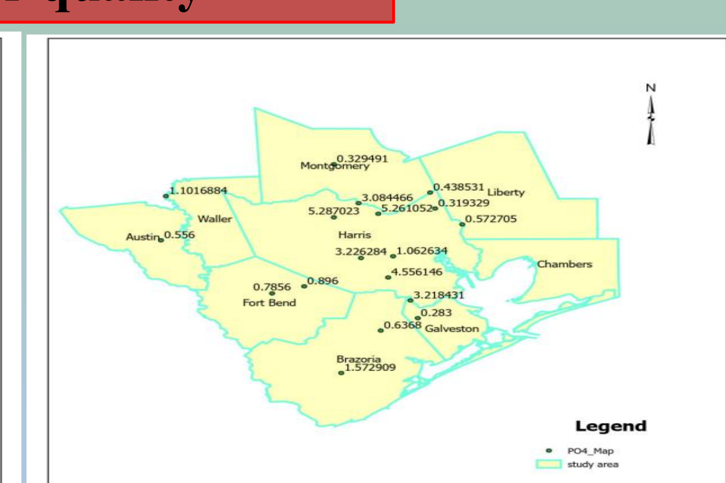


SS in half of the stations remains stable.

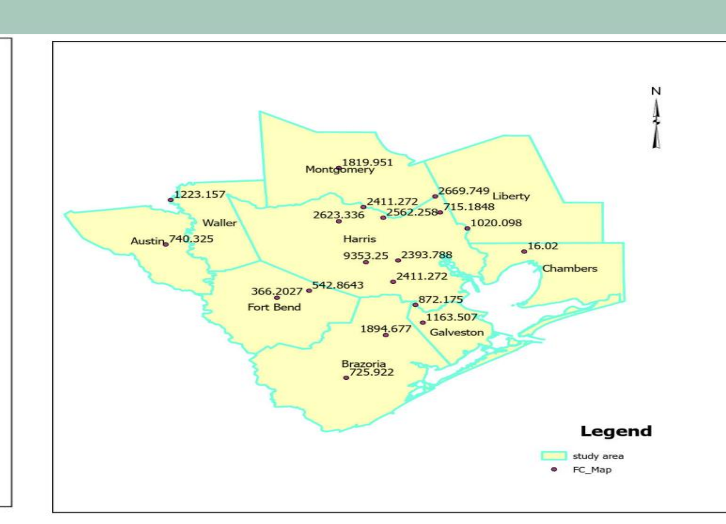
Spatial distribution of water quality



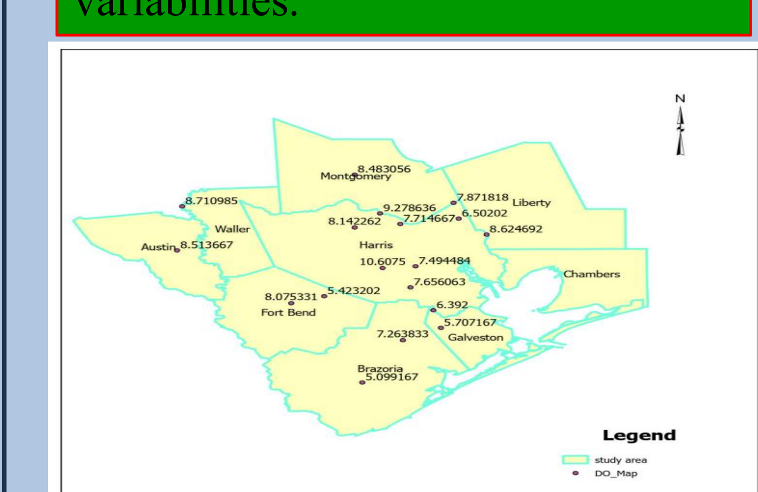
NIT exhibits great spatial variabilities.



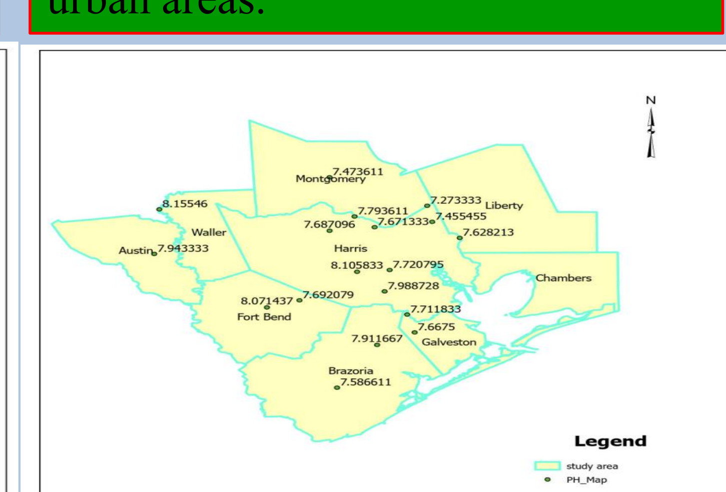
PO4 is strongly correlated with urban areas.



Higher concentration in densely populated areas.



DO ranges from 5-9.



Ph value is typically 7-8.

SS shows great variability.

Population density and water quality