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Impact Assessment of Monsoon Precipitation on Groundwater Level in Lahore District GEE Script

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Introduction/Importance of Study: Precipitation is a crucial component of the global water cycle and a primary source of freshwater, with groundwater being vital for drinking water worldwide, especially in regions like Lahore, Pakistan, where it supports 60-70% of the population.
Novelty Statement: This study uniquely addresses the impact of monsoon precipitation on groundwater levels in Lahore, providing a comprehensive analysis that has not been previously undertaken.
Material and Method: Data from the Pakistan Meteorological Department and WASA's hydrology branch (2018-2022) were analyzed using GIS-based Inverse Distance Weighted Interpolation and statistical methods to assess precipitation patterns and groundwater levels.
Result and Discussion: The findings indicate that monsoon rainfall significantly raises groundwater levels by 2-3 meters due to seepage and infiltration. Spatial and temporal analyses revealed that the monsoon period, especially July and August, contributes the most to groundwater recharge. Despite this, the overuse of groundwater during non-monsoon months and extensive urban infrastructure limit overall groundwater recharge. The study found a positive correlation between monsoon precipitation and groundwater levels, emphasizing the critical role of sustainable aquifer management in maintaining groundwater resources.
Concluding Remarks: Sustainable management of aquifer recharge is essential to ensure the long-term availability of groundwater resources in Lahore.

Keywords: Assessment; Ground Water Level; Lahore, Monsoon; Hydrology; Spatiotemporal.

Introduction:

Precipitation is a key element of the global water and energy cycle and is only the principal source of freshwater [1]. Groundwater is the most important natural resource for drinking water provision worldwide, contributing approximately 34% of the total annual water supply consumed for commercial, domestic, or industrial purposes [2] [3]. Groundwater's importance is more than surface water in almost every region of the world. It is estimated that about 60-70% inhabitants of Pakistan are directly or indirectly dependent on groundwater for their livelihood [4] [5]. Precipitation is a significant feature in studying the climate of an area and plays a key part as a water source impacting any regional freshwater availability [6] [7]. In Lahore, the precipitation pattern varies annually and monthly. Rainfall is typically low during December, January, and October and fluctuates from month to month [8] [9]. During the period of monsoon, Lahore experiences heavy downpours. February, March, April, and November fall in the category of light to moderate rainfall, [10]. Groundwater recharge is vital for the sustainable withdrawal of water. Aquifer recharge is a process by which groundwater is restored and is significantly influenced by rainfall and agricultural land use, which facilitate water absorption [11] [5]. The recharge rate from rainfall ranges from 10-25%, depending on factors such as location, intensity, and rainfall amount [12]. In Lahore city, the recharge rate due to rainfall is less than 10 % due to extensive urbanization, with much of the land covered by buildings and roads [13] [14]. Lahore lies in a sub-tropical, semi-arid region. The average monthly precipitation is low and varies throughout the year [15]. The Monsoon period in July and August months comes with the highest rainfall which makes about 40% contribution to annual groundwater recharge [16]. The average annual rainfall is approximately 575 mm, varying from 300-1200 mm [10]. The selected study area managed by the Lahore Water and Sanitation Agency (WASA) was established by the Lahore Development Authority in 1976 for the planning, designing, development, and maintenance of water supply sewerage and draining system in Lahore [17] [18]. An essential component of this mandate is the delivery of a safe, reliable, and efficient water supply to satisfy the demand of all sectors, [19]. The areas under WASA's jurisdiction are densely populated, making the daily extraction of groundwater crucial for identifying changes in groundwater levels.

Objectives:

- Analyze Monsoon rainfall patterns and their temporal changes using data from the Pakistan Meteorological Department.
- Assess spatial and temporal changes in groundwater levels using data from the Department of Hydrology, WASA, Lahore.
- Determine the impact of precipitation on groundwater levels through descriptive statistics, specifically using the Scatter Plot Correlation Technique.
- Utilize GIS-based Spatial Interpolation (IDW) technique to figure out spatial and temporal precipitation intensity across the study area.

Study Area:

Lahore is the capital of the province of Punjab and the second largest city with 13 million populations situated in the northeastern part of Pakistan. A major portion of the city lies towards the east and south of River Ravi, a tributary of the mighty River Indus. The district lies between 31º-15' and 31º-43' north latitude and 74º-10' and 74º -39' east longitudes (GOP, 2017) [19].

The Lahore Water and Sanitation Agency (WASA) is responsible for delivering water to approximately 7 million residents through a comprehensive network of pipelines and tube wells, with a water extraction capacity of 2-4 cusecs. WASA manages an area of approximately 245 km², divided into 33 sub-divisions [20]. The included map (Figure. 1) displays the study area within Lahore District. WASA domestic water supply area (Jurisdiction), subdivisions, location of boreholes (tube wells), and installed precipitation gauges at various places from precipitation especially Monsoon precipitation data collected are shown in Figure 2. Jurisdictional areas are the areas of the public water supply system under the control of WASA, Lahore. Jurisdictional areas further divided into 33 different sub-service areas as a subdivision named as per locality as Samanabad, Gulshan Ravi, Allama Iqbal Town, Mustafa Town, Sabzazar, Shahdara, Farrukhabad, Ravi Road, City, Anarkali, Shalimar, Shadbagh, Baghbanpura, Garden Town, Mughalpura, Taj Pura, Mustafabad, Gulberg, Mozzang, Ichra, Town Ship, Green Town, Industrial Area, Johar town, Jublee town, Misri shah, etc. for provision of better and efficient public water supply system. Locations of boreholes (tube wells) and rain gauge stations installed by WASA for monitoring of precipitation pattern mentioned which utilized to collect the groundwater level data during pre and post-monsoon and total monsoon precipitation for the period last five years, 2018-2022. The pertaining data is utilized to monitor and maintain the records relating to ground water level rest of the year [20].

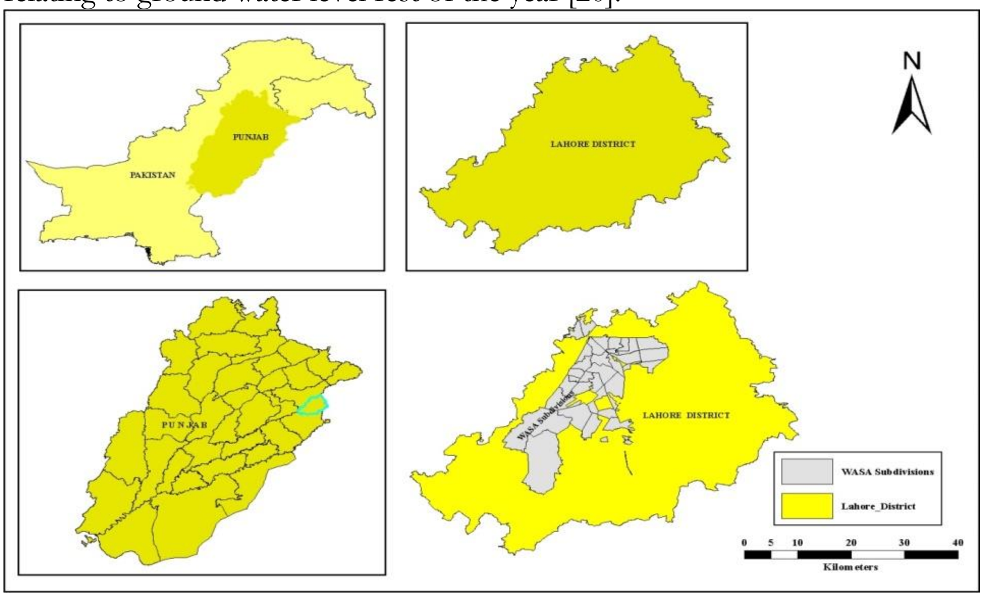

Figure 1: Study Area, **Source:** Author, 2023

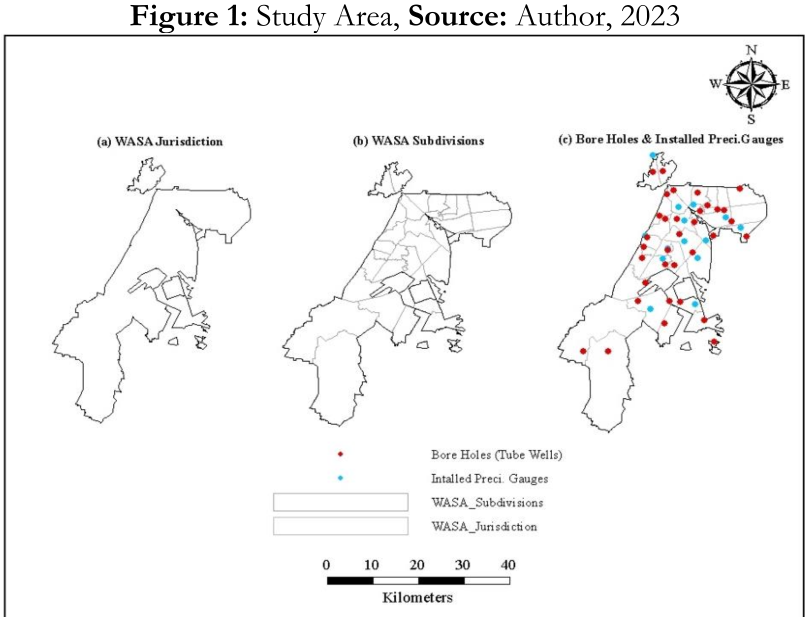

Figure 2: WASA Jurisdiction, Subdivisions and Location of Bore Holes and Installed Precipitation Gauges**, Source:** Author, 2023

Materials and Methods: Google earth engine was used for data collection, processing, analysis and mapping of results by feeding a script described below and the flow of methodology used to conduct this research is as under:

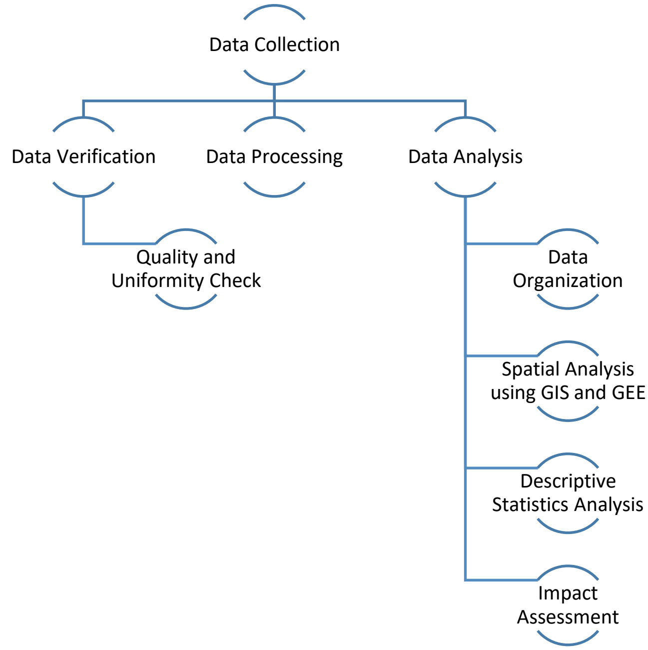

Figure 3: Flow of methodology

Data Collection and Preparation:

- Time series data on precipitation and groundwater monitoring were collected from reliable sources: monthly average precipitation over the last three decades from the Pakistan Meteorological Office and monsoon total precipitation data (2018-2022) from WASA Lahore's rain gauge stations.
- Groundwater level data from borehole locations (tube wells) and piezometers, specifically pre- and post-monsoon periods, were obtained from the Hydrology branch of WASA Lahore.

Data Quality Assurance and Processing:

- Collected data underwent rigorous verification for quality and uniformity to ensure reliability.
- Data were formatted and organized into Excel and SPSS formats for systematic analysis.

Spatial Analysis Using GIS and Google Earth Engine (GEE):

- Graphical data representations were prepared and integrated into ArcGIS for spatial analysis.
- The Inverse Distance Weighted (IDW) Interpolation technique was employed using both ArcGIS and GEE to analyze precipitation intensity and its spatial distribution across the study area.
- In GEE, CHIRPS precipitation data and groundwater level data were imported, and IDW interpolation was applied to estimate groundwater levels.
- Monthly precipitation sums for monsoon periods (July and August) over the given period (2018-2022) were calculated using GEE.

GEE Script Integration:

Javascript code

```
// Define the study area (Lahore, Pakistan)
var lahore = ee.Geometry.Rectangle([74.0, 31.2, 74.6, 31.7]);
```

```
// Define the time range
var startDate = '2018-01-01';
var endDate = '2022-12-31';
var monsoonStartDate = '2018-07-01';
var monsoonEndDate = '2022-08-31';

// Import CHIRPS precipitation data
var precipitation = ee.ImageCollection('UCSB-CHG/CHIRPS/DAILY')
  .filterDate(startDate, endDate)
  .filterBounds(lahore)
  .select('precipitation');

// Import hypothetical groundwater level data (replace with actual data)
var groundwaterLevels = ee.ImageCollection('users/your_username/groundwater_levels')
  .filterDate(startDate, endDate)
  .filterBounds(lahore)
  .select('groundwater_level');

// Function to calculate IDW interpolation
function idwInterpolation(imageCollection, bandName) {
  var points = imageCollection.select([bandName]).reduceToVectors({
    geometryType: 'point',
    reducer: ee.Reducer.mean(),
    scale: 1000,
    geometry: lahore
  });

  var interpolated = points.inverseDistanceWeighted({
    range: 10000,
    propertyName: 'mean',
    maxDistance: 50000,
    reducer: ee.Reducer.mean()
  });

  return interpolated;
}

// Calculate IDW interpolation for groundwater levels
var interpolatedGroundwaterLevels = idwInterpolation(groundwaterLevels,
'groundwater_level');

// Calculate monthly precipitation sums
var monthlyPrecipitation = precipitation.filterDate(monsoonStartDate, monsoonEndDate)
  .map(function(image) {
    var date = ee.Date(image.get('system:time_start'));
    var year = date.get('year');
    var month = date.get('month');
    var monsoonPeriod = ee.Image.constant(1).set({'year': year, 'month': month});
    return image.multiply(monsoonPeriod).set({'year': year, 'month': month});
  })
```

```
  .sum()
  .select(['precipitation'], ['monthly_precipitation']);

// Visualize the results
Map.centerObject(lahore, 10);

Map.addLayer(monthlyPrecipitation, {min: 0, max: 500, palette: ['blue', 'green', 'yellow',
'orange', 'red']}, 'Monthly Precipitation');
Map.addLayer(interpolatedGroundwaterLevels, {min: -10, max: 10, palette: ['blue', 'green',
'yellow', 'orange', 'red']}, 'Interpolated Groundwater Levels');

// Chart for precipitation over time
var precipitationChart = ui.Chart.image.series({
  imageCollection: precipitation,
  region: lahore,
  reducer: ee.Reducer.mean(),
  scale: 5000,
  xProperty: 'system:time_start'
}).setOptions({
  title: 'Monthly Precipitation Over Time',
  vAxis: {title: 'Precipitation (mm)'},
  hAxis: {title: 'Date'}
});

print(precipitationChart);

// Chart for groundwater levels over time
var groundwaterChart = ui.Chart.image.series({
  imageCollection: interpolatedGroundwaterLevels,
  region: lahore,
  reducer: ee.Reducer.mean(),
  scale: 5000,
  xProperty: 'system:time_start'
}).setOptions({
  title: 'Groundwater Levels Over Time',
  vAxis: {title: 'Groundwater Level (meters)'},
  hAxis: {title: 'Date'}
});

print(groundwaterChart);

// Calculate the correlation between precipitation and groundwater levels
var correlation = precipitation.select('precipitation')
  .reduceRegion({
    reducer: ee.Reducer.pearsonsCorrelation(),
    geometry: lahore,
    scale: 5000
  });

print('Correlation between precipitation and groundwater levels:', correlation);
```

Statistical Analysis:

- Descriptive statistics, including scatter plot correlation techniques, were applied to assess changes in groundwater levels in response to monsoon precipitation.
- The correlation between precipitation and groundwater levels was calculated using GEE.

Impact Assessment:

- The study evaluated the impact of precipitation on groundwater levels within the WASA supply area.
- Insights gained also contributed to understanding climate change effects on agricultural practices in non-WASA areas of Lahore.

Results and Discussions:

Precipitation:

Mean monthly precipitations over the last three decades (1992-2022) has been presented in Figure 4. The area under study experienced the lowest precipitation (>40 mm) from October to April. During this period, precipitation is reduced due to cold weather conditions and less evapotranspiration.

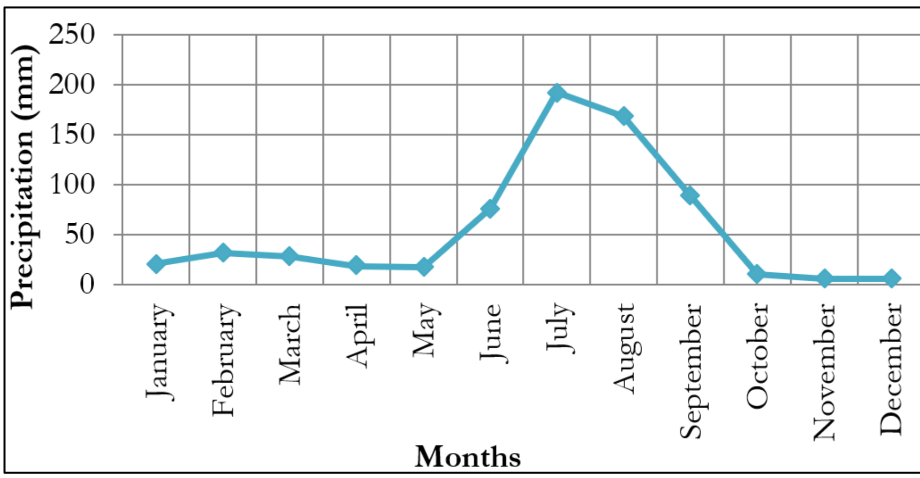

Figure 4: Mean Monthly Precipitation

Source: Pakistan Metrological Department, 2023

The mean monthly precipitation gradually increases from May to September, coinciding with the summer season. This increase in precipitation can be attributed to extreme heat and high evaporation rates, which trigger a system of intensified rainfall. The highest mean monthly rate of precipitation, less than 180 mm, occurs during July and August, also considered the monsoon period. Overall, the situational trend reflects the seasonal change in precipitation rate. The monsoon period brings more precipitation, which generates surface runoff, seepage (10% of total available rainwater), and infiltration (0.76 million cubic meters per day). The estimated rate of infiltration is calculated based on land use systems in the study area. Surface water, through the processes of seepage and infiltration, becomes part of the groundwater, resulting in a significant rise in groundwater levels (2-3 meters), as discussed later.

The temporal pattern of monsoon precipitation from 2018 to 2022 is detailed in Figure 5. The study area experiences summer monsoon precipitation from June to September, with the highest amount occurring in July, which is considered the wettest month of the year, receiving less than 250 mm of rainfall. An extreme precipitation event was recorded in July 2019, with a heavy downpour of 395.45 mm. Other months of the monsoon period, including June, July, August, and September, also experienced moderate to high precipitation rates, each receiving less than 160 mm. In 2022, August surpassed July in average precipitation, receiving less than 280 mm. The overall pattern of monsoon precipitation shows an upward trend, as illustrated in Figure 5.

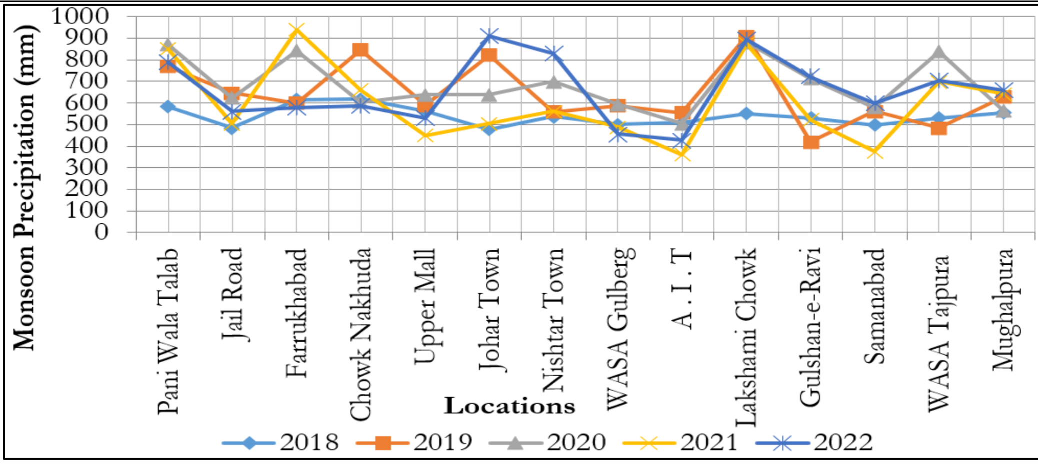

Figure 5: Total Monsoon Precipitation (2018-2022)

Source: PMD & WASA, 2023

Spatiotemporal Distribution of Monsoon Precipitation:

A comparison of the spatial distribution of monsoon precipitation is presented in Figure 6. The spatial interpolation technique, Inverse Distance Weighting (IDW), was utilized in ArcGIS to calculate the pattern of monsoon precipitation from 2018 to 2022. As depicted in Figure 6, the map of the study area shows red areas indicating high-intensity monsoon precipitation, yellow areas indicating medium-level precipitation, and blue areas indicating lower rates of precipitation. These patterns and spatial shifts can be observed in the provided maps.

Spatiotemporal Pattern and Comparison of Groundwater Levels:

Groundwater level elevation data for pre- and post-monsoon periods from 2018 to 2022 was collected from spatially distributed regions across the study area. The relevant data was tabulated and processed using Excel and SPSS, and the processed files were attached to an ArcGIS map for spatial analysis. The inverse distance weighted interpolation technique was applied to calculate the geometrical interval and reclassify both pre- and post-monsoon patterns of groundwater levels. As shown in Figure 6, the pre-monsoon period (2018-2022) exhibits red areas, indicating greater depth and a decline in groundwater levels in various parts of the study area.

The variation in groundwater levels, represented by a gradual yellow-to-green color trend, indicates medium to low depth. During the pre-monsoon period, groundwater levels continue to decline due to minimal or no precipitation, as depicted in Figure 4. Conversely, the analysis of post-monsoon groundwater levels reveals a rise of 2-3 meters, attributed to monsoon precipitation and subsequent infiltration through exposed surfaces. The decreasing concentration of red on the maps illustrates the upward trend in groundwater levels. A comparative analysis of pre- and post-monsoon periods in 2019 (Figures 7b and 7g) and 2020 (Figures 7c and 7h) clearly demonstrates the significant impact of monsoon precipitation, with a marked elevation in groundwater levels. Furthermore, the comparative analysis of pre- and post-monsoon periods from 2018 to 2022 elaborates on the substantial influence of monsoon precipitation on groundwater levels in the study area.

Impact of Precipitation on Ground Water Level Depth:

The results indicate whether there is a statistically significant change in groundwater level depth during both the pre-monsoon and post-monsoon periods from 2018 to 2022. Precipitation and the specific months of the monsoon period are represented on the horizontal axis, illustrating the trend in precipitation. Precipitation (mm) is depicted on the primary vertical y_1-axis, while groundwater level depth (m) is shown on the secondary vertical y_2-axis.

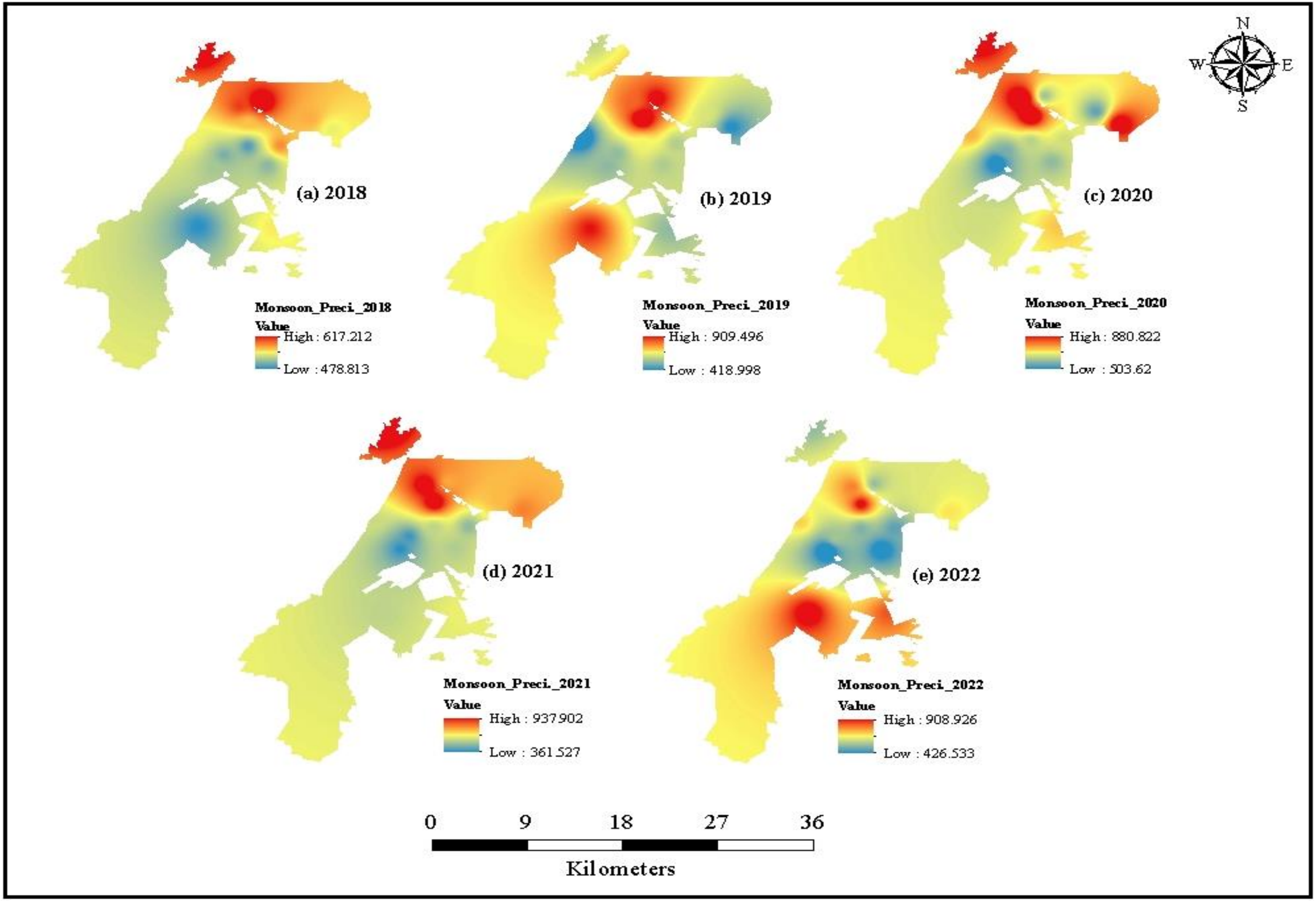

Figure 6: Spatial Distribution of Monsoon Precipitation (2018-2022) **Source:** Author, 2023

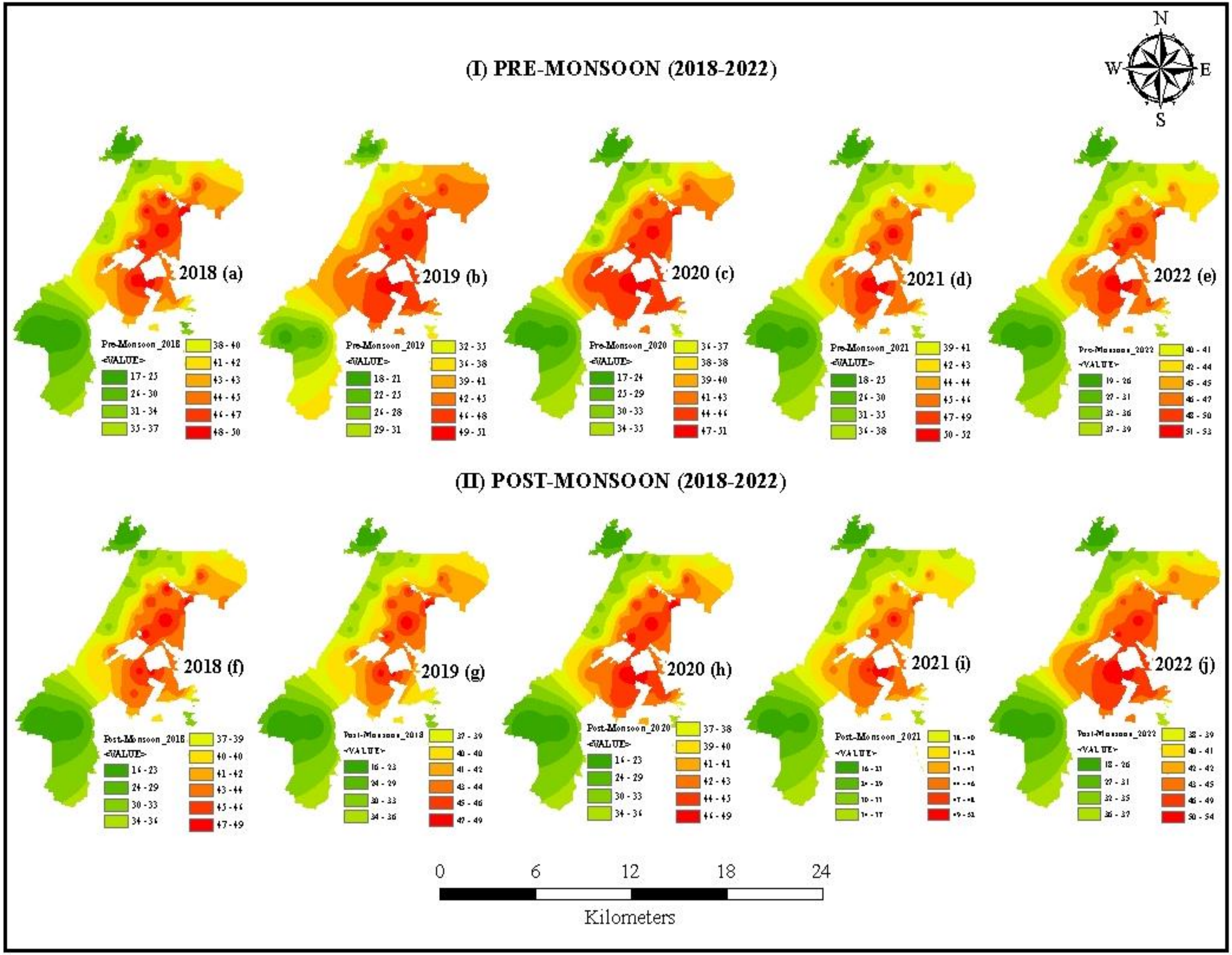

Figure 7: (I) Pre & (II) Post-Monsoon Ground Water Level (2018-22) **Source:** Author, 2023

The grey bars indicate a rising trend in precipitation during June, July, August, and September, with minimal precipitation observed in the remaining months. Statistical analysis reveals a significant impact of monsoon precipitation on groundwater level depth.

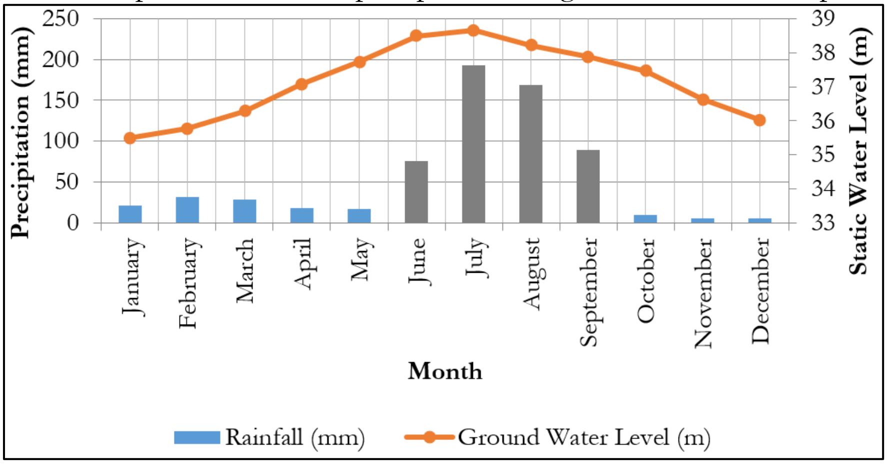

Figure 8: Impact of Monsoon Precipitation on Groundwater Level
Source: PMD & WASA, 2023

The average difference in groundwater levels between pre-monsoon and post-monsoon periods is approximately 2-3 meters. The temporal change in the hydrograph, represented in red, indicates a declining trend during the pre-monsoon period. However, during the post-monsoon period, the estimated contributions of seepage (10% of total precipitation) and infiltration (0.76 million cubic meters per day) raise groundwater levels, as illustrated in Figure 8. The analysis indicates that excessive withdrawal leads to a decline in groundwater levels. Additionally, heavy monsoon rainfall significantly impacts the groundwater levels in the WASA public water supply area.

Degree of Correlation between Precipitation and Ground Water Level:

The results reveal a statistically significant relationship between groundwater level depth and precipitation. The study areas exhibit a positive correlation between precipitation and groundwater level depth, with an R-value of 0.4929. The current trend in monsoon precipitation has contributed to an annual rise in groundwater level depth of 2-3 meters. This positive relationship between precipitation and groundwater level depth is illustrated in Figure 9.

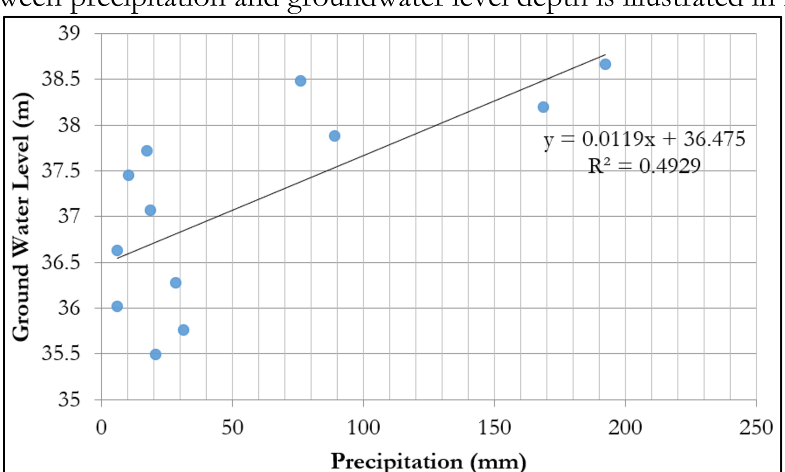

Figure 9: Correlation between Precipitation and Ground Water Level
Source: Author, 2023

Conclusion and Summary:

This study was conducted to highlight the interaction between monsoon precipitation and groundwater levels within the WASA jurisdictions of the domestic water supply system.

Spatiotemporal groundwater monitoring, mean precipitation data, monsoon precipitation data, and ArcGIS-based interpolation were utilized for the evaluation of the proposed approach. The analysis results reveal that the overuse of groundwater during other months of the year, combined with low precipitation levels, leads to a decline in groundwater levels, averaging 2-3 meters. This decline persists into the pre-monsoon period. During the monsoon period (June, July, August, and September), precipitation contributes a significant amount of water as surface runoff. Seepage and infiltration gradually recharge the groundwater levels over time, ultimately impacting the groundwater depth. Notably, there is a positive correlation between monsoon precipitation and groundwater levels. Consequently, in open spaces, monsoon precipitation has a greater impact on groundwater level rise due to increased water infiltration. The unplanned expansion of urban infrastructure threatens the sustainability of the area by adversely affecting the groundwater environment. To conserve groundwater sources, managed aquifer recharge patterns are necessary for future sustainable development.

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