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Application of GIS in Rainwater Harvesting Potential Regions – Hyderabad Case Study

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Abstract

Rapid urbanization and population growth in metropolitan regions have led to increased demand for water resources, exerting pressure on existing water supply systems. In this scenario, Rainwater Harvesting (RWH) emerges as a viable solution to alleviate water scarcity by capturing and utilizing rainwater, thereby conserving natural water bodies. In this context, understanding the spatial distribution of RWH potential becomes crucial for implementing the same. This study aims to delineate RWH potential zones within Stormwater Zone 12 of the Greater Hyderabad Municipal Corporation (GHMC) by integrating GIS and remote sensing data along with hydrogeological features. The Analytical Hierarchy Process (AHP) was employed to assign weights to the considered factors and to calculate the correlation matrix, which is followed by Weighted Overlay Analysis (WOA) to formulate the results. In addition to topographic data such as Digital Elevation Model (DEM), Land Use/Land Cover (LULC), soil data, and socio-economic datasets were also integrated into this study. The results of this study categorized the study area into five distinct classes based on RWH capacity, namely 'Very Low', 'Low', 'Moderate', 'High' and 'Very High'. This study revealed that the final outcomes were highly sensitive to changes in the parameters- LULC, DEM and rainfall patterns. The majority of the area was classified into moderate to low categories, with limited instances of very high potential. In urbanized areas, reduced natural infiltration capacity along with increased anthropogenic activities, impede the retention of incoming rainwater, contributing to the scarcity of areas with very high potential.

Keywords: Rainwater Harvesting, GIS, Remote Sensing, Urbanization, GHMC, AHP, Weighted Overlay Analysis, Socio-economic Factors.

1. INTRODUCTION

Urban floods, occurring with high frequency among all the natural disasters, have a global impact which affects a significant portion of the population (Naresh & Naik, 2023). Various methodologies have been employed over an extensive period to address the complexities of urban water management (Smith et al., 2023). Rainwater harvesting has gained significant attention as a sustainable water management practice (Day & Sharma, 2020), emphasizing the need for a comprehensive understanding of its potential in effectively managing urban water resources. Understanding the potential regions of the rainwater to be harvested is crucial for managing city water. Thus, the identification of potential zones for such rain water harvesting methods is necessary for mitigating urban flooding and enhancing water security (Patil et al., 2022). Geographic Information System (GIS) and Remote Sensing (RS) techniques have emerged as valuable tools for the evaluation and administration of surface and groundwater resources (Muneer et al., 2020). The combined use of GIS and Multi-Criteria Decision Analysis (MCDA) offers an effective approach to identify and delineate areas with high potential for surface storage (Waghaye et al., 2023). This integrated method connects spatial data and decision-making criteria to systematically evaluate and prioritize suitable zones for surface water storage, facilitating informed planning and management of water resources (Asgher et al., 2022). The Analytical Hierarchy Process (AHP) method offers adaptability in assigning weights to chosen themes, taking into account regional hydrogeological characteristics and expert input. The inclusion of consistency checks for all chosen criteria enhances the accuracy of criteria selection and improves the precision of delineating appropriate zones for RWH (Waghaye et al., 2023). Thus, the study emphasizes on determining the RWH potential zones. In the context of Indian urban environments, particularly within densely populated cities such as Hyderabad, the inadequacies in managing urban floods exacerbate the severity of consequential socio-economic and environmental impacts. This study aimed to identify the potential zones suitable for rainwater harvesting within an urban stormwater zone, which is a sub-catchment of the Hyderabad Urban Watershed. This zone is one among the sixteen hydraulic zones managed by the Greater Hyderabad Municipal Corporation (GHMC) in the state of Telangana.

2. STUDY AREA & DATASETS USED

Hyderabad, established along the southern bank of the Musi River in 1591, has evolved into India's fourth-largest city, spanning 650 km² on the Deccan plateau at an elevation of 542 meters above sea level. The Indian Meteorological Department (IMD) records indicate that heavy rainfall, primarily during July, August, and September, contributes significantly to Hyderabad's average annual precipitation, which averages around 810 mm (https://hydro.imd.gov.in/). The unique terrain of Hyderabad, marked by its undulating landscapes, often channels rainwater into low-lying regions. With a population of approximately 3.82 million as of the 2001 Census, Hyderabad experiences localized flooding, particularly in densely built-up and low-lying areas (Singh et al., 2024). Urbanization trends have resulted in the increase of impermeable surfaces, heightening runoff rates and overwhelming the stormwater drainage infrastructure's capacity. Consequently, the city's recurrent flooding is primarily attributed to human activities rather than natural meteorological or hydrological phenomena. The area under consideration for this study is one of the urban stormwater zone, situated between 17° 34' 35.44" N and 17° 24' 34.03" N latitude and 78° 22' 51.34" E and 78° 28' 40.39" E longitude, covering approximately 173.68 km². This zone is comprised of 15 delineated sub-catchments, as illustrated in Figure 1(a). Hussain Sagar Lake serves as the outlet point for the selected urban zone, which is mainly included in Kukatpally area of the city.

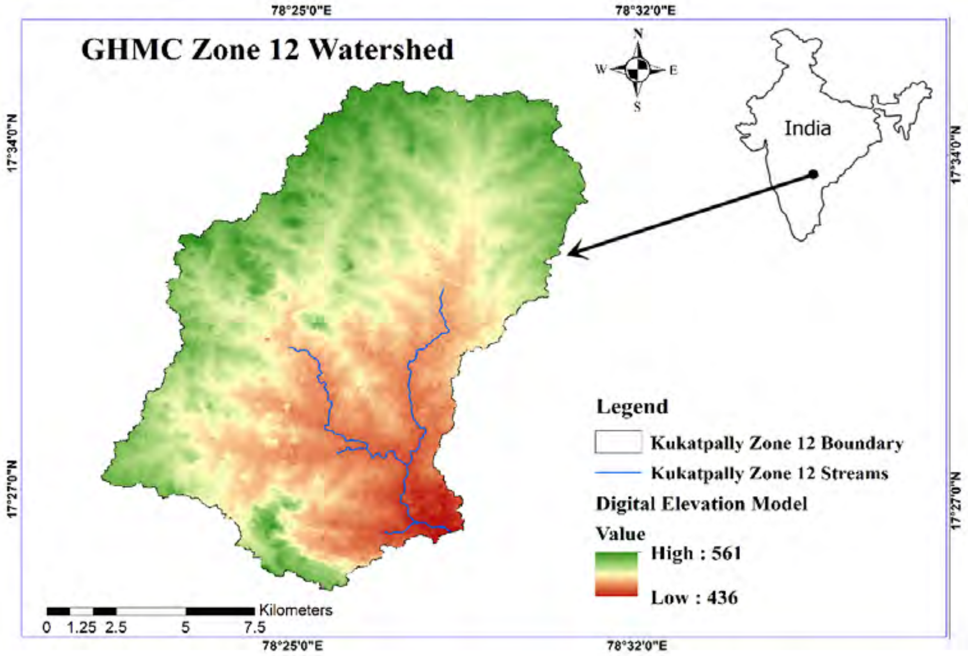

Figure 1. Delineated Map of GHMC Zone 12

2.2 Datasets Used

Table 1 summarizes the data sources and resolutions used for the various topographic factors included in this study. The Digital Elevation Model (DEM) was acquired from ALOS PALSAR data archive with a resolution of 30 meters. Land use and land cover data were obtained from ESRI Sentinel-2 with a resolution of 10 meters and was acquired for 2022 (Figure 2-a). Geomorphological data was sourced from the Geological Survey of India (GSI) with a resolution of 30 meters (Figure 2-b). Soil texture data was obtained from the National Bureau of Soil Survey & Land Use Planning (NBSS&LUP) at the highest available resolution and the latest time period. Finally, road and settlement data were gathered from Open Street Map (OSM) at the highest available resolution and the latest time period. Rainfall data for the period 2004-2023 was obtained from the Telangana State Development Planning Society for seven different stations inside the Kukatpally region.

Table 1. Source of the data and the normalized weightages for each of the factors

Topographical factors	Source	Resolution	Time Period	Normalized weight (%)
DEM	ALOS PALSAR	30 m	2024	33
Land Use Land Cover	ESRI Land Use Time Series	10 m	2022	15
Geomorphology	Geological Survey of India (GSI)	30 m	2024	12.5
Soil	National Bureau of Soil Survey & Land Use Planning	High Resolution	Latest	11.2
Road and Settlements	Open Street Map	High Resolution	Latest	9.8
Rainfall	Telangana State Development Planning Society	High Resolution	2004-2023	18.5

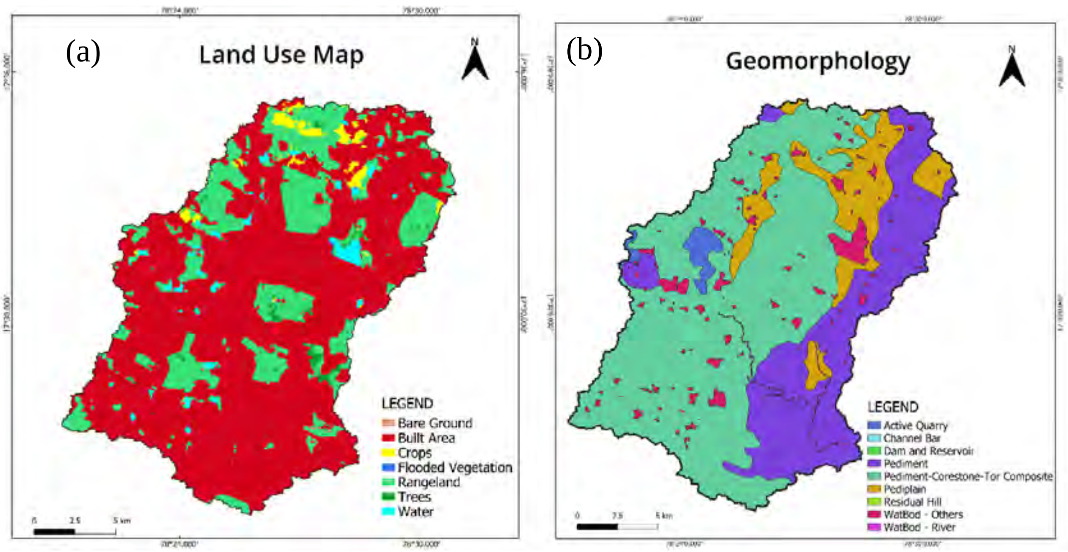

Figure 2. (a) Land Use Land Cover Map (b) Geomorphology Map of GHMC Zone 12

3. METHODOLOGY

The methodology employed in this study involves the integration of AHP with Weighted Overlay Analysis to identify suitable zones for rainwater harvesting within the considered stormwater zone. Initially, AHP is utilized to establish the relative importance of criteria such as land use, slope, soil type, and drainage density in determining the suitability of potential harvesting sites. Expert opinions and regional hydrogeological characteristics as well as previous literatures are considered in assigning weights to these criteria. The weights are in a scale of 1 to 9. To compare the chosen thematic layers, a weighted matrix was created. The consistency ratio (CR) was calculated to assess the reliability of these weights as per Equation 1 (Saaty, 1980). This ratio considers both the consistency index (CI), derived from the matrix's largest eigenvalue, and a random consistency index (RI) based on matrix size. The CI value, a function of the principal eigenvalue as given in Equation 2 (Saaty, 1980), determines the extent of consistency in the assigned weights. A CR value below 0.1 indicates acceptable consistency. If the CR exceeds this threshold, the weights need to be adjusted to achieve a more consistent weighting scheme.

$$CR = \frac{CI}{RI} \quad (1)$$

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (2)$$

where n is the number of themes considered, and λ_{max} is the principal eigenvalue. The normalized weightages given to each of the thematic layers are shown in Table 1. The thematic layers of Slope, Drainage Density, and Topographic Wetness Index (TWI) have been generated from the Digital Elevation Model (DEM), with their respective combined weights specified in Table 1. Subsequently, Weighted Overlay Analysis is performed to combine the weighted criteria layers and generate a composite suitability map, highlighting areas with the highest potential for rainwater harvesting. The flowchart showing the detailed methodology performed in this study is depicted in Figure 2.

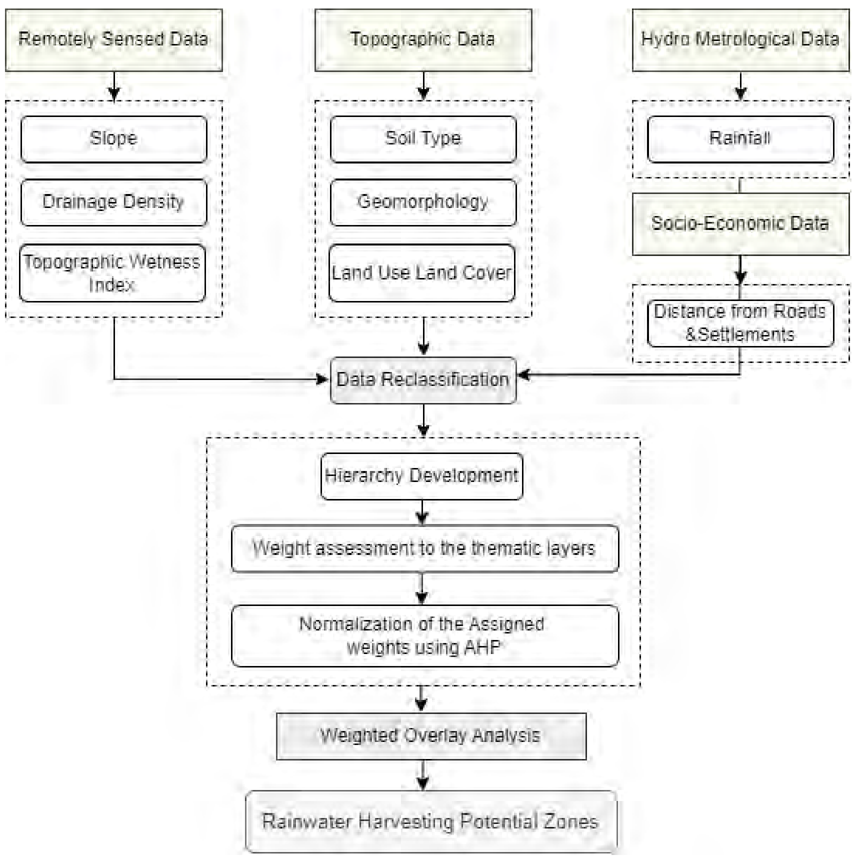

Figure 3. Methodology for Identifying Rainwater Harvesting Potential Zones using Remote Sensing, Topographic, and Hydro-Meteorological Data with AHP

4. RESULTS AND DISCUSSION

After data acquisition and digitization, the thematic raster layers underwent reclassification. All layers were converted to a raster format with values ranging from 1 (lowest potential) to 5 (highest potential). This standardization, for example, assigned a value of 5 in the DEM to areas with the lowest elevation (highest water accumulation potential) and vice versa. A weighted overlay analysis in GIS, integrating various thematic layers, identified suitable areas for rainwater harvesting. The resulting RWH potential map classified zones into five categories: 'Very Low', 'Low', 'Moderate', 'High', 'Very High' as shown in Figure 3. The statistics of the area identified for each suitability class is given in Table 2. Notably, 'Moderate' potential zones were the most extensive, covering 56.62% (98.34 km^2) of the study area. The 'High' class comprises 26.13 percent of the total area, equivalent to approximately 45.39 km^2. Subsequently, the remaining three classes follow: 'Low' class occupies 23.64 km^2, 'Very High' class covers 0.73 km^2, and 'Very Low' class occupies 0.06 km^2. The analysis reveals that the obtained results are highly sensitive to variations in the weighting assigned to the DEM, Land Use, and Rainfall parameters.

Also, the results are found in accordance with the nature of the thematic layers chosen for this study. For instance, "Very High" and "High" potential zones likely correspond to areas with steeper slopes, greater drainage density, or more permeable soils, all factors that contribute to higher rainwater harvesting potential. Conversely, "Low" and "Very Low" potential zones may represent areas with flatter topography, lower drainage density, or less permeable soils, making them less suitable for rainwater harvesting.

Table 2. Spatial Coverage of different suitability classes derived for GHMC Zone 12

Suitability Criteria	Area covered (km^2)	Percentage of total area
Very Low	0.06	0.036
Low	23.94	13.78
Moderate	98.34	56.62
High	45.39	26.13
Very High	0.73	0.418

5.CONCLUSIONS

- In conclusion, this study has provided valuable insights into the dynamics of urban flooding within the highly urbanized stormwater zone.
- The weighted overlay analysis conducted in GIS provided a comprehensive understanding of the RWH potential across the landscape, resulting in the delineation of zones into five distinct categories based on suitability: from 'Very Low' to 'Very High'.
- The statistical analysis revealed that 'Moderate' potential zones, constituting 56.62% of the total area, and 'High' potential zones, comprising 26.13% of the total area, formed the largest portions of the study area. This underscores their paramount importance in rainwater harvesting initiatives.
- The alignment of the results with the inherent characteristics of the thematic layers chosen for this study further validates the accuracy and reliability of the findings, offering valuable insights for urban water management and sustainable development initiatives.
- Additional research is warranted to delve into the potential of integrating socio-economic factors and community resilience measures into urban flood modeling frameworks. This avenue of

exploration is crucial given the absence of proper validation for the results obtained from this study, which serves as a notable limitation warranting further investigations.

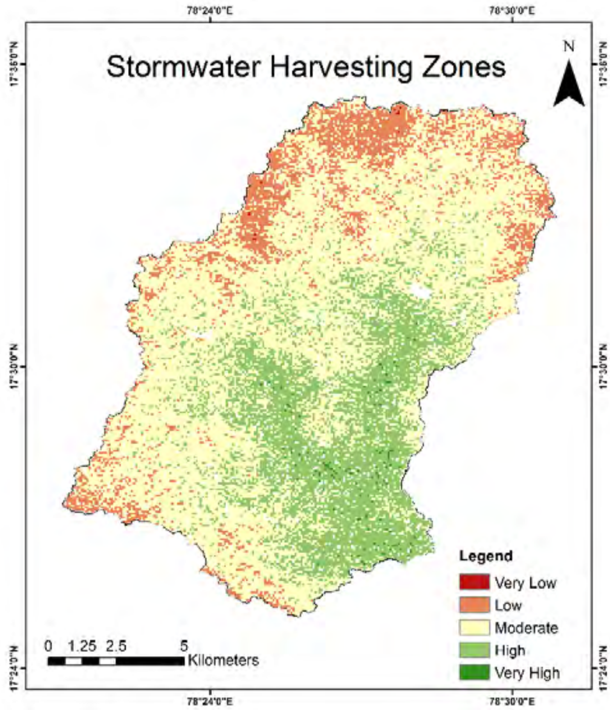

Figure 3. Rainwater Harvesting Potential Zones Identified for GHMC Zone 12

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