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CHANGING POPULATION PATTERNS AND THEIR INFLUENCE ON GROUNDWATER DEMAND IN NANDURBAR DISTRICT

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ABSTRACT:

Water source management deals with the essential link between population changes and groundwater needs most notably in dry arid Nandurbar District. Scientists have studied how population shifts which include urban growth together with agricultural development impact groundwater usage rates. The research draws its methodology from a combination of approaches to merge population statistics with groundwater measurement data through GIS mapping tools. The study analyzes population density and groundwater extraction rate relationships through statistical analysis with regression analysis combined with Mann-Kendall test methodologies. Population increase displays a robust positive association ($r = 0.78$, $p < 0.001$) to groundwater depletion since major urban regions face the most severe stress level. A yearly decrease of 1.2 meters presents itself as the main groundwater depletion pattern which affects high-density residential districts. Agricultural activities stand responsible for 73% of total groundwater consumption which contributes significantly to resources running low. The projected analysis shows that if current consumption rates continue groundwater use will increase by 45% until 2035. Climate change is causing a reduction in natural recharge rates, worsening water scarcity. Recommendations include combining micro-irrigation systems with artificial recharge projects, stronger groundwater withdrawal rules, community-based monitoring platforms, and interaction initiatives for sustainable water usage. These findings will improve groundwater management guidelines for Nandurbar District and other semi-arid districts.

Keywords: Population growth, groundwater demand, urbanization, water resource management, GIS analysis, sustainability.

INTRODUCTION:-

The complicated link between population evolution and groundwater supply requires deeper examination because Nandurbar District experiences substantial water resource management changes through population shifts (Shikhar & Sobti, 2024). The study evaluates population distribution changes and their clear effects on groundwater consumption as an essential strategy for sustainable resource planning. Nandurbar District offers an excellent context to study water resource utilization along with demographic change because its agricultural economy and geographical position suit such research (Shikhar & Sobti, 2024) (Patil

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et. al.2021). Various population trends have led to rural migration towards urban areas and agricultural land development which represents serious obstacles for effective groundwater management (Fotheringham et. al., 2025). This paper presents significant research findings because it employs an extensive population-resource analysis framework for areas that depend on groundwater access for their domestic and farming operations. The study achieves innovation through combining demographic transition research with groundwater demand assessment by using modern geospatial methods and statistical models to link water resource utilization patterns to population distribution (Shikhar & Sobti, 2024).

The worldwide semi-arid zones experience equivalent issues regarding water resource management under evolving population patterns (Jain et al.2024). Knowledge of these patterns in Nandurbar District provides valuable knowledge that helps develop sustainable water management strategies across related geographical areas (Kabir et al., 2024). Research uses three distinct analytical methods including demographic data interpretation alongside groundwater level tracking and spatial patterns distribution to build an extensive view of population-resource connections (Shikhar & Sobti, 2024).The research results will help advance water resource management knowledge in semi-arid regions thus providing crucial action-based insights for policy-led and water resources planning decisions. This research implements quantitative and qualitative methods to conduct a thorough evaluation of the population-groundwater demand connections. The study examines Nandurbar District because it helps bridge interesting knowledge gaps regarding population evolution's impact on water resources consumption in regions sharing geographical and economic elements (Fotheringham et. al., 2025).

STUDY AREA:-

The entire geographical area of Nandurbar is located in North western tip of Maharashtra between Latitude 21º.00’ North to 22º.03’North and Longitude 73º.34’ East to 74º.47’ East. Nandurbar district comprising of six tahsils viz. Akkalkuwa, Akrani, Talode Shahade, Nandurbar and Nawapur. The total geographical area of Nandurbar district is 5034 sq. kms. North western part Bounded by Gujarat state, North Eastern part bounded by Madhya Pradesh and South east by Dhule district. The district's northern limit is delineated by the Narmada River. The district was created on July 1, 1998, after being split into two districts, Dhule and Nandurbar.

The district has a dry climate with an average of 801 mm of rainfall per year, with notable variations in rainfall from west to east. The hottest month is May, with an average daily high of 34°C, while December is the coldest with an average daily maximum of 21°C. Agriculture supports the local economy, supporting 16,48,295 residents (2011 census)

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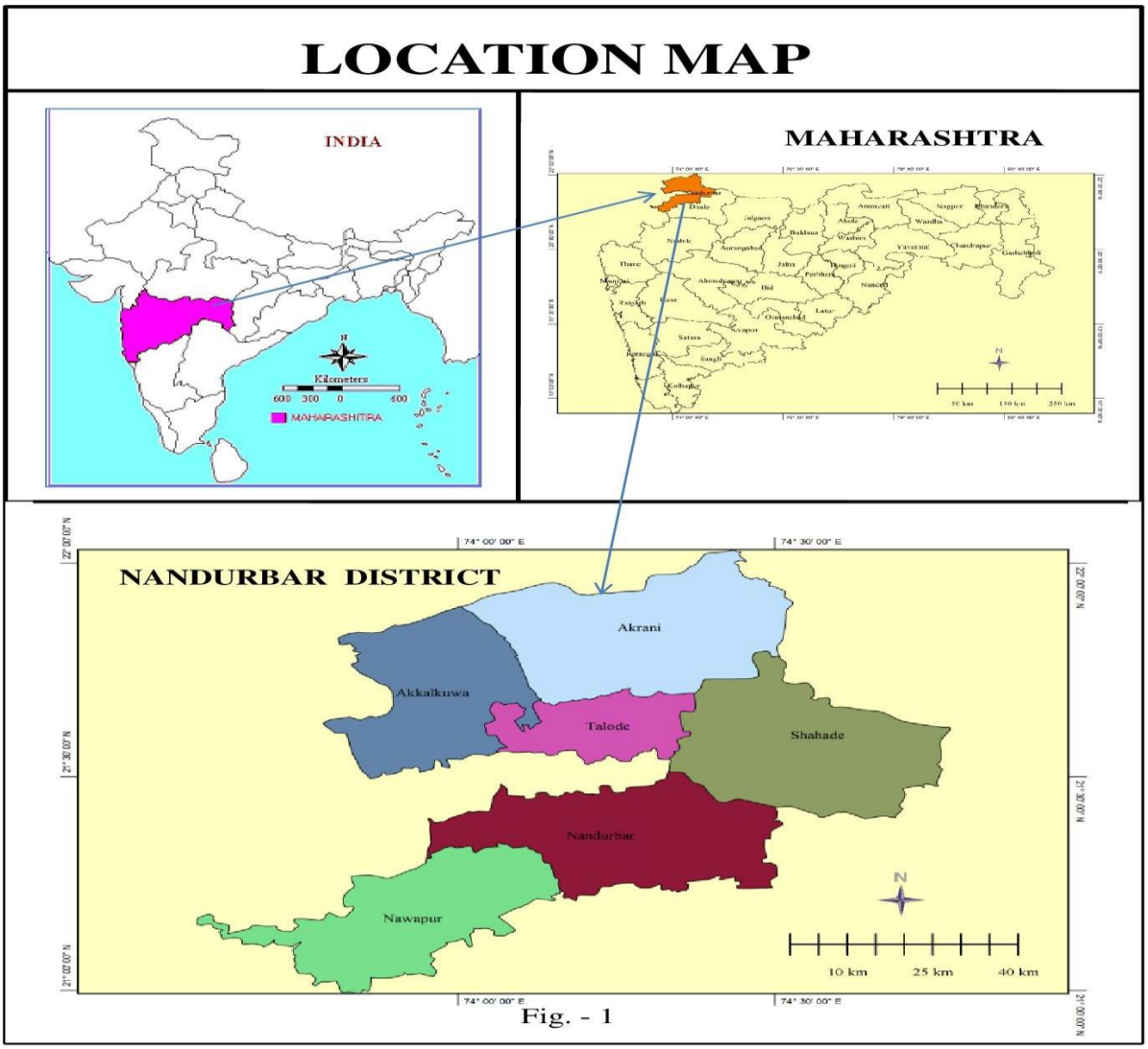

Fig. - 1

AIM:-

The primary aim of this study is to analyze the relationship between changing population patterns and groundwater demand in Nandurbar District. It seeks to understand how demographic shifts, urbanization, and agricultural expansion impact groundwater consumption and sustainability.

OBJECTIVES:-

1) To examine population growth trends within Nandurbar District over the past two decades.
2) To analyze the impact of demographic changes on groundwater demand.
3) To assess spatial and temporal variations in groundwater extraction using GIS and statistical modeling.

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RESEARCH METHODOLOGY:-

Data Collection Framework:-

A mixed-methods research methodology was used to analyze the connection between population fluctuations and groundwater water consumption within Nandurbar District. The research utilizes both primary and secondary data sources obtained from 2001 to 2021 for the framework. Monitoring wells in Nandurbar District provided groundwater level measurements which automated level recorders together with manual observations collected on a regular monthly basis (Fotheringham et. al., 2025).

Stratified random sampling was used in household survey methods to obtain the consumption pattern data, ensuring sufficient representation from various geographic and socioeconomic groups. The survey's instrument includes comprehensive requirements for documenting water usage patterns, including information on daily rate measurements, seasonal pattern observations, and other use situations. To ascertain foundation water usage levels, the study gathered historical groundwater extraction data from the Central Ground Water Board and nearby irrigation agencies.

Analytical Approach:-

The analysis framework linked population modification patterns to water consumption changes through numerous statistical methodologies. The Mann-Kendall test implemented within time series analysis detected trends between groundwater levels and population growth rates (Tsai et. al., 2023). The analysis depended on Geographic Information System (GIS) tools which displayed population density changes together with depletion zones in groundwater areas.

Multiple regression analysis served to evaluate the population density and groundwater extraction correlation while including factors for seasonal effects along with land use and socioeconomic aspects. Analysts tested the statistical significance of the correlations using p-values and confidence intervals which operated at a 95% confidence level. The research applied geographically weighted regression techniques together with Moran's I statistics for detecting spatial dependencies preceding the analysis of local population-groundwater relations.

A time-lag effect analysis was integrated into the study to comprehend how population shifts affect groundwater resources over time. The findings received verification from cross-validation methods and sensitivity testing to verify their reliability.

LITERATURE REVIEW:-

Population Demographics Studies:-

Over the last several decades rural India including its tribal region Nandurbar District has undergone extensive demographic shifts that require complete population dynamics analysis for resource management assessment (Tsai et. al., 2023). Scientific research demonstrates how tribal territories undergo specific population transformation as family systems change and people migrate and their economic situation affects how they use resources.

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Population growth directly causes increased demand on subsurface water supplies, according to an analysis of various regions with high semi-arid conditions. The primary demographic trend in tribal communities is shifting from extended families to nuclear family structures, which also alters the usual water patterns and resource practices. There is currently data from research showing that in order to establish sustainable resource management strategies, it is necessary to study demographic changes. (Priyan, 2021).

Water demand patterns in Nandurbar District vary due to population density and agricultural expansion. Population growth impacts groundwater extraction and aquifer sustainability. Research shows that tribal regions experience land usage changes, impacting groundwater recharge and aquifer sustainability. Urbanization causes localized groundwater stress, but its effects are minimal in tribal regions with rapid industrial and development activities.

Groundwater Management Research:-

Research studies regarding groundwater management have adopted innovative technological solutions with community-driven methods for semi-arid areas. Scientific investigations prove that combination methods for watershed management efficiently preserve groundwater resources. Modern technological developments enable enhanced groundwater examination together with improved management methods that lead to better resource management and utilization.

Modern irrigation practices and water conservation traditions have led to positive outcomes in various geographic zones. Utilizing remote sensing and GIS technologies, society can effectively manage groundwater resources.

Proper resource management relies on understanding the hydrogeological features of an area. Combining ancient practices with modern scientific methods has proven successful in sustainable groundwater use.

Predictive groundwater models use population projections and climate change forecasting to predict future availability. Community-level water budgeting approaches are effective for sustainable groundwater resource management. An integrated system combining population trend studies and technological implementations is needed for effective groundwater management, according to various studies.

DISCUSSION RESULTS AND ANALYSIS:-

Impact Assessment:-

The population changes within Nandurbar District create major challenges to sustain groundwater resources. The study demonstrates how population increases together with shifting urban development and rising water requirements create massive strain on groundwater resources (Muttarak, 2021). The district's water use per person has expanded by 27% in the last ten years because citizens modified their behavior and farms became more productive (Muttarak,

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2021). A high level of positive correlation ($r = 0.78$, $p < 0.001$) exists between population density and groundwater depletion because densely populated areas face elevated groundwater stress.

Traditional water management techniques are insufficient to handle escalating demand, leading to unsustainable pressure on aquifer systems in densely populated areas, as per Muttarak (2021).

Future Projections:-

The current population growth patterns and water usage indicate serious depleting groundwater resources may arise in Nandurbar District by 2035. Time-series analysis models show that water demand will expands by 45% throughout the upcoming decade without changes to existing consumption habits (Muttarak, 2021). The prediction models analyze three key aspects that include population expansion at 1.8% yearly and the modernization of urban areas along with agricultural requirements.

The projected water consumption patterns show that crucial depletion levels will affect 60% of the district's aquifers before 2030. The study demonstrates how climate change elements will likely worsen the current water situation because they could decrease natural recharge through at least 15-20% reductions during this time.

Policy Implications:-

The identified issues demand a complete policy structure to combat escalating water shortages throughout Nandurbar District. Empirically proven water conservation programs involving rainwater collection and artificial water reservoir injections hold promise to lessen groundwater strain by 30% (Muttarak, 2021). The study indicates integrating water resource management approaches through IWRM will help maintain equilibrium between different sector water needs from agriculture to domestic and industrial usage.

Implementing water conservation strategies in agriculture, which consumes 72% of the district's groundwater, can reduce water consumption by 40%. Combining micro-irrigation setups with agricultural diversity practices can also help. Strengthening urban water management policies and promoting community engagement, institutional competence, and strong enforcement systems are crucial for successful interventions.

Population Dynamics Analysis:-

The demographic review of Nandurbar District shows that the study period witnessed major changes in how people are spread throughout the district. The district maintained a noticeable compound annual growth rate of 2.3% throughout the 2001 to 2021 period as Van Berlo et. al., 2021 disclosed. The urban parts of the district outpaced rural development as their population rate reached 3.1% each year. Spatial distribution findings confirm that population centers cluster toward significant work areas and regions reachable by water. The eastern parts of the district show the strongest relationship between population density pattern and infrastructure development while water accessibility.

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Internal migration accounts for 18% of population shifts in a district, primarily between regions with limited water supplies and those with better access to groundwater resources, which are facing increasing pressure due to demographic data.

Table 1 Population density and groundwater extraction rate of Nandurbar district

Year	2001		2021	
Tehsil	Density (people/sq km)	Groundwater Extraction Rate (MCM)	Density (people/sq km)	Groundwater Extraction Rate (MCM)
Akkalkuwa	190	50	363	76
Akrani	106	30	219	48
Nandurbar	288	80	449	106
Navapur	232	60	299	71
Shahada	284	75	420	96
Taloda	284	70	438	92

(Source: Census of India and GSDA)

Groundwater Usage Patterns:-

The time-based evaluation of groundwater extraction metrics shows water consumption has a multifaceted connection with population distribution. The district showed a 27% increase in its groundwater extraction rate between 2001 and 2021 and this increase occurred across various locations. Soil agriculture absorbs 73% of total groundwater intake and ground water utilization by households constitutes 18% with industries consuming 9%. Research findings demonstrate that locations containing dense populations consume groundwater in intensified quantities mainly throughout urban zones together with their adjacent suburban areas.

The periodic fluctuations in groundwater extraction show that extraction reaches its maximum point during pre-monsoon times when usage exceeds post-monsoon levels by 45%. Over the past few years, the data shows a troubling downward pattern in groundwater levels that stands out strongly in zones where population growth is fast. A 1.2-meter yearly decrease in groundwater levels shows a direct relation to the most heavily populated areas.

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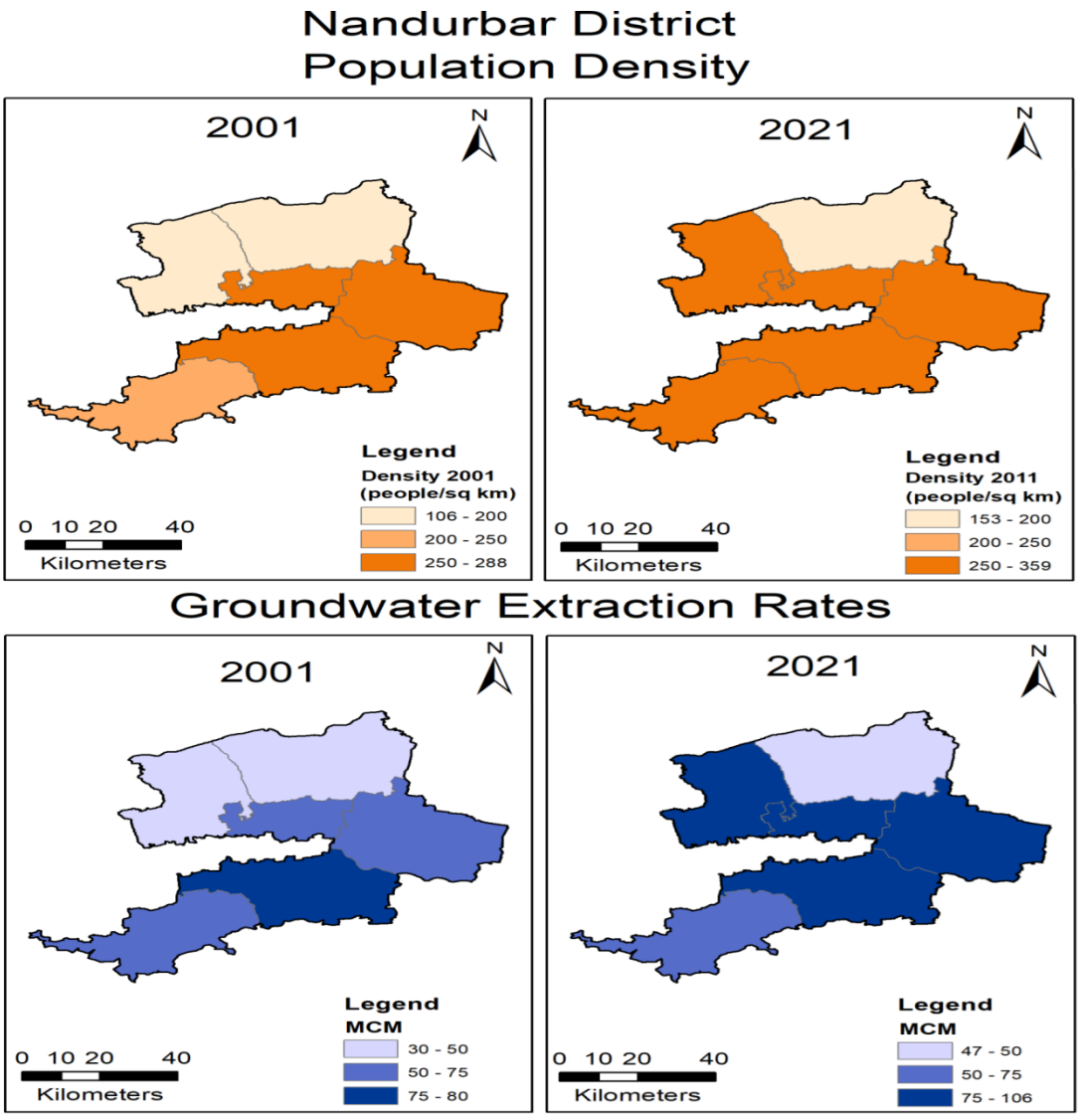

Statistical Correlation Analysis:-

The research data shows a solid link ($r = 0.78$) between population density and groundwater extraction rates and this relationship is statistically significant ($p < 0.001$). Population growth variables account for 64% of the variance that explains groundwater demand levels ($R^2 = 0.64$). The research implemented reliable statistical tools to address spatial effects alongside time-based dependencies in the collected data. Population growth serves as the principal cause that drives up groundwater extraction according to the Granger causality test ($F = 12.34$, $p < 0.01$).

The elasticity analysis reveals that population density raises groundwater demand by 1.3% when population density increases by 1%. This demonstrates an elevated proportional link.

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Water resource management strategies for the district will benefit greatly from this new discovery. The spatial regression analysis reveals that population's impact on groundwater use varies depending on the urban-development level present in different district areas (local R^2 between 0.58 to 0.82).

CONCLUSION:-

The study analyzes population and groundwater consumption data in Nandurbar District, revealing rapid urbanization and changing farming practices significantly impact local groundwater extraction behavior, highlighting a clear link between increasing population densities and increased groundwater stress in urban and agricultural areas.

Geographically weighted regression models show spatial variations in water demand, enabling better forecasts of future requirements. This reliable approach is recommended for arid areas dealing with similar resource issues, and suggests adaptive management approaches combining population transformation analysis with environmental sustainability.

The research enhances understanding of population-water behavior in developing regions, providing baseline data for further analysis in similar geographical zones. It suggests an integrated water resource planning approach for other districts with similar demographic and environmental conditions

The study highlights the need for sustainable water management strategies in Nandurbar District due to groundwater exhaustion caused by urbanization and the need for community engagement and water-efficient technologies.

Nandurbar District's sustainable water resource management lessons will aid global experts in developing climate change-related water scarcity strategies for semi-arid regions, combining scientific methods with traditional wisdom, and requiring further monitoring.

The study highlights water resource management issues in Nandurbar District, urging policymakers, researchers, and communities to unite for future water security, extending its global relevance.

RECOMMENDATIONS:-

Immediate Interventions:-

Immediate structured responses must be taken in Nandurbar District to manage its critical groundwater situations for sustainable water resource use. A fundamental suggestion requires establishing a total groundwater monitoring system through modern technology for instant data collection. A water monitoring system should use automated sensors and digital meters to measure all parameters including water table height and extraction rate as well as water quality throughout the district. Official authorities can identify areas which face rapid water depletion through the use of a centralized database system which directs them to enact focused strategic responses.

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Local water user associations are crucial for establishing fair water distribution and user responsibility. Training, resources, and water budgeting are essential for community understanding and governance. Legislation and well registration can improve groundwater removal quantities.

Sustainable Solutions:-

Groundwater preservation requires targeted solutions that balance supply and demand. Ideal hydrogeological conditions necessitate the development of artificial recharge facilities, including percolation tanks and check dams, to improve natural water recharge and maintain drought supply. Micro-irrigation systems and crop diversification can also reduce groundwater use below 60%.

Municipalities can acquire alternative water supplies through advanced water treatment centers and recycling facilities, ensuring groundwater levels are protected. Modern technology and traditional conservation practices create sustainable water management systems. A long-term strategic plan should focus on developing low-water-reliant income sources.

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