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Research Article

Land use/Land cover Dynamics and Groundwater Quality Mapping of Mal Municipality, West Bengal using Geospatial Technology

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ABSTRACT

The expansion of urban areas and agricultural land, driven by population growth and economic development, has notably altered the landscape. Concurrently, the reduction in forest cover and natural vegetation raises concerns about ecological sustainability and biodiversity loss. This research examines the dynamicity of land use and land cover (LULC) and water quality of Mal Municipality, located in the Jalpaiguri district of West Bengal. Utilizing Landsat satellite imagery and GIS technology, the research identifies significant changes in the region's LULC over the past two decades. Water quality analysis, conducted through sampling and laboratory testing, reveals the impact of these LULC changes on local water resources. Key parameters such as pH, TDS, turbidity, hardness, chloride and sulphate, magnesium and calcium hardness have been measured to assess the health of the groundwater in Mal Municipality. The result of the present study explains Vegetation covers and surface water bodies of Mal municipality are continuously declining in the last two decades, whereas built up areas are increasing day by day. A great variation is observed among the water quality parameters throughout the Mal Municipality. The present study has ended with the water quality assessment of Mal municipality, which indicates that the maximum parts of Mal Municipality have good to very poor-quality groundwater. Although the overall groundwater quality of most parts comes under usable condition, significant parts have unsuitable groundwater which really needs the attention of the environmental planners. The findings underscore the urgent need for integrated land and water resource management strategies to mitigate environmental degradation. This study serves as a crucial baseline for policymakers, urban planners, and environmentalists aiming to promote sustainable development in Mal Municipality while safeguarding its natural resources.

Keywords: GIS; Groundwater; Groundwater Quality Index; LULC Dynamics; Mal Municipality

Introduction

Understanding land use and land cover (LULC) dynamics and water quality is critical for sustainable urban and environmental planning. Mal Municipality, situated in the Jalpaiguri district of West Bengal, India, provides a compelling case study due to its unique geographical location, rapid urbanization, and rich natural resources. This introduction explores the importance of examining LULC changes and water quality in Mal Municipality, highlighting the interplay between human activities and environmental health. It is evident that anthropogenic modification of land use and land covers often significantly hamper the natural quantity and quality of both surface and ground water [1].

Land use and land cover dynamics refer to the changes in the landscape driven by natural processes and anthropogenic activities. Monitoring these changes is essential for understanding how land utilization affects ecological balance, resource availability, and environmental quality. In the last few decades, south-Asian countries are the countries facing massive and rapid loss of ecosystem due to urbanisation [1]. It is predicted that by 2050, urbanisation all over the world would come up as a major issue and should be handled with proper management planning [2]. Land use change, if not managed, can cause a severe damage to the food, water, wildlife, agricultural production and many other parameters and places rich in forest cover and wild life are to be the highest sufferers [3]. For example, in Sundarban area of West Bengal is facing a continuous degradation of water quality due to immigration, land encroachment due to agriculture and many other anthropogenic activities [4]. To measure the intensity and dynamics of LULC change, several techniques have been opted by researchers, but studying LULC change through image analysis have been proved to be the best [5].
Various land use land cover change analysis has elucidated the impact of the process and continuously degrading water quality which is the outcome of this anthropogenic modification, has become a global concern now a days. This impact deepens with the spatio-temporal scale of anthropogenic modification of the land use [6]. This intensified anthropogenic activities effect the quality of crops produced [7], biogeochemical cycle, biodiversity and water quality [8] [9]. These negative impacts have not only degraded the quality of natural resources but also declined those income sources which are connected to tourism industry [10].
Water quality is a significant indicator of environmental healthiness and human well-being. Natural ecosystems have an innate quality of rejuvenating and monitoring water quality but anthropogenic activities like deforestation and farming often lead to losses of natural nutrients and sediments which in turn elevates the intensity of water pollution in the region [11]. That is why LULC change is considered as direct driver of water quality both surface water and ground water [12]. Surface water is more exposed to anthropogenic activities. As a result water bodies in industrial areas are more susceptible to heavy metals and water bodies close to agricultural lands are effected by fertilizers and pesticides [13]. Ground water, another source of fresh water, is also contaminated through mineral toxicity through unplanned waste dumping, unrestrained use of fertilisers, industrial waste generation and disproportionate extraction of ground water [14]. Water quality index (WQI) first developed by Horton, is a weighted arithmetic calculation, is one of the most popular method used in water quality monitoring activities [15] [16]. This index can be used for both surface and ground water and has four major steps of parameter selection, data validation, weightage determination and WQI calculation [17]. WQI is extremely effective to understand the status of water quality in any region. Moreover it can assess the spatio-temporal and seasonal change in water quality of any region [18] [19].

On a global scale in recent years, sources of water pollutants may be categorised in seven categories which are pharmaceuticals, personal care and cosmetics, industrial substances, other substances, pesticides, biological agents and unintentional persistent organic pollutants [20]. All these pollutants can come from point and non-point sources released intentionally or unintentionally and can create a harmful consequences on human health along with negative impact upon environment [21] [22]. In India numerous studies have been conducted to understand water quality in different water bodies. One of the major rivers of the country is Ganga. A study on water quality of Ganga River has shown that the river water is vulnerable to several pollutants. Industrial, agriculture and urban domestic waste are responsible for high turbidity and high pollution level in Ganga River [23]. In Beas river basin area, heavy metal pollution has been found which is a result of industrial waste disposal [24]. Rural areas are also affected by the industrial discharge and daily household activities [25]. Water pollution in any form is a threat to humankind and other organisms as well. Recently several techniques are being adopted to prevent water pollution such as using fly ash as landfill geoliner to reduce ground water pollution [26], incorporation of chitin/chitosan structure of carbonaceous material which is an activated carbon composite to improve mechanical and thermochemical properties of water and for absorption of water pollutants [27], using metal organic framework (MOF) to remediate water environment [28], as an efficient absorbent of water pollutants graphene-materials are now being promoted in 3d format [29]. In spite of all these modern techniques, water pollution is still persistently increasing and needs continuous monitoring and attention.
Mal Municipality is nestled in the picturesque foothills of the Eastern Himalayas, along the banks of the Neora River. This strategic location has historically supported diverse ecosystems, including lush forests, fertile agricultural lands, and extensive tea gardens. The municipality's economy is predominantly agrarian, with tea cultivation playing a central role. However, recent years have witnessed significant demographic and economic shifts, leading to rapid urban expansion and intensified land use.
The socioeconomic landscape of Mal is characterized by a growing population and increased economic activities. These changes have necessitated the expansion of infrastructure, housing, and commercial areas. Consequently, the traditional land use patterns are undergoing transformation, impacting both the natural environment and local livelihoods.

In Mal Municipality, rapid urbanization, agricultural expansion, and deforestation are altering the region's land cover, with potential consequences for biodiversity, soil health, and hydrological cycles. The growth of urban areas often leads to the conversion of agricultural and forested lands into residential, commercial, and industrial zones. This process can result in habitat fragmentation, loss of green spaces, and increased surface runoff, contributing to soil erosion and water pollution. Intensified agricultural activities, particularly the use of chemical fertilizers and pesticides, can degrade soil quality and contaminate water sources. The expansion of agricultural land at the expense of natural vegetation also impacts local flora and fauna. The reduction of forest cover not only diminishes biodiversity but also disrupts ecological functions such as carbon sequestration, climate regulation, and water retention. Forests play a crucial role in maintaining the hydrological cycle, and their loss can lead to altered rainfall patterns and reduced water availability.

In Mal Municipality, the Neora River and other water bodies are essential for drinking water, irrigation, and industrial uses. However, the quality of these water resources is increasingly threatened by anthropogenic activities. The usage of manures and insecticides in agriculture can lead to nutrient loading and contamination of water bodies. This runoff can cause eutrophication, resulting in algal blooms, oxygen reduction, and damage to aquatic life. Inadequate waste management practices, including the improper disposal of household and industrial waste, contribute to the pollution of surface and groundwater. This contamination poses health risks to the local population and disrupts aquatic ecosystems. The lack of proper sewage infrastructure leads to the discharge of untreated or partially treated sewage into water bodies. This can introduce pathogens, organic matter, and hazardous chemicals into the water, affecting both human health and aquatic organisms.

This study aims to analyze the LULC dynamics and assess water quality in Mal Municipality, providing insights into the environmental impacts of urbanization and land use changes. Utilizing satellite imagery and GIS technology, the research maps LULC changes over the past two decades. Water quality is evaluated through the collection and laboratory testing of water samples from various sources, measuring parameters such as pH, TDS, turbidity, hardness and contaminant levels.

The investigation of LULC dynamics and water quality in Mal Municipality is crucial for developing sustainable land and water management strategies. By understanding, the interactions between human activities and environmental health, policymakers, urban planners, and environmentalists can implement measures to mitigate negative impacts and promote the sustainable development of this rapidly evolving region. This study aims to contribute to the broader discourse on environmental sustainability, offering valuable data and recommendations for preserving ecological integrity and improving the quality of life in Mal Municipality.

The Study Area

Mal Municipality, located in the Jalpaiguri district of West Bengal, India, is a small yet significant urban settlement with a rich historical and cultural background. Nestled in the foothills of the Eastern Himalayas, Mal is known for its picturesque landscapes, diverse communities, and growing urban infrastructure. Mal Municipality is situated approximately 55 kilometers away from Siliguri, a major city and the gateway to the Northeast of India. Its geographical coordinates are roughly 26.86°N latitude and 88.75°E longitude (Fig.1). The town is strategically located along the banks of the River Neora, which adds to its scenic beauty and agricultural viability. The region is well-connected by road and rail. The Malbazar Railway Station serves as the main railway hub, linking the town to important cities like Siliguri, Alipurduar, and Kolkata. The National Highway 31C passes through Mal, facilitating easy access to various parts of the state and neighboring regions. The population of Mal is a melting pot of various ethnic groups and communities, including Bengalis, Nepalis, Biharis, and indigenous tribes. This diversity is reflected in the town's cultural fabric, where festivals like Durga Puja, Diwali, Losar, and Christmas are celebrated with equal fervor. The linguistic diversity includes Bengali, Hindi, Nepali, and English, with Bengali being the predominant language.

The economy of Mal is primarily agrarian, with tea gardens playing a significant role. The region is part of the Dooars, an area renowned for its tea plantations. These tea estates not only contribute to the local economy but also attract tourism, providing employment to a large number of people. Agriculture, with crops like paddy, maize, and vegetables, also supports the livelihood of the residents. Additionally, small-scale industries and trade businesses contribute to the town's economic activities.

Mal Municipality has been making strides in improving its urban infrastructure and public services. The town is equipped with essential amenities such as schools, healthcare facilities, and markets. The educational institutions range from primary schools to higher secondary schools, providing quality education to the local children. Healthcare services are catered to by government and private hospitals and clinics, ensuring medical care for the residents.

Mal's proximity to the Eastern Himalayas and its location in the Dooars make it a gateway to several tourist attractions. The Gorumara National Park, known for its population of Indian rhinoceroses, and the Chapramari Wildlife Sanctuary, famous for its elephants and diverse bird species, are easily accessible from Mal. The lush tea estates and the picturesque landscape of the riverbanks entice tourists from various destinations. The town also caters as a base for tourists heading to the popular hill stations of Darjeeling, Kalimpong, and Gangtok.

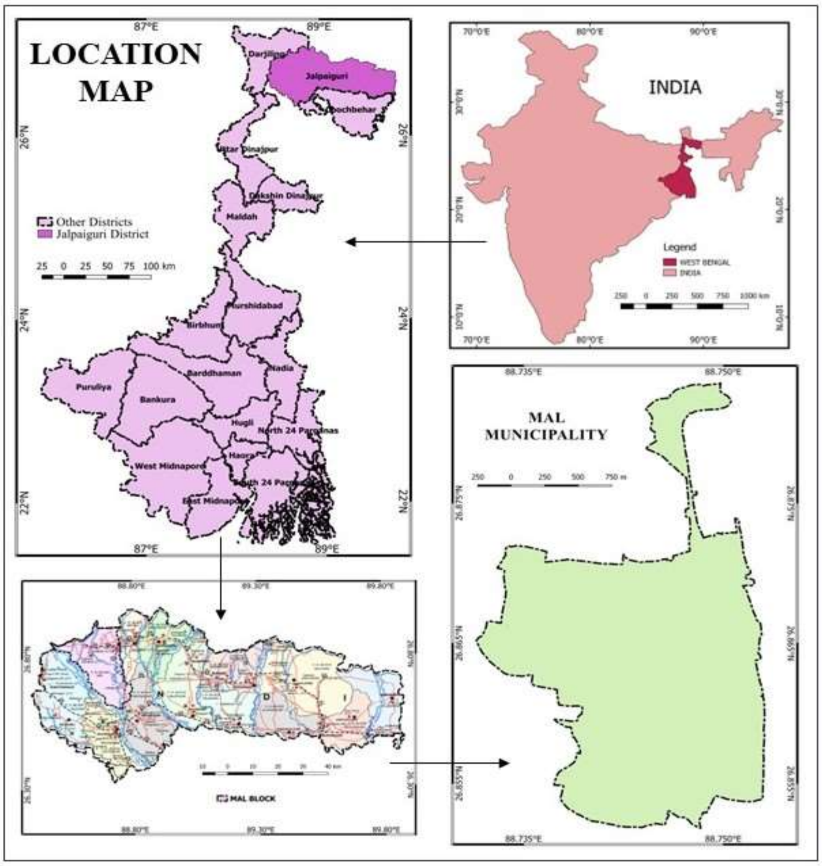

Fig. No. 1: Location of the Study Area

Materials and Methods

Acquiring LANDSAT Images

Landsat 5 images from November 2000 and November 2010, as well as Landsat 8 (OLI) images from November 2022, were acquired via the USGS Earth Explorer platform. All datasets were pre-referenced using the WGS-84 datum and Universal Transverse Mercator (UTM) Projection system. Subsequent atmospheric and radiometric corrections were performed using Erdas Imagine 2014 and ArcGIS 10.3 software. Detailed specifications of the images are listed below (Table-1).

Methods for calculating rate of LULC Dynamics

To determine the rate of Land Use/Land Cover (LULC) Dynamics, supervised image classification techniques were utilized for individual features. The process employed key spatial indices—MNDWI for identifying water bodies, NDBI for detecting built-up areas, and NDVI for assessing vegetation for each year[30]. The classification of surface water bodies, vegetation, and built-up areas was executed independently using Erdas Imagine 2014 (ESRI) software. For accuracy assessment, the Kappa Coefficient was used, with validation performed through Google Earth for each year. Subsequently, changes in area were calculated based on the classified maps.

Accuracy assessment of land use classes

In this study, accuracy was determined using a confusion matrix (also known as an error matrix), which is based on comparing the actual and predicted pixel values [31] [32]. A total of 170 sample locations were meticulously selected from Google Earth and cross-verified with the LULC map for validation (Table-2). The overall accuracy was then calculated using the following equation:

$$T = \frac{\Sigma Dii}{N}$$

Where,
T = Overall accuracy,
ΣDii = Total number of correctly classified pixel,
N = Total number of pixels in data matrix.

Producer's and User's accuracy assessments were calculated using the formulas -

$$\text{Producer's accuracy} = \frac{\textit{Diagonal value of column}}{\textit{Column total}} \text{ x } 100$$

$$\text{User's accuracy} = \frac{\textit{Diagonal value of row}}{\textit{Row total}} \text{ x } 100$$

The Kappa coefficient is considered a more advanced measure of accuracy compared to overall accuracy [33] [34] [32]. The calculation of the Kappa coefficient was done using the following formula:

$$\text{Kappa co-efficient (K)} = \frac{\frac{\Sigma a}{N} - \Sigma ef}{1 - \Sigma ef}$$

Where,
a = Diagonal frequency, N = Total number of frequency, ef = expected frequency.

$$\text{Expected frequency (ef)} = \frac{\textit{Row total x Column total}}{N}$$

A higher K value indicates a stronger agreement between the observed and predicted classifications, thus reflecting a more accurate classification system[35].

Table:1 Image Specification

Satellite	Sensor	Path/Row	Year	Month	Bands	Resolution	Wavelength
Landsat-8	OLI & TIRS	139/41	2020	November	Band 1-Coastal aerosal	30	0.43-0.45
					Band 2-Blue	30	0.45-0.51
					Band 3-Green	30	0.53-0.59
					Band 4-Red	30	0.64-0.67
					Band 5- Near Infrared(NIR)	30	0.85-0.88
					Band 6- SWIR 1	30	1.57-1.65
					Band 7- SWIR 2	30	2.11-2.29
					Band 8- Panchromatic	15	0.50-0.68
					Band 9- Cirrus	30	1.36-1.38
					Band 10- Thermal Infrared(TIRS) 1	100	10.6-11.19
					Band 11- Thermal Infrared(TIRS) 2	100	11.50-12.51
Landsat-5	Thematic Mapper	139/41	2000 & 2010	November	Band 1-Visible Blue	30	0.45 - 0.52
					Band 2- Visible Green	30	0.52 - 0.60
					Band 3-Visible Red	30	0.63 - 0.69
					Band 4-NIR	30	0.76 - 0.90
					Band 5- SWIR 1	30	1.55 - 1.75
					Band 6-Thermal	120	10.40 - 12.50
					Band 7- SWIR 2	30	2.08 - 2.35

Table: 2 Accuracy Assessment

Year	Land use Category	Built up area	Vegetation	Water body	Others	Total	User's Accuracy	Kappa Co-efficient
2000	Built up area	48	1	1	1	51	94.12	
	Vegetation	1	47	2		50	94.00	
	Water body		1	37	1	39	94.87	
	Others	1	1		28	30	93.33	
	Total	50	50	40	30	170		0.92
	Producer's Accuracy	96.00	94.00	92.50	93.33			
	Over all Accuracy	94.12						
2010	Built up area	47	1	1	1	50	94.00	0.89
	Vegetation	1	46	1	1	49	93.87	

	Water body	1	1	37		39	94.87	
	Others	1	2	1	28	32	87.50	
	Total	50	50	40	30	170		
	Producer's Accuracy	94.00	92.00	92.50	93.33			
	Over all Accuracy	92.94						
2020	Built up area	45	1	1	1	48	93.75	0.89
	Vegetation	2	47	1	1	51	92.15	
	Water body	2	1	37	1	41	90.24	
	Others	1	1	1	27	30	90.00	
	Total	50	50	40	30	170		
	Producer's Accuracy	90.00	94.00	92.50	90.00			
	Over all Accuracy	91.76						

Groundwater quality Mapping

Groundwater quality mapping is crucial for assessing the quality of subsurface water and managing them sustainably. In Mal Municipality, this process is crucial due to the reliance on groundwater for drinking, agriculture, and industrial purposes. This methodology outlines the steps for collecting, analyzing, and mapping groundwater quality using four samples from different locations within Mal Municipality.

Four sample sites have been selected including residential, agricultural, industrial and natural areas within Mal Municipality for collecting water sample (Fig.2). Groundwater samples have been collected using sterilized PET (polyethylene terephthalate) plastic bottles to prevent contamination. Each bottle has been labelled properly with site name, date and time of collection. After collecting the water quality parameters have been tested in CSIR-CMERI Laboratory, Durgapur, WB. Total ten parameters including Ph, TDS, turbidity, EC, Total alkalinity, total hardness, Ca $^{+2}$, Mg $^{+2}$, Cl and SO_4 have been tested.

Finally for mapping the groundwater quality in Mal Municipality ArcGIS 10.3 software has been used. Inverse Distance Weighted Interpolation (IDW) method has been used for mapping all the groundwater quality parameters using ArcGIS 10.3 Software.

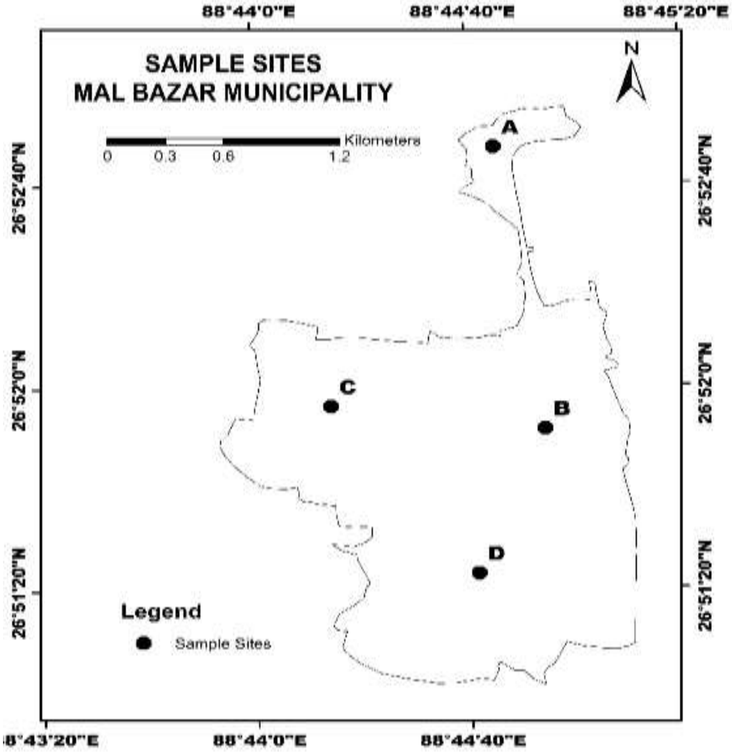

Fig. No. 2: Location of Sample collecting sites

Calculating Groundwater Quality Index (GWQI)

The Groundwater Quality Index (GWQI) is a useful means for summarizing the overall quality of water in a simple, understandable format. It aggregates multiple water quality parameters into a single number, which reflects the general condition of the water. In this methodology, we use the Bureau of Indian Standards (BIS) values to calculate the GWQI for water samples from Mal Municipality. The following steps have been used for calculating GWQI-

Determination of Quality Rating Scale (Qn)

Calculate the Quality Rating Scale (Qn) for each parameter. The Quality Rating Scale reflects the relative value of each parameter compared to its BIS standard.

$Qn = (Vn-Id)/(Sn-Id)\times100$

Where:

Vn = Measured value of the nth parameter

Sn = BIS standard value for the nth parameter

Id = Ideal value (usually zero for all parameters except pH, where it is 7)

For parameters where the ideal value is not zero (e.g., pH):

$Qn = (Vn-7)/(Sn-7)\times100$

Determination of Unit Weight (Wn)

Calculate the unit weight (Wn) for each parameter. The unit weight reflects the relative importance of each parameter in the overall water quality assessment.

$Wn = K/Sn$

Where:

K = Proportionality constant (usually 1)

Calculation of Sub-Index (SI_n)

Calculate the sub-index (SI_n) for each parameter, which is the product of the Quality Rating Scale and the unit weight.

$SIn = Qn\times Wn$

Calculation of Overall Groundwater Quality Index (GWQI)

Sum the sub-indices to obtain the overall GWQI.

$GWQI = \sum Sin$

Interpretation of GWQI

Groundwater Quality Index (GWQI) is a numerical expression used to assess the overall quality of water. It combines multiple water quality parameters into a single score, making it easier to understand the status of water quality in a particular area.

Categorization of GWQI Scores

Excellent (<25): Groundwater quality is pristine and suitable for all uses, including drinking.

Good (26-50): Groundwater quality is generally acceptable for most uses, including drinking, but might need minor treatment.

Poor (51-75): Groundwater quality is marginal and may not be suitable for drinking without significant treatment, but still acceptable for irrigation and industrial use.

Very Poor (76-100): Groundwater quality is poor and generally unsuitable for drinking and most uses without extensive treatment.

Unsuitable (>100): Groundwater quality is very poor and highly polluted, not suitable for any use without treatment.

Result and Discussions

LULC Dynamics

For identifying the temporal change in vegetation cover, three separate maps for November of the years 2000, 2010, and 2022 were prepared using Landsat 5 and Landsat 8 (OLI) images within a software environment. The results of this study indicate a continuous decrease in the vegetation cover of Mal Municipality. In 2000, the total area of vegetation cover was 0.98 km^2. By 2010, this area had decreased to 0.45 km^2. In 2022, the vegetation covers further declined to only 0.09 km^2.

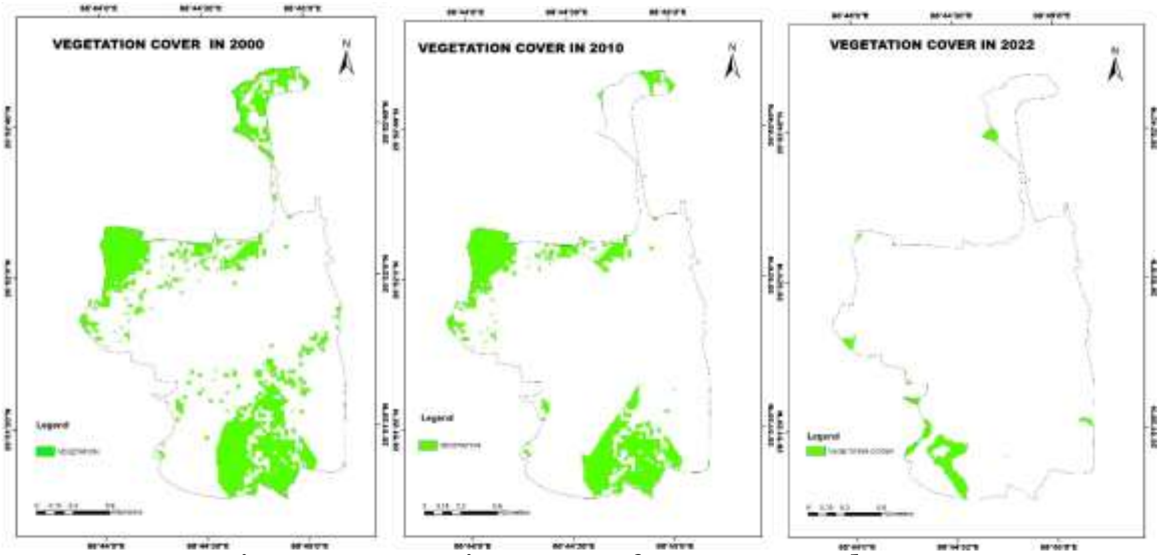

Fig. No.3: Vegetation covers of 2000, 2010 and 2022

The present study clearly shows that the vegetation cover in Mal Municipality is steadily decreasing over time. A significant negative trend in vegetation cover has been observed, with an R^2 value of 0.97. The primary factors contributing to this loss of vegetation are urban and agricultural expansion driven by population growth.

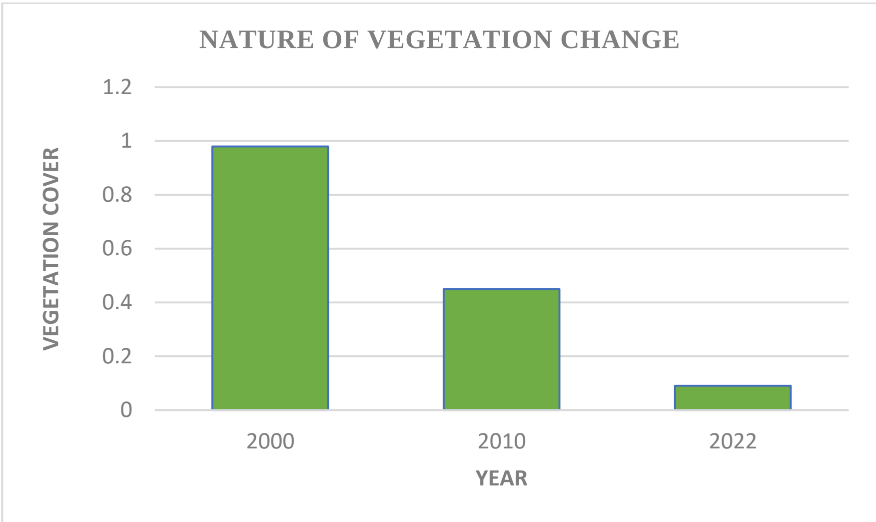

Fig. No. 4: Nature of Vegetation Change

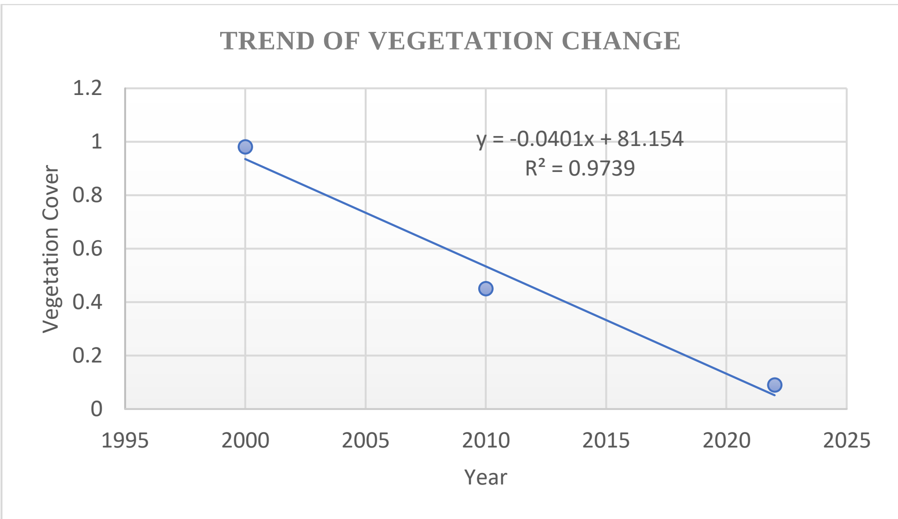

Fig. No.5: Trend of Vegetation Change

To identify the temporal changes in surface water bodies, three separate maps for November of the years 2000, 2010, and 2022 were prepared using Landsat 8 (OLI) images in a software environment. The study results indicate a continuous decrease in the surface water bodies of Mal Municipality. In 2000, the total area of surface water bodies was 0.25 km². By 2010, this area had decreased to 0.07 km². In 2022, the surface water bodies further declined to only 0.02 km².

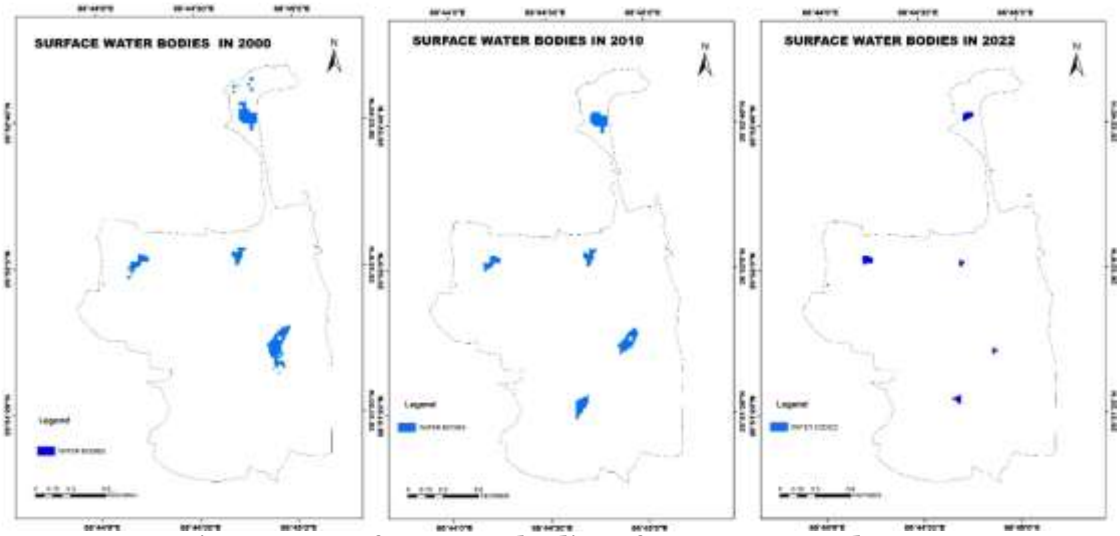

Fig. No.6: Surface water bodies of 2000, 2010 and 2022

The present study clearly shows that the surface water bodies in Mal Municipality are diminishing rapidly. A significant negative trend in the change of surface water bodies has been observed, with an R^2 value of 0.87. The primary reason for this loss is urban expansion driven by population growth.

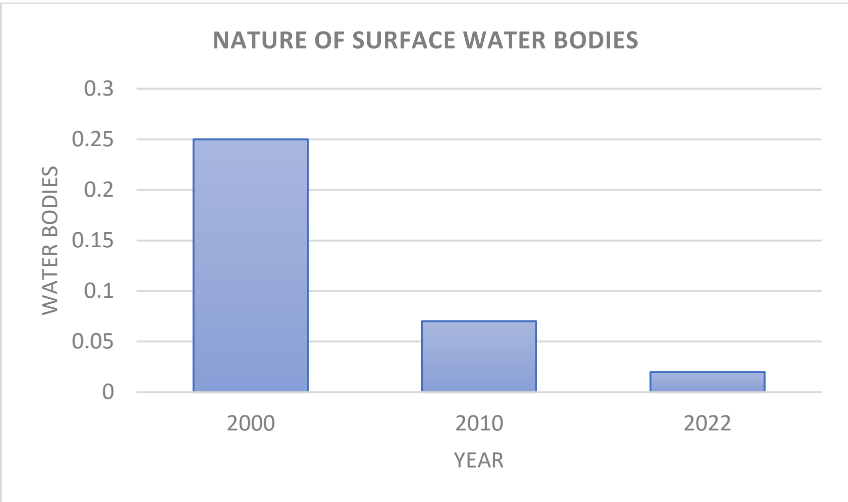

Fig. No. 7: Nature of Distribution of Surface Water bodies

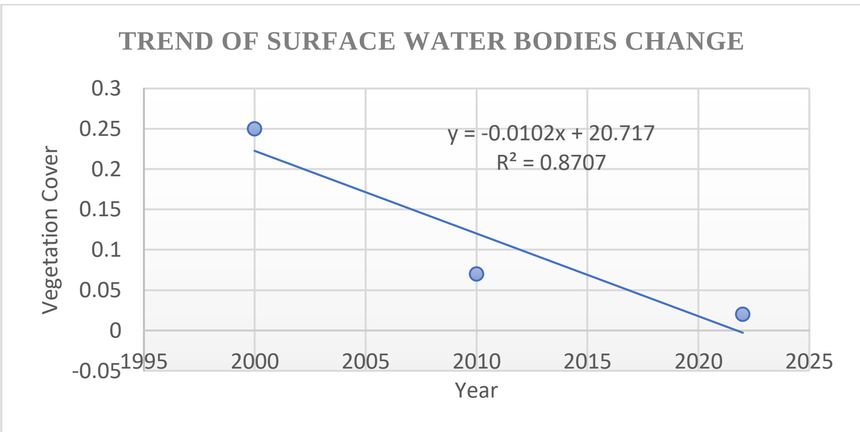

Fig. No. 8: Trend of Surface Water bodies Change

To identify the temporal changes in the built-up area, three separate maps for November of the years 2000, 2010, and 2022 were prepared using Landsat 8 (OLI) images in a software environment. The study results indicate a continuous increase in the built-up area of Mal Municipality. In 2000, the total built-up area was 1.68 km². By 2010, this area had increased to 2.02 km². By 2022, it had further expanded to 2.68 km². The majority of this area is now covered by settlements.

The present study clearly shows that the built-up area in Mal Municipality is steadily increasing. A significant positive trend has been observed, with an R^2 value of 0.97. The primary reason for the increasing built-up area is urban expansion driven by population growth.

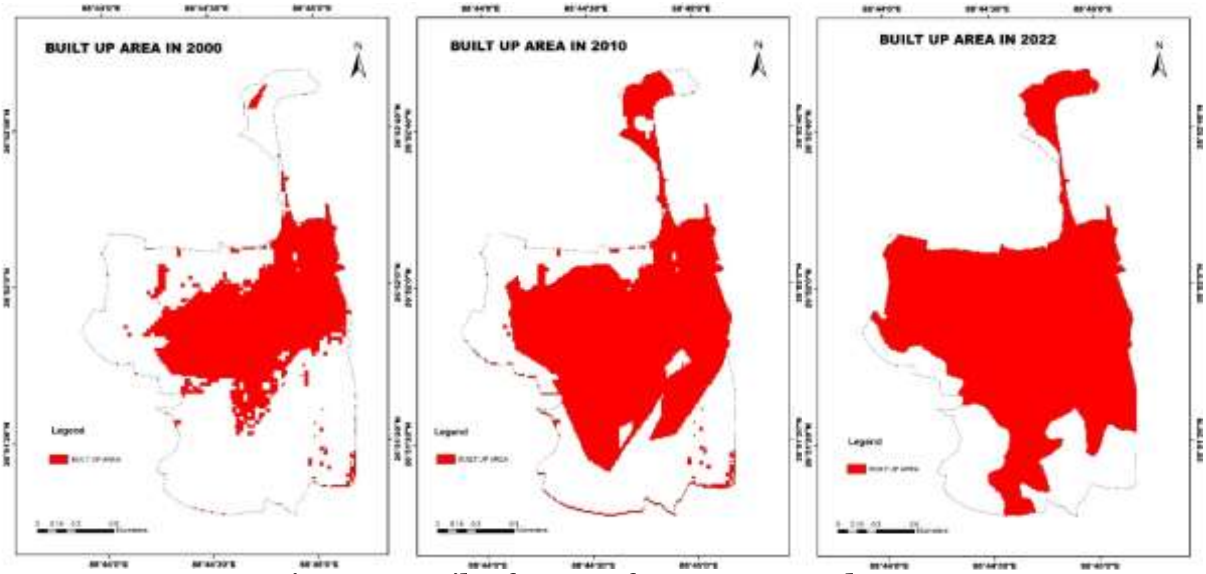

Fig. No.9: Built of Areas of 2000, 2010 and 2022

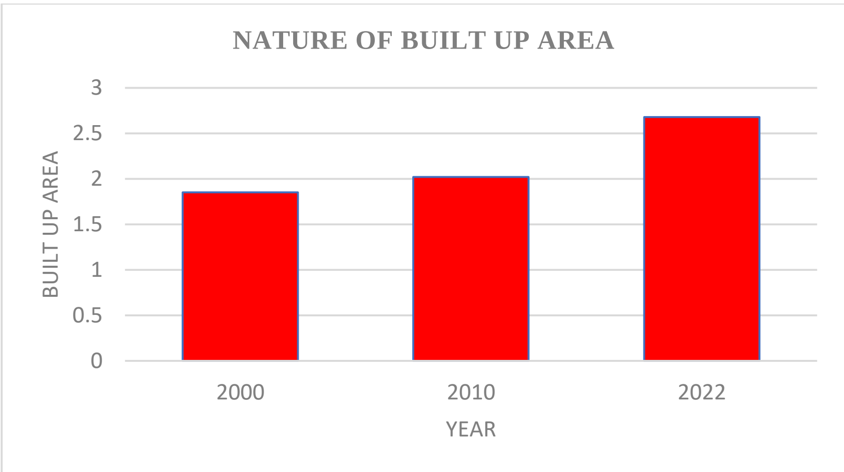

Fig. No.10: Nature of built-up areas

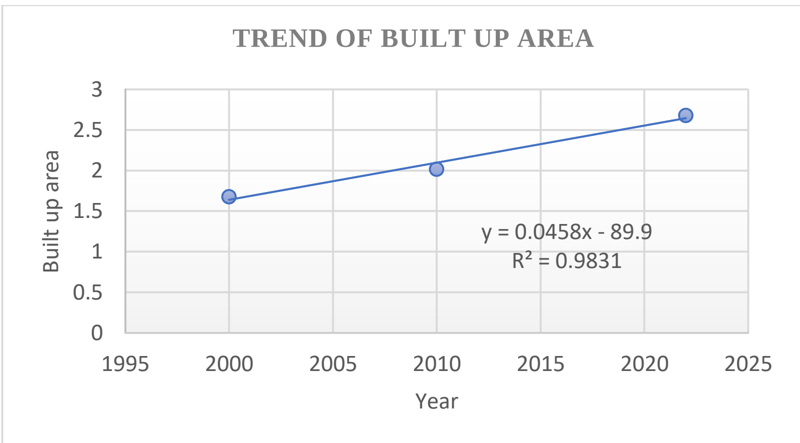

Fig. No.11: Trend of built-up areas

Physiochemical Properties of Groundwater

Water pH

Water pH measures its acidity or alkalinity on a scale from 0 to 14, with 7 being neutral. pH levels below 7 indicate acidity, while levels above 7 indicate alkalinity. The pH of water significantly impacts the solubility and bioavailability of chemicals and heavy metals, influencing water quality and safety. For drinking water, maintaining a pH within the BIS recommended range of 6.5 to 8.5 is essential to prevent corrosion in pipes, ensure effective disinfection, and safeguard human health. Deviations from this range can lead to adverse health effects and environmental issues, emphasizing the importance of regular pH monitoring.

Among the four sample sites in the study area, sites A, C and D are showing a water pH value within the tolerance limit whereas site B which is situated in the eastern part of the municipality, is showing a value slightly higher than the tolerable limit set as per BIS standard.

TDS

Total Dissolved Solids (TDS) in water represent the combined content of all inorganic and organic substances dissolved in the liquid. This includes minerals, salts, and ions such as calcium, magnesium, sodium, and potassium, as well as bicarbonates, chlorides, and sulfates. High TDS levels can affect the taste and hardness of water, making it less palatable and potentially harmful over prolonged consumption. They can also cause scaling in pipes and reduce the efficiency of water heaters and boilers. The Bureau of Indian Standards (BIS) recommends a maximum TDS level of 500 mg/l for drinking water, ensuring its suitability and safety for consumption.

In case of TDS, site A and d situated in the northern and southern part of the municipality respectively, are showing a value within the BIS recommended level of TDS i.e. 500mg/L. Site B and C, situated in the middle part of the municipality, have a high TDS value of 921 and 812 respectively.

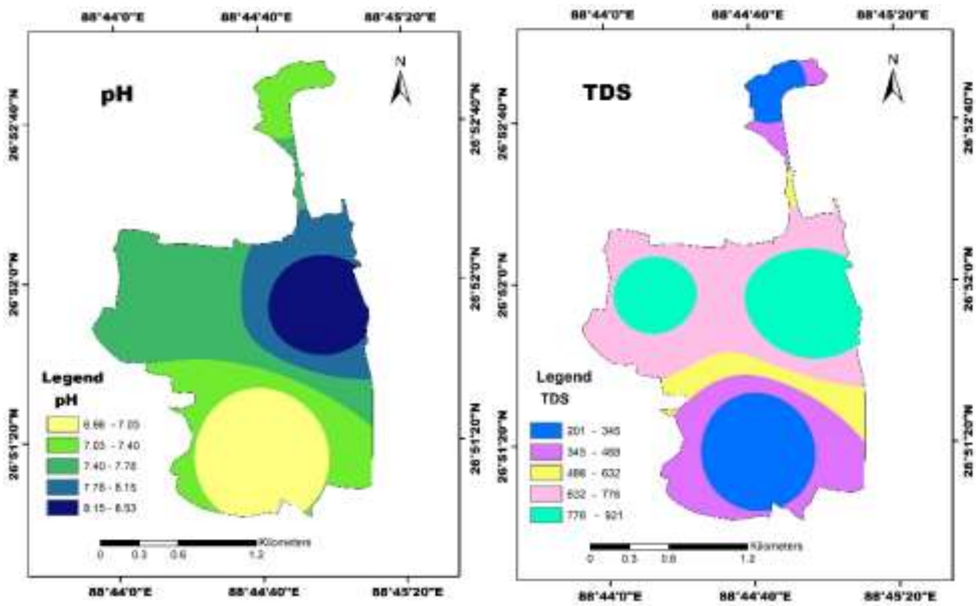

Fig. No.12 & 13: Variation of P^{H} and TDS distribution

Total Hardness

Water Total Hardness is a measure of the concentration of calcium and magnesium ions in water, expressed in milligrams per litre(mg/l) as calcium carbonate ($CaCO_3$). High hardness levels lead to scale formation in plumbing, reduced soap efficiency, and potential appliance damage. While not harmful to health, hard water can cause skin irritation and aesthetic issues. Managing water hardness ensures the longevity of plumbing systems and enhances daily living. The Bureau of Indian Standards (BIS) recommends a maximum total hardness of 300 mg/L for drinking water. Regular monitoring and softening treatments can effectively mitigate the adverse effects of hard water.

Apart from site D, located in the southern portion of the city, all other sites have a total hardness value way below than the recommended level. The mean value of 233.75 is also under the tolerance limit and the SD for this parameter is 131.41.

Table No. 3: Concentration of Various Groundwater Quality Parameters

Properties	Standard Value		Observed Value			
	BIS	WHO	Minimum	Maximum	Average	SD
pH	6.5-8.5	45511.00	6.66	8.53	7.49	0.77

TDS (mg/l)	500-2000	600-1000	201.00	921.00	563.50	256.02
Turbidity (NTU)	1.0 -5.0	1.0 -5.0	0.70	7.20	3.58	2.83
EC (µS/cm)	300.00		135.00	815.00	549.25	304.48
Total Hardness(mg/l)	300.00	200.00	95.00	412.00	233.75	131.41
Alkalinity(mg/l)	200-600		185.00	495.00	304.25	141.43
$MG^{+}2$(mg/l)	30.00		10.25	82.40	46.29	33.21
$CA^{+}2$(mg/l)	75.00	100-300	19.20	145.00	81.35	70.09
Chloride(mg/l)	250.00	200-300	40.00	135.00	92.50	43.30
Sulphate(mg/l)	250.00	250.00	17.00	110.00	65.00	44.17

Total Alkalinity

Water Total Alkalinity measures the capacity of water to neutralize acids, primarily due to the presence of bicarbonates, carbonates, and hydroxides. It acts as a buffer, preventing drastic pH changes and maintaining water stability. High alkalinity levels can protect aquatic life and prevent corrosion in pipes, while low levels may make water more susceptible to pH fluctuations, affecting its quality and safety. The Bureau of Indian Standards (BIS) does not specify a limit for alkalinity, but maintaining it within a balanced range is crucial for ensuring water quality and suitability for drinking, agriculture, and industrial uses. Regular monitoring helps manage and optimize water alkalinity.

In site B total alkalinity is 495 mg/l. The three sites have total alkalinity values of 185, 210 and 327 mg/l. So, Site B and D with a alkalinity value of 495 and 327 mg/l respectively can be considered as places with highly alkaline water. Rest of the two sites have values within manageable limits. Still for total alkalinity, continuous water treatment and monitoring is essential for keeping the values within limit.

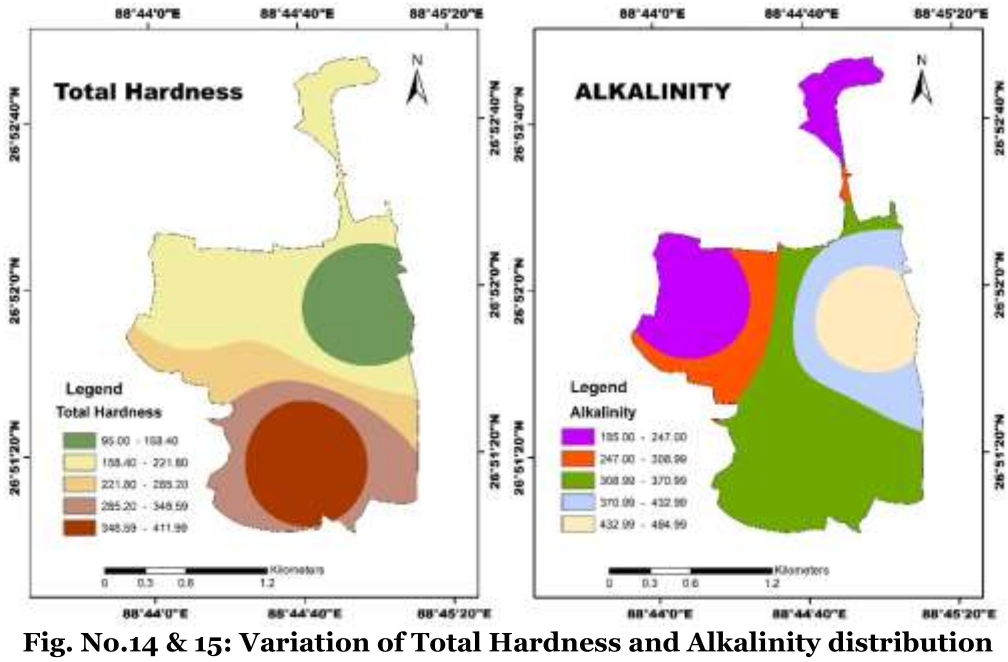

Fig. No.14 & 15: Variation of Total Hardness and Alkalinity distribution

Turbidity

Water turbidity measures the cloudiness or haziness of water caused by suspended particles, such as silt, clay, organic matter, and microorganisms. High turbidity levels can indicate pollution and may harbour pathogens, making water unsafe for drinking and other uses. It also interferes with disinfection processes and affects the aesthetic quality of water. The Bureau of Indian Standards (BIS) recommends a maximum turbidity level of 1 NTU (Nephelometric Turbidity Units) for drinking water. Regular monitoring and filtration treatments are essential to maintain low turbidity levels, ensuring water clarity and safety for consumption and environmental health.

Water turbidity in Mal municipality varies widely from one sample site to another. Site B contains the highest water turbidity of 7.20 NTU followed by site C with a value of 4.30. Site A has a value of 2.10 and site D has the value of 0.70 which is the lowest turbidity value among the four sample sites. So, the central part of the municipality has the highest water turbidity and the southern part has the lowest but overall, the water turbidity in Mal municipality is high as the average turbidity value reaches up to 3.58 NTU in compare to BIS standard of tolerance limit of 1 NTU for water turbidity.

Magnesium Hardness

Magnesium ($Mg^{+}2$) is a naturally occurring mineral found in water, contributing to its hardness. It is essential for human health, playing a crucial role in muscle and nerve function, blood glucose control, and bone health. However, high concentrations in drinking water can cause an unpleasant taste and have a laxative effect. Excessive magnesium can also contribute to scale formation in pipes and appliances. The Bureau of Indian Standards (BIS) recommends a maximum magnesium concentration of 30 mg/L in drinking water. Regular monitoring ensures safe magnesium levels, maintaining water quality and protecting public health.
Magnesium hardness is lowest in site B with a value of 10.25 mg/l. The highest value of 82.40 mg/l is found in site C. Site A also displays a high range of magnesium hardness of 65.30 mg/l. As both these two values are way over the tolerable maximum value of 30 mg/l, the total average of 46.29 mg/l is also beyond the recommended limit.

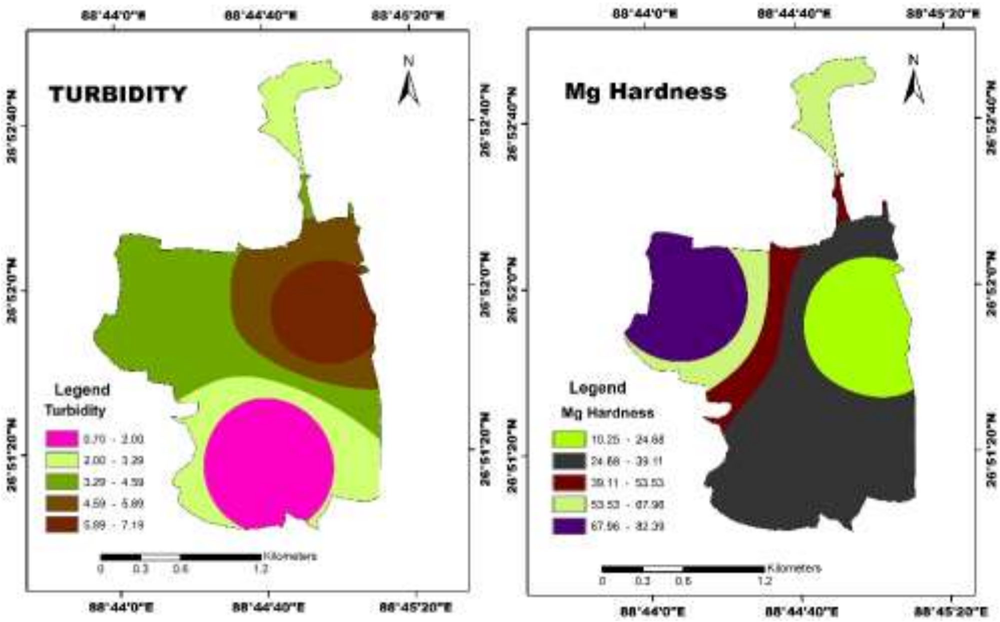

Fig. No.16 & 17: Variation of Turbidity and Magnesium Hardness distribution

Calcium Hardness

Calcium ($Ca^{+}2$) is a vital mineral found in natural water sources, contributing significantly to water hardness. It is essential for human health, aiding in bone development, muscle function, and nerve transmission. While calcium in drinking water provides a beneficial dietary supplement, high levels can lead to scaling in pipes, boilers, and household appliances, reducing their efficiency and lifespan. The Bureau of Indian Standards (BIS) recommends a maximum calcium concentration of 75 mg/l for drinking water. Regular monitoring and appropriate treatment methods, such as water softening, help maintain safe calcium levels, ensuring water quality and protecting both health and infrastructure.
Calcium hardness is high in site B and C with values of 145 and 139 mg/l respectively. Site A and D have a very low value of 22.0 and 19.2 mg/l respectively. These reveals a clear picture that the central part of the city has high calcium harness whereas the south and north portion of the city contains a low value. Due to high calcium hardness in the central city area, average value of calcium hardness which is 81.35 mg/l, is also high and beyond the limit.

Electrical Conductivity

Electrical Conductivity (EC) in water measures its ability to conduct electricity, primarily influenced by dissolved salts and minerals like sodium, calcium, magnesium, and chloride ions. High EC levels indicate high salinity, which can affect water's suitability for drinking, irrigation, and industrial processes. EC is a crucial indicator of water quality, reflecting dissolved solids and pollution levels. The Bureau of Indian Standards (BIS) does not specify a maximum EC for drinking water but recommends monitoring it alongside other parameters to assess overall water quality. Regular monitoring and appropriate management strategies help mitigate the impacts of elevated EC on water resources and ecosystems.
Electrical conductivity is highest in site D with a value of 815 µs/cm. Lowest EC value is found in site B. The value is 135 µs/cm. The average EC value for the city is 549.25 µs/cm and the standard deviation is 304.48. So, the value has high variety throughout the city.

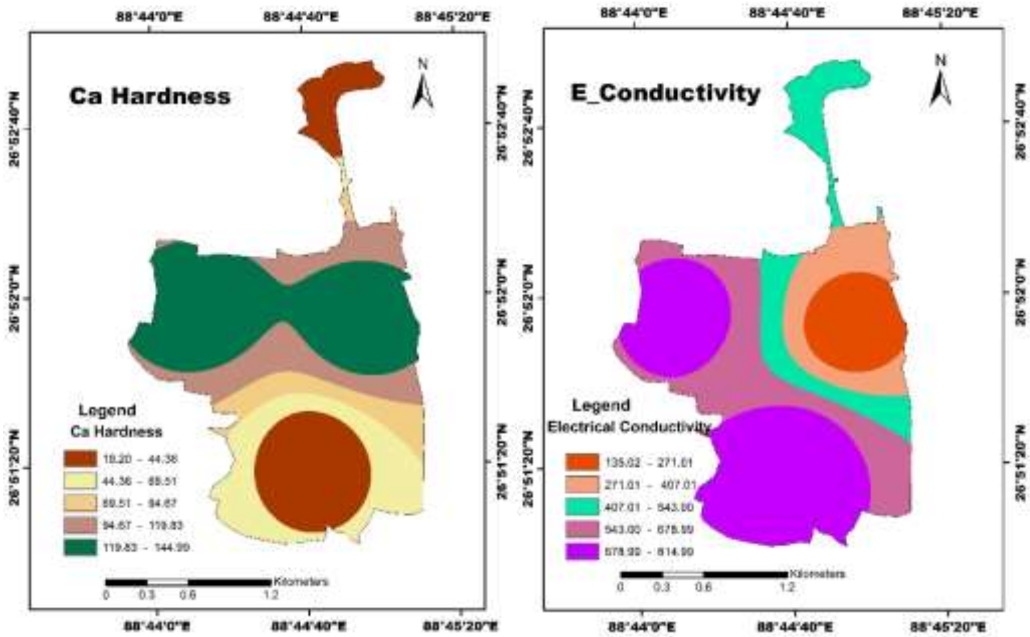

Fig. No.18 & 19: Variation of Calcium Hardness and E-conductivity distribution

Chloride

Chloride in water originates from natural sources like seawater intrusion or geological deposits, and human activities such as wastewater discharge and industrial effluents. It is essential to monitor chloride levels as high concentrations can impart a salty taste, corrode pipes and equipment, and affect agricultural crops. The Bureau of Indian Standards (BIS) sets a limit of 250 mg/l for chloride in drinking water to ensure safety and palatability. Regular monitoring and appropriate treatment measures are crucial to manage chloride levels, safeguarding water quality for consumption and protecting environmental health in Mal Municipality and beyond.

Among all the water pollutants present in the water samples collected from Mal municipality, Chloride and Sulphate are the two for which all the sample sites are showing a value well beneath the tolerance level of 250 mg/l. Four sample sites A, B, C and D have Chloride value of 75, 120, 135, 40 mg/l respectively. The average chloride value in water is 92.5 mg/l which is also within the BIS recommended limit.

Sulphate

Sulphate in water derives from natural mineral deposits, industrial discharges, and agricultural runoff. It is crucial to monitor sulphate levels as high concentrations can lead to a laxative effect and affect the taste of water. Additionally, sulphate can contribute to scaling in pipes and equipment. The Bureau of Indian Standards (BIS) recommends a limit of 200 mg/L for sulphate in drinking water to ensure safety and quality. Regular monitoring and appropriate treatment methods, such as ion exchange or reverse osmosis, help manage sulphate levels, ensuring water suitability for consumption and minimizing environmental impacts in Mal Municipality and beyond.

For Sulphate also, all the four values are remarkably low and within the BIS recommended tolerance limit. Highest sulphate concentration is found in site C. The value is 110 mg/l. In the other three sites values are below hundred. So, the average value of sulphate concentration in Mal municipality is 65.50 mg/l. The value is well below the BIS recommended tolerance level of 200 mg/l.

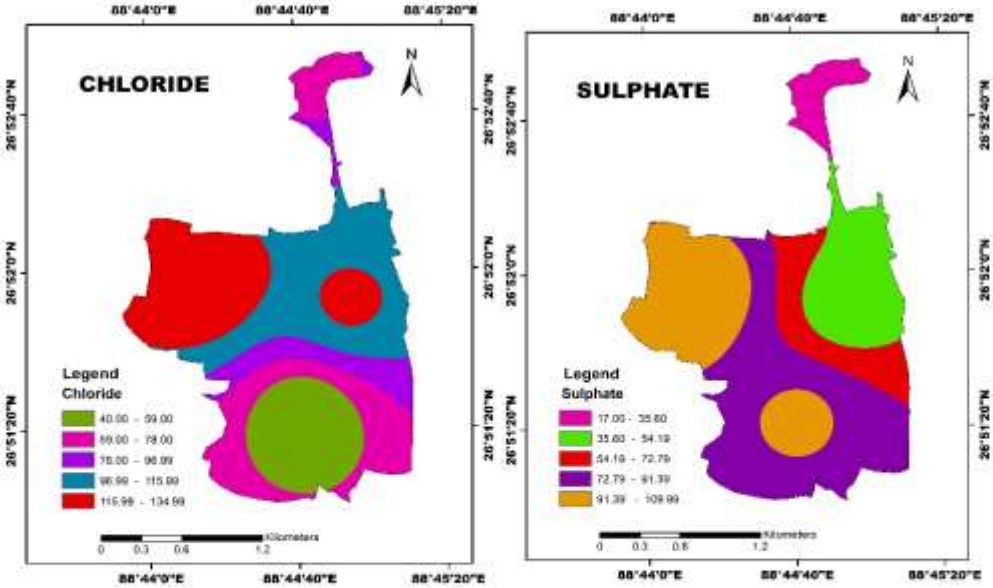

Fig. No.18 & 19: Variation of Chloride and Sulphate distribution

Groundwater quality index (GWQI)

Mal municipality is nested in the lap of eastern Himalaya by river Mal in the eastern side of the municipality. Total area of the municipality is 3.73 km^2. The whole area is divided into five classes on the basis of water quality index values. Keeping parity with the BIS guideline, GWQI value less than 25 is considered as excellent in terms of water quality. 26 to 50 GWQI value represents good quality of water. 51 to 75, 76 to 100 and greater than 100 GWQI values represent poor, very poor and unsuitable condition of water respectively in terms of water quality. In Mal municipality unsuitable condition of drinking water is found in the eastern part of the city. This result is anticipated as this region of the city is most densely populated as well as the proportion of built-up area is also very high here. Around 12.86% of the total area comes under this category. 64% of the total urban area, mostly covering central and southern part of the city falls under the category of very poor water quality. This area is also highly populated with dense built-up area. Poor water quality is found in the western part of the city covering around 17% of the total area. Northern part of the city has excellent and good quality of water but this area covers only 6.01% of the total area of the municipality. The northern most part of the city is comparatively less populated. Narrow shape of the municipal boundary here allows the natural vegetation to grow closer to the urban area. As a result, the quality of water is extremely good in this part of the city.

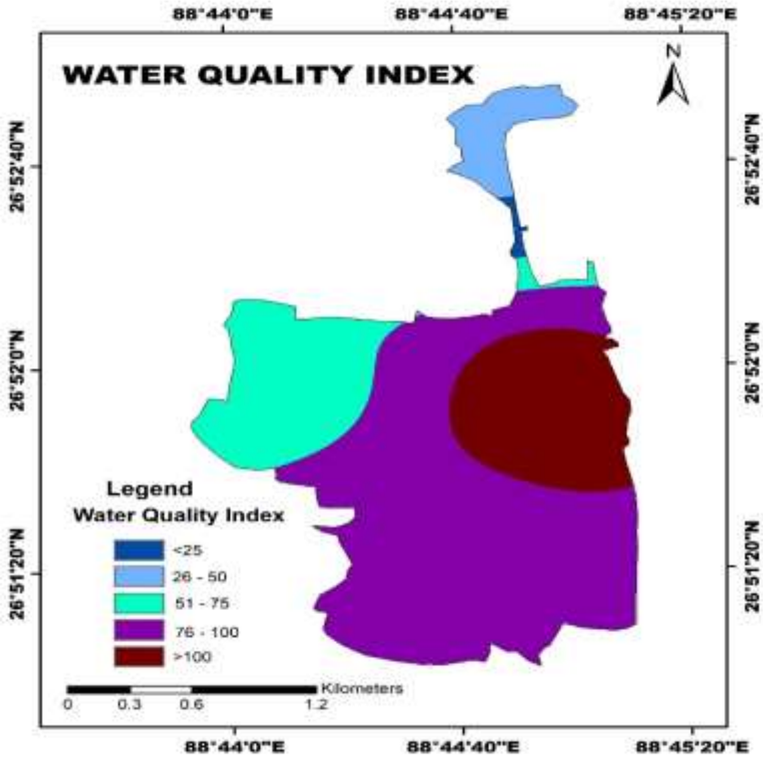

Fig. No.20: Groundwater Quality Index of Mal Municipality

Conclusion

The study of Land-use/Landcover (LULC) dynamics and Groundwater Quality Index (WQI) mapping in Mal Municipality reveals significant insights into the environmental health and sustainability of the region. Over the past few decades, Mal Municipality has experienced notable changes in land use and land cover, largely driven by urbanization, agricultural expansion, and deforestation. These alterations have profound implications for the region's water resources, influencing both the quantity and quality of water available to the community.

Mal Municipality has witnessed significant LULC changes over recent decades, primarily driven by urbanization, agricultural expansion, and deforestation. Urban areas have expanded, often encroaching upon agricultural lands and natural ecosystems such as forests and wetlands. Over the past two decades vegetation covers and surface water bodies are continuously decreasing whereas built up areas are increasing which clearly indicates the urban expansion of Mal Municipality. The reduction in forest cover has led to increased surface runoff, soil erosion, and a decline in natural groundwater recharge areas.

The Groundwater quality mapping shows spatial variation in water quality across the municipality, with some areas experiencing significant degradation. Key parameters affecting groundwater quality include pH, total dissolved solids (TDS), chloride, sulphates etc. Groundwater near urban and agricultural zones shows higher contamination levels due to inadequate waste management, excessive use of fertilizers, and improper sewage disposal.

The correlation between LULC changes and groundwater quality reveals that land use practices significantly influence groundwater conditions. Forested areas contribute to higher groundwater quality by acting as natural filters and promoting groundwater recharge. Conversely, urban and agricultural activities contribute to groundwater pollution through increased infiltration of contaminants from surface runoff and leaching.

In conclusion, the study of LULC dynamics and groundwater quality in Mal Municipality reveals a clear link between land use practices and groundwater health. Addressing the challenges posed by rapid urbanization and agricultural expansion requires a holistic approach that integrates sustainable land use, effective water management, and robust policy frameworks. By fostering collaboration among stakeholders and implementing adaptive management strategies, Mal Municipality can protect its groundwater resources, ensuring environmental sustainability and improved quality of life for its residents.

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Conflict of Interest
It is declared that there is no conflict of interest among the Authors of this work.

Data availability Statement
All data sets have been used here are available upon request to the corresponding author.

Ethics Approval Statement
This work does not involve any humans or animals.

Authors' Contribution
The conceptualization, data collection, testing, data analysis, draft manuscript writing has been made by first author whereas final editing, idea of techniques, verify the results and final manuscript editing have been made by corresponding author.

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