Review of Literature

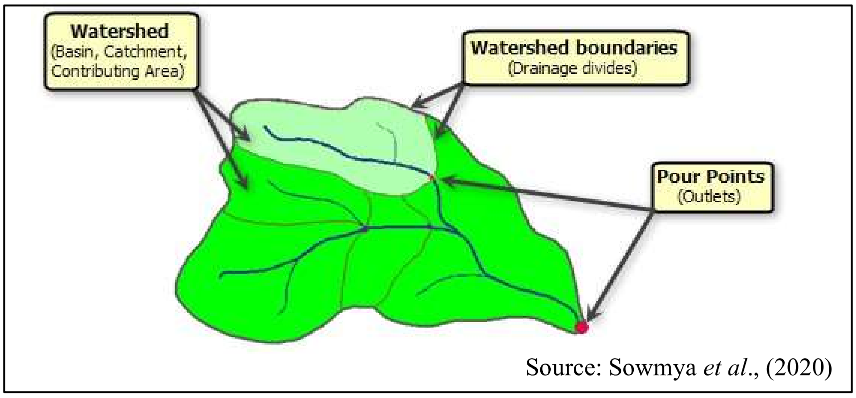
CHAPTER II

REVIEW OF LITERATURE

This chapter reviews the concepts of watershed, watershed development programmes, the impact assessment of watershed development projects and the indicators used for evaluation. It includes a detailed literature review on watershed delineation, morphometric characteristics of watershed, analysis of Land Use and Land Cover (LULC) changes, Normalized Difference Vegetation Index (NDVI) variations and changes in groundwater level analysed using GIS techniques and organized under specific subheadings.

2.1 WATERSHED

A watershed is a geographical area that drains to a common point, making it an ideal unit for conserving soil and optimizing the use of surface and groundwater for crop production. (Kerr *et al*., 2000). It is an integral unit as it connects soil, vegetation, water and human activities. This makes it a holistic system for managing natural resources, facilitating coordinated planning and sustainable practices to meet both environmental and human needs. Watershed management simplifies conservation efforts and land use management (Wani *et al.,* 2002). Fig 2.1 describes the watershed and its components. The boundary that separates one watershed from another is called a drainage divide. The specific point where water flows out of a watershed into the next is known as an outlet point or snap pour point.



Source: Sowmya *et al*., (2020)

Fig 2.1 Watershed components

2.1.1 Watershed development programmes

The importance of watershed development for rural growth has resulted in significant investments from central and state governments, NGOs and international agencies in watershed development programmes. These initiatives include different forms of watershed management activities, such as soil and moisture conservation techniques on farming areas (like contour bunds, terraces, and trenches), drainage line interventions (including loose boulder check dams, both minor and major check dams, and retaining walls) and water resource management strategies (which consist of percolation ponds, farm ponds, and drip and sprinkler irrigation systems). Additionally, there are crop production demonstrations, horticultural plant cultivation and reforestation efforts.

Since the early 1970s, the Government of India has launched and implemented various watershed development projects. Over time, the watershed approach in the country has advanced considerably. Several development programs, such as the Drought Prone Area Program (DPAP), Desert Development Program (DDP), River Valley Project (RVP), National Watershed Development Project for Rain-fed Areas (NWDPRA), and Integrated Wasteland Development Program (IWDP), have been introduced in various hydro-ecological regions that have consistently face water scarcity and drought-like situations. Moreover, NABARD-supported watershed initiatives are also being conducted in the state (Palanisami *et al*., 2009).

The Department of Soil Survey and Soil Conservation (DSSSC) in Kerala has been engaged in watershed projects and flood protection initiatives with financial support from NABARD under the RIDF project since 1995. The main objective of these efforts is to boost agricultural productivity in targeted watershed regions by employing soil and water conservation measures. These activities are aimed at addressing soil erosion, regulating water flow, conserving water resources, minimizing flood damage, and preventing saline intrusion, all of which contribute to enhancing agricultural yields.

The soil and water conservation measures such as stone pitched contour bunds, graded bunds, moisture conservation pits, continuous trenches, staggered trenches, farm ponds, dug-out ponds, check dams, retaining walls, sluices, ramp, roof water harvesting structures, live fencing, agro-forestry, agro-silvicultural measures, eco-restoration measures and drainage line protection works are generally proposed activities under this watershed development project (DSSSC, 2024).

2.1.2 Impact of watershed development programmes

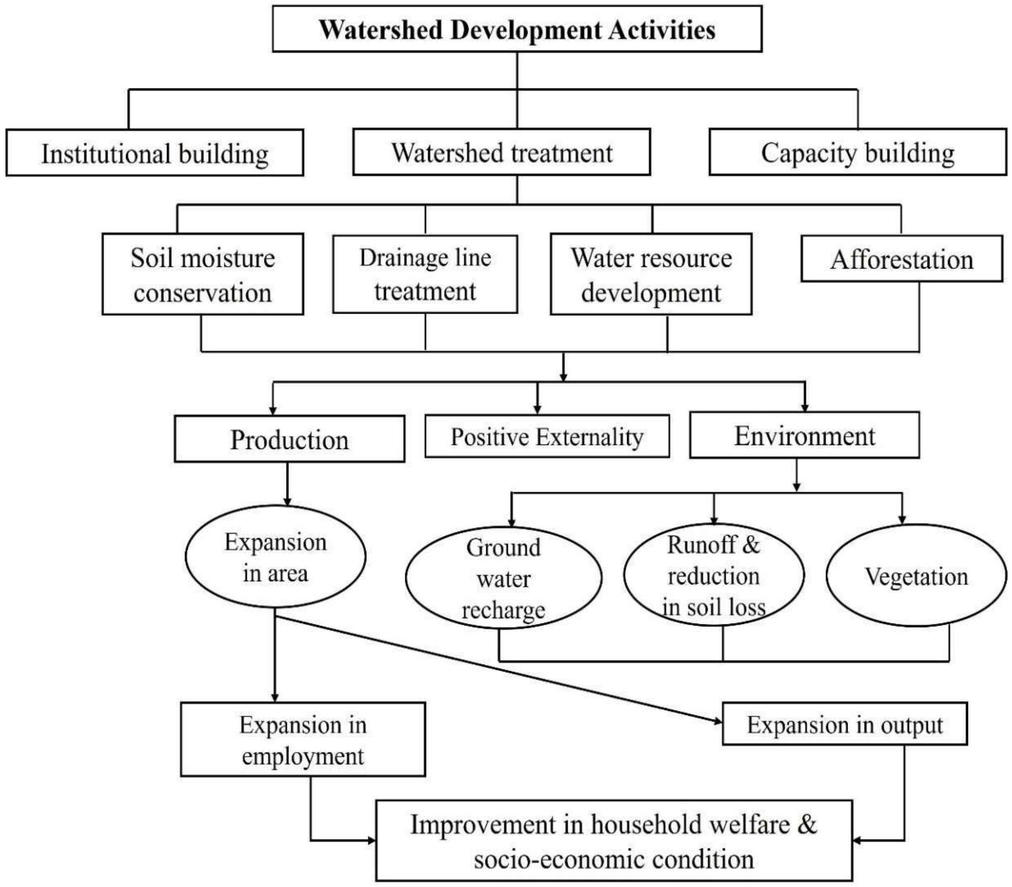
The watershed development programs influence different aspects like agricultural production system, environment and socioeconomic conditions of the watershed villages (Fig 2.2). The impacts of watershed development programs are as follows:

- Increased agricultural productivity
- Community involvement
- Improved socio-economic conditions
- Environmental benefits
- Better resource management
- Institutional development
- Sustainability

In conclusion, the development of watershed is essential for sustainable production of food, fodder and fuel wood, while also tackling social, economic and cultural challenges faced by rural communities. The advantages are not limited to those directly involved but also reach farmers who do not participate (Palanisami *et al.*, 2009).

2.1.3 Need for impact assessment

For any development project, proper planning, monitoring and evaluation are essential steps. Monitoring help track the progress of project activities, ensuring that they are being implemented as planned and within the designated timeframe. The absence of monitoring mechanism hinders midterm adjustments in ongoing programmes. Evaluation or impact assessment of watershed project provides critical data to assess the effectiveness, impact and sustainability, ensuring that the objectives are met and informing future improvements.



Source: Palanisami *et al*., (2009)

Fig 2.2 Framework for watershed impact assessment

It helps evaluate whether the project has achieved its objectives such as improving soil and water conservation, increasing agricultural productivity and enhancing resource management. Additionally, it ensures that resources were used efficiently and that the benefits justify the costs, promoting accountability and transparency to stakeholders. It provides valuable information that helps in making decisions about whether to expand, adjust, or discontinue a policy. This data also aids in determining the prioritization of public actions (Sharda *et al*. 2012).

2.1.4 Evaluation types and approaches

2.1.4.1 Types of evaluation

The project can be assessed either during its implementation phase (mid-term or ongoing evaluation) or after its completion. Ongoing evaluation consists of regular reviews of the monitored data to analyse trends, evaluate the project's progress and determine its relevance, current and future outputs and effectiveness during implementation. The emphasis is on evaluating the project design and objectives, measuring its effects and reviewing cost-effectiveness. This form of evaluation is oriented toward specific targets. Conversely, terminal evaluation is carried out after the project has been completed to assess its impact, success, or failure. The goal is to evaluate output of the project, effects and overall impact while extracting lessons for future planning and development. This type of evaluation is focused on benefits, as it examines the effects on the beneficiaries (Palanisami *et al*., 2009).

2.1.4.2 Approaches used for evaluation

The impact analysis can be conducted in two main ways. The first approach compares the parameters of the project during its implementation with the situation before the project, revealing the incremental benefits generated by the project. However, this method sometimes overestimates the benefits, as the improvements could also be influenced by the introduction of new technologies. The second approach compares the project parameters with those from a non-project control region, which helps adjust for the effect of the technology without the influence of project. This follows the "with and without" method. Some researchers combine both the "before and after" and "with and without" approaches to provide a more accurate assessment (Palanisami *et al*., 2009).

2.1.5 Indicators used for evaluation

Indicators are quantifiable measures used to evaluate changes in a condition, phenomenon, or quality over time. They serve as tools to monitor progress toward specific short-term, intermediate or long-term objectives. They offer a standardized framework for assessing the performance of activities in comparison to predefined targets. It is essential to differentiate indicators from targets, as targets define specific outcomes in terms of quantity and time, while indicators are tools used to monitor progress toward achieving those outcomes (Sharda *et al*. 2012).

A single indicator cannot comprehensively capture the success of a watershed development project thus, the most effective approach is to assess performance using multiple indicators. Table 2.1 shows the different types of indicators to be considered for impact assessment of watershed development project.

Table 2.1 Indicators to be considered for impact assessment

Natural resource Indicators	**Social Indicators**	**Economic Indicators**	**Institutional Indicators**
•Increase in the crop yield •Cropping pattern diversified •Drinking water availability •Ground water recharged, water quality •Productivity in Non- arable •Soil erosion reduced •Environmental Aspects	•Literacy rate •Drinking water facility •Housing pattern •Employment opportunities •Women Empowerment •Reduction in migration •Health centres, Dispensaries	•Household Income •Living standards •Changes in land prices •Increase in wage rates •Economic assets •NPV, BCR, IRR	•Formation and Functioning of SHGs/UGs/VWCs •Functioning, Action plan preparation, Training programmes, Beneficiary selection •Linkages among different groups •Convergence with other development programmes (MNREGA etc.) •Role,responsibility & cooperation among Govt, NGOs, other institutions.

Source: Sharda *et al.*, (2012)

2.1.6 Applications of RS and GIS

Remote sensing data is widely used in natural resource management, particularly for planning and monitoring of watershed projects. It provides data from various sensors and platforms with different spatial, temporal, radiometric and spectral resolutions. It offers several advantages over other methods such as large-scale coverage, a non-destructive nature, temporal monitoring, multispectral capabilities, cost-effective and rapid data acquisition. Therefore, this technique has become an effective tool for monitoring and evaluation of soil and water conservation measures implemented in watersheds (Abdulraheem *et al.*, 2023).

2.2 WATERSHED DELINEATION AND MORPHOMETRIC ANALYSIS

2.2.1 Watershed delineation

Thomas and Prasannakumar (2015) compared basin morphometry derived from topographic maps, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Shuttle Radar Topographic Mission Digital Elevation Models (SRTM DEM) for the Ithikkara River basin in Kerala to assess their accuracy for hydrological applications and terrain characterization and found that despite its coarser resolution, the SRTM DEM outperforms the ASTER DEM in terms of drainage delineation and basin morphometry. The variability in basin morphometry was attributed to differences in elevation, raster grid size, and the vertical accuracy of the DEMs, providing valuable insights into the challenges and considerations of using DEMs for hydrological studies.

Sowmya *et al.* (2020) used a 30m SRTM DEM to define 150 sub-watersheds in the Bangalore South region. They extracted outlet points from elevation data and calculated flow direction using a modified D8 algorithm. The stream network was created by combining the outlets and flow direction. Stream order was determined using Strahler's algorithm. The accuracy of the flow direction was 95.45 percent and the accuracy of the stream order method was 91.83 percent, which was compared with the Soil and Water Assessment Tool (SWAT) and Arc hydro tools.

Mishra *et al.* (2023) conducted a study in the Dhenkanal district of Odisha to identify, delineate, prioritize and plan for sustainable watershed management using RS and GIS. DEMs were used to visualize the terrain and identify drainage patterns, which were essential for managing water flow. ArcGIS software utilizing its Hydrology toolset, created key maps such as flow direction and accumulation to track water movement. The integration of DEMs and ArcGIS enabled the accurate delineation of watershed boundaries, helping identify areas that required management. Overall, the combination of these tools contributed to planning sustainable water resource management and addressing environmental challenges in Dhenkanal district.

Ragi and V (2023) carried out a study on watershed delineation and morphometric analysis using GIS and RS in Chittoor, Andhra Pradesh. By integrating remote sensing data, the study accurately delineated watersheds and examined their morphometric features, which play a crucial role in understanding hydrological behaviour. The findings emphasized the importance of advanced technologies in watershed management, providing a solid foundation for developing sustainable conservation strategies.

Ping *et al.* (2024) aimed to evaluate the effectiveness of three distinct DEMs (Contour-based DEM, SRTM DEM, and IFSAR (Interferometric Synthetic Aperture Radar) DEM) using ArcGIS software to assess their accuracy in delineating catchment areas across various locations. The study concluded that both Contour-based DEM and SRTM DEM were viable alternatives to IFSAR DEM, with less than a 3.5% variance in the delineated catchment areas across all tested locations. Among the alternatives, SRTM DEM showed superior performance, exhibiting higher accuracy as indicated by lower Root Mean Square Error (RMSE) values compared to the Contour-based DEM.

2.2.2 Morphometric characterization of watershed

Putty (2007) in his study analysed the quantitative aspects of the channel network geometry across 32 catchments, ranging in size from 13 km^2 to 1070 km^2 in Kaveri basin, Sahyadri ranges of Karnataka. The study provided a detailed understanding of the geomorphological characteristics of the upper Kaveri basin, confirmed the applicability of Horton’s laws, identified factors influencing drainage density and highlighted unique features of the region through comparative analysis.

Pareta and Pareta (2011) analysed the morphometric parameters of a watershed in the Yamuna basin using ASTER DEM data and GIS. This analysis revealed that the erosional development of the area had progressed beyond maturity and was influenced by lithology in shaping drainage patterns. The results offered important perspectives for designing rainwater harvesting systems and executing successful watershed management techniques.

Raj and Azeez (2012) conducted a study on the morphometric analysis of the Bharathapuzha River Basin (BRB) in Southern India. It provided essential baseline morphometric data for the BRB and its sub-basins. The BRB was classified as a seventh-order river basin with a dendritic drainage pattern. The mean stream length varied significantly, ranging from 0.69 to 166.17 km across different stream orders. The morphometric characteristics were influenced by the geology, slope and rainfall patterns. The linear aspects of the basin highlighted the role of relief, while the areal ratios reflected the elongated nature of the basin.

Vincy *et al.* (2012) conducted a study to examine the morphometric characteristics of the Tikovil and Payappara sub-watersheds of the Meenachil River basin in Kottayam district, Kerala using GIS techniques. It was found that the drainage network exhibited a dendritic to sub-dendritic pattern with stream orders ranging from fifth to sixth. The Payappara sub-watershed had a higher channel maintenance value (0.59), indicating fewer disturbances. The form factor values suggested an elongated shape for Payappara and a more circular shape for Tikovil. It was concluded that GIS techniques are effective for morphometric analysis, revealing the natural stream system characteristics in both sub-watersheds.

Sujatha *et al.* (2015) conducted a study focusing on the morphometric analysis of a sub-watershed in the Western Ghats using ASTER DEM data. The analysis revealed that the Palar sub-watershed exhibited a dendritic drainage pattern and a mean bifurcation ratio of 3.69 indicated structural control in stream network development. Variations in stream orders across micro-watersheds were attributed to local topography and geological disturbances, reflecting the complex evolution of the basin. It also suggested that the sub-watershed had high discharge capability but limited groundwater potential, which was crucial for watershed planning.

Bera *et al.* (2018) conducted a study to analyse the morphometric characteristics of the Adula River Basin, Maharashtra, India using ASTER DEM data to examine the basin’s stream networks, shape and relief and it was found that the Adula river showed a dendritic to sub-dendritic drainage pattern with a 4th-order stream and a mean bifurcation ratio of 5.36 indicating uniform geology. The basin had an elongated shape with a low overland flow (0.63) suggested moderately low surface runoff. The drainage density (0.79 km/km^2) and drainage texture (0.84) indicated permeable subsoil material.

Choudhari *et al.* (2018) conducted a study to extract morphometric parameters from the Mula River Basin using GIS techniques and to prioritize sub-watersheds for groundwater potential and conservation structures. It was divided into five sub-watersheds with a dendritic drainage pattern. Each morphometric parameter was ranked, with lower values indicating higher priority for conservation measures and the study identified suitable locations for conservation structures in the prioritized sub-watersheds, aiding in soil erosion prevention and effective land and water management.

Aziz *et al.* (2020) aimed to analyse the morphological features and basin properties of the Diyala River focusing on watershed delineation and morphometric parameters using GIS and delineated five sub-basins, each with different stream orders and drainage densities and the use of GIS allowed for the extraction of key basin characteristics, offering a detailed understanding of the region's hydrological structure. It provided valuable insights that can assist regional planners and policymakers in developing effective agricultural water management strategies and the results highlighted the importance of GIS and morphometric analysis for informed decision-making in watershed management.

Srinivas *et al.* (2023) conducted a study on the morphometric analysis of the Halayapura micro-watershed in Karnataka, India using geospatial techniques to evaluate its drainage characteristics and geo-hydrological behaviour and the results indicated that the micro-watershed has a stream order ranging from I to IV, with specific metrics such as drainage density and elongation ratio contributing to its elongated shape. This analysis was crucial for effective water resource management and planning recharge structures in the region.

Manikpuri and Tripati (2024) focused on the quantitative analysis of morphometric characteristics across 13 sub-watersheds of the Nawagarh watershed in the Mahanadi basin, Chhattisgarh using GIS. It was found that the Nawagarh watershed had a high drainage density of 0.80 km^{-1}, indicating a significant drainage network. The watershed showed a dendritic drainage network with 2760 streams and a high relief ratio in certain sub-watersheds suggesting rapid stream flow and increased erosion susceptibility. It also indicated that the watershed is elongated with low permeability affecting its hydrological response and the study highlighted the need for effective erosion control methods in the Nawagarh watershed to protect the land and manage hydrological responses effectively.

2.3 LAND USE LAND COVER (LULC) CHANGE ANALYSIS AND NDVI CHANGE DETECTION

2.3.1 Land use land cover (LULC)

Land is a vital natural resource encompassing soil, water and the associated flora and fauna, forming an integral part of the ecosystem. However, economic activities such as industrialization, urbanization and the conversion of forests into agricultural land have significantly exploited land resources, resulting in widespread land degradation. The changing patterns of Land Use Land Cover (LULC) serve as a key indicator of these transformations. (Jayakumar and Arockiasamy, 2003).

Land use refers to the ways in which humans utilize land for various economic activities. On the other hand, land cover describes the visible (bio)-physical features on the Earth's surface such as vegetation, artificial structures, bare rock, soil and water bodies etc. (Herold *et al.*, 2006).

LULC classification refers to distinguishing different land cover types using various classification techniques developed in the field of remote sensing. It assigns land cover classes to pixels and organizes them into categories. The primary objective of image classification is to automatically group all pixels in an image into specific land cover classes or themes (Alshari and Gawali, 2021).

LULC maps are often needed by planners and policymakers for effective decision-making and management at local, national, regional and global levels. It has been developed through various methods such as field-based surveys and the processing of remotely sensed images. RS technology has proven to be a practical and cost-effective method for accurately classifying LULC offering advantages like wide-area coverage, frequent revisits, multispectral and multisource data and digital storage, which facilitates future updates and compatibility with GIS systems.

It can be created using different tools and techniques at various scales to achieve different levels of accuracy. With the development of RS technologies, efforts have been made to improve the accuracy and consistency of these maps. Machine learning approaches have been used to generate LULC maps with varying degrees of accuracy by processing different satellite images (Singh *et al.*, 2021).

2.3.2 LULC classification and change detection

Shanwad *et al.* (2012) conducted a study to assess the impact of the Muchkulnal watershed development project in Gulbarga district, Karnataka using LISS-III satellite imagery to analyse LULC and NDVI changes over time. The analysis revealed an increase in double-cropped areas, indicating expanded irrigation, while previously rainfed and wasteland areas were converted into cultivated lands, particularly in scrublands and rabi-cropped regions. Wastelands in the sub-watershed decreased slightly by 36 ha. NDVI analysis highlighted the effectiveness of watershed development by showing improvements in vegetation cover and agricultural productivity over time and the study concluded that watershed development projects significantly contributed to rural development and poverty alleviation by enhancing resource management and socio-economic conditions in the targeted areas.

Ganasri and Dwarakish (2015) studied LULC changes in the Harangi catchment, Coorg District, Karnataka using LISS-III satellite imagery from 2007, 2010, and 2013. Their research evaluated three classification techniques such as Parallelepiped, Minimum distance to mean and Maximum likelihood algorithm based on their accuracy and kappa values. In 2013, the Maximum likelihood algorithm achieved the highest performance, with an accuracy of 89.36 percent and a kappa coefficient of 0.81, whereas the Minimum distance to mean algorithm recorded the lowest accuracy at 78.67 percent.

Rwanga and Ndambuki (2017) conducted a study to classify and map LULC in the Limpopo region, the northernmost part of South Africa using Landsat-8 images. The study focused on the accuracy of the classification process and identified major LULC classes such as agriculture (65.0 percent), built-up areas (18.3 percent), and water bodies (4.0 percent). The classification achieved an overall accuracy of 81.7 percent and a kappa coefficient of 0.722 reflecting substantial agreement.

Fahad *et al.* 2020 conducted a study to examine LULC changes in Baghdad, Iraq over a period of 28 years from 1990 to 2018 using Landsat Thematic Mapper (TM) and Operational Land Imager OLI 8 satellite images. The classification accuracy was found to be 85.11 percent and 88.14 percent. The study revealed that urban areas expanded by 3 percent and soil land levels increased by 20 percent. However, vegetation, wetlands, and water bodies declined by 5 percent, 17 percent and 1 percent respectively. It highlighted significant urban sprawl in Baghdad, leading to environmental challenges such as reduced vegetation and degraded water quality, emphasizing the need for effective urban planning strategies.

Naikoo *et al.* (2020) analysed LULC changes and built-up expansion in the suburbs of Delhi, India using Landsat datasets to study urban growth dynamics and its environmental implications. The study found that built-up areas increased by approximately 326 percent and open or fallow land grew by 44 percent, while agricultural land and vegetation cover decreased by 12 percent and 34 percent respectively during the study period. The rapid expansion of built-up areas indicated urban sprawl and heightened development pressures, highlighting the need for effective urban planning and management to address the challenges of rapid urbanization and its environmental impacts.

Reddy *et al.* (2021) conducted a study to assess the impact of watershed programs on LULC and NDVI in Srikakulam District, Andhra Pradesh using Linear Imaging Self-Scanning IV (LISS IV) satellite data from Resourcesat-2 to compare pre- and post-treatment land use changes. The study founded significant increases in cultivated land, with fallow land decreasing from 17922 ha to 11981 ha. Additionally, the area of water bodies increased due to rainwater conservation activities associated with the project. NDVI analysis indicated improvements in vegetation health and density and it concluded that in the Muddada watershed, the implemented Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)-Watershed programmes led to notable improvements in LULC and vegetation vigour.

Gull *et al.* (2022) investigated LULC changes in four key watersheds of the Kashmir Himalayas from 2003 to 2013 using Landsat 5 TM satellite images. The study employed the maximum likelihood algorithm for LULC classification, which revealed significant shifts in land cover, including a decrease in forest cover, river beds, water bodies, non-perennial snow and glaciers. In contrast, there was an increase in scrubland, horticulture, rock mass, built-up areas, barren land and agriculture, although scrubland decreased in the Sindh watershed. It highlighted the complex changes in LULC driven by deforestation, climate change and agroforestry expansion and emphasized the need for sustainable land-use practices and effective policy implementation in the region.

Kinattinkara *et al.* (2022) analysed LULC changes in the Noyyal watershed, Coimbatore over an 18-year period from 1999 to 2017 using Landsat satellite images. The study revealed a significant decrease in forest cover from 22.69 percent in 1999 to 6.09 percent in 2017 and a decline in agricultural land from 17.8 percent to 0.86 percent. Settlements increased from 15.59 percent to 27.14 percent, highlighting the impact of urbanization and industrialization, while barren land increased sharply from 17.2 percent to 50.93 percent due to deforestation. The LULC classification achieved an overall accuracy of 73.19 percent and a Kappa coefficient of 0.72, indicating strong agreement for the 2017 map.

Vilasan and Kapse (2022) monitored LULC changes in Ernakulam district, Kerala using RS and GIS techniques to assess land consumption rates and changes over recent years. The maximum likelihood classifier achieved LULC classification accuracies of 81.49 percent, 81.87 percent and 82.79 percent for 2006, 2011 and 2016 with kappa coefficients of 0.75, 0.75 and 0.77 indicating substantial accuracy. The results showed significant urbanization with built-up areas increasing from 8 percent in 2006 to 14 percent in 2016. Agricultural land decreased from 57 percent in 2006 to 50 percent in 2016, reflecting a shift toward non-agricultural uses. It emphasized the need for sustainable land-use strategies to manage urban expansion and protect natural resources, suggesting the integration of ecological preservation into LULC management and further research using high-resolution data to enhance findings.

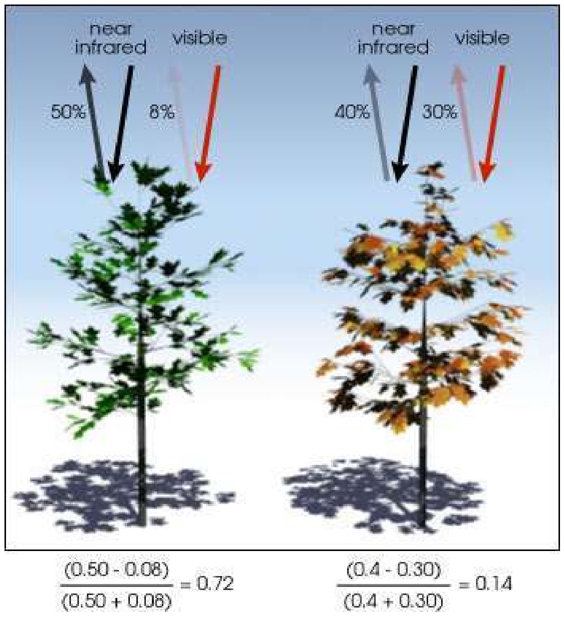
Mani *et al.* (2023) analysed LULC dynamics in selected watersheds of Malappuram district, Kerala focusing on the effects of floods and changing land use patterns on soil erosion and landslides. The study identified significant land use changes between 2013 and 2020 including a decline in plantation, paddy and mixed plantation areas along with an increase in barren and waste land. The LULC classification demonstrated high accuracy, with overall accuracies of 84.93 percent (2013), 86.21 percent (2018) and 87.5 percent (2020) and Kappa values indicated strong agreement. The findings suggested that the reduction in agricultural land types and the expansion of barren areas had heightened disaster risks in the region. To address these risks, the study recommended measures such as afforestation with trees and grasses (e.g., shrubs and vetiver grass), the construction of ponds, the development of green walls and the creation of vegetation clusters in high-risk zones based on their categorization.

2.3.3 Normalized difference vegetation index (NDVI)

The NDVI is one of the most commonly used indices for detecting living green vegetation in multispectral remote sensing data. NDVI identifies vegetation and measures the photosynthetic potential of forest canopies. It is widely used around the world to monitor and predict agricultural productivity, drought conditions, help identify high-risk fire zones, and map desert expansion (Jackson and Huete, 1991).

To evaluate the vegetation density in a specific area, the unique wavelengths of visible and near-infrared light that plants reflect are examined. When sunlight strikes objects, certain wavelengths are absorbed while others are reflected. Chlorophyll in plant leaves absorbs visible light (0.4 to 0.7 μm) for photosynthesis, while the cellular structure of the leaves strongly reflects near-infrared light (0.7 to 1.1 μm). The more leaves a plant has, the more these light wavelengths are influenced.

NDVI is calculated by comparing the visible and near-infrared (NIR) light reflected by vegetation. Fig 2.3 illustrates the NDVI measurement in RS, where healthy vegetation (left) absorbs most visible light and reflects more NIR light, while unhealthy or sparse vegetation (right) reflects more visible light and less NIR light (NASA Earth Observatory, 2000).



Source: NASA Earth Observatory, 2000

Fig 2.3 Example for NDVI calculation

NDVI is calculated as,

NDVI = (NIR – RED)/ (NIR + RED) …Eqn.1

Where, NIR and RED represents Near Infrared and Red light respectively.

The NDVI values range from -1 to 1. Negative values (closer to -1) are associated with water, while values near zero (-0.1 to 0.1) typically correspond to barren land such as rock, sand or snow. Low positive values (around 0.2 to 0.4) are linked to shrubland and grasslands, whereas high values (near 1) indicate temperate and tropical rainforests.

Gandhi *et al.* 2015 aimed to enhance change detection methods for analysing satellite images using the NDVI to classify land cover and assess vegetation changes over time. The research revealed that NDVI effectively detected surface features, aiding in land cover classification. From 2001 to 2006, forest and shrubland decreased by 6 percent and barren land by 23 percent while agricultural land, built-up areas and water bodies increased by 19 percent, 4 percent and 7 percent respectively. It was concluded that the NDVI method was valuable for policymakers in decision-making, disaster prediction, and developing protective strategies based on vegetation analysis.

Sha *et al*. (2020) investigated the impact of climate change on vegetation health and productivity in Kerala using the NDVI as a key measure. NDVI estimation was performed using the NIR and visible bands of Landsat-8 satellite data. The research revealed a significant correlation between NDVI, temperature and precipitation indicating that both natural climate variability and human activities affected vegetation. It concluded that Kerala had been experiencing drastic climate changes, leading to increased occurrences of floods and landslides, which threatened both vegetation and human livelihoods.

Sohail *et al*. (2020) conducted a study to classify urban vegetation in Karachi using NDVI through RS and GIS techniques based on Landsat 8 satellite images. The study found that only 5% of the total study area (3633 km^2) was vegetated, with sparse to no vegetation prevailing due to the region's climatic conditions. Dense vegetation was particularly scarce in urban areas. It highlighted the effectiveness of remote sensing for vegetation assessment and land use classification and emphasized the need for urban plantation and the development of green areas to improve urban ecosystem in Karachi.

Thangavelu *et al*. (2021) used NDVI to analyse changes in vegetation cover along the Kannur coast, Kerala over three time periods 1979, 1999 and 2019. The NDVI values revealed a decline in vegetation cover, with the highest index recorded in 1979 (68.42 percent) and the lowest in 2019 (51.23 percent). NDVI proved essential for monitoring coastal vegetation dynamics, offering insights into the ecological health and the effects of human activities and natural processes on coastal environments.

Nalawade *et al*. (2022) conducted a study on vegetation change detection in Nashik City, Maharashtra from 2001 to 2021 using RS and GIS tools to examine changes in vegetation cover through the NDVI. In Nashik City, the study found a decrease in high-density vegetation from 11.66 percent to 5.54 percent and an increase in very low-density vegetation from 25.51 percent to 55.87 percent over the study period. The decline in vegetation in urban areas like Nashik underscored the need for sustainable urban planning and conservation strategies to mitigate the adverse effects of urbanization on the environment. This method proved effective in assessing urban vegetation dynamics, which were crucial for understanding the impacts of urbanization on natural environments.

2.4 ASSESSMENT OF GROUNDWATER LEVEL CHANGE

2.4.1 Groundwater

Groundwater is a vital natural resource, typically found as fresh water and plays a crucial role in meeting the demands of domestic, industrial and agricultural sectors. Many agriculture-based countries rely on groundwater for irrigation. However, rapid population growth, urbanization, the decline of flora and fauna and other factors have altered climate and rainfall patterns, leading to putting more pressure on groundwater resources across the world. This stress is particularly pronounced in arid and semi-arid regions, where excessive groundwater extraction is contributing to a continuous decline in groundwater levels (GWLs) (Wakode *et al.*, 2018).

India is an agricultural nation, with over 70 percent of its population relying on agriculture as reported by the Food and Agriculture Organization (FAO) of the United Nations. A significant portion of irrigation in the country relies on groundwater resources. The countries leading in irrigated land area include China (73 million hectares), India (70 million hectares), the USA (27 million hectares), and Pakistan (20 million hectares). There is a significant variation in the percentage of total groundwater extraction used for irrigation among these nations. India stands as the largest global consumer of groundwater, with an estimated annual extraction of 251 cubic kilometers, where an impressive 89 percent is dedicated to irrigation purposes (Pointet, 2022).

Typically, a decrease in precipitation results in less water available for replenishing groundwater. The groundwater level (GWL) has been falling due to over-extraction and mismanagement of groundwater resources. In the last ten years, there has been a need for deeper boreholes to extract groundwater, either because existing shallow boreholes have ceased to function or because additional effort is required to pump water during the summer months, despite it being available at shallower depths during the monsoon and post-monsoon seasons. This suggests that the GWL declines in the pre-monsoon period and gets replenished during the monsoon season. Soil and water conservation efforts play a significant role in groundwater management by enhancing the recharge rate and curbing depletion. Thus, it is essential to analyse the fluctuations in rainfall and GWL to gain a better insight into the problem of GWL depletion (Choudhary *et al*., 2024).

2.4.2 Spatial and temporal changes of groundwater

Sumiya and Khatun (2016) studied the relationship between groundwater levels, rainfall variability, and the use of groundwater for rice irrigation in Bangladesh. They presented the changing patterns of groundwater levels using maps created through the Inverse Distance Weighted (IDW) interpolation method in ArcGIS 10.3. The analysis revealed a growing reliance on groundwater over surface water for irrigation across the country, with groundwater levels declining more rapidly in the northern regions compared to the southern parts. The study emphasized the need for sustainable groundwater management to address the challenges posed by varying rainfall and extensive irrigation practices.

Palanichamy (2017) investigated groundwater levels and fluctuations in Tiruchirappalli District, Tamil Nadu using GIS to evaluate long-term groundwater data and assess the dynamics of groundwater in relation to recharge and discharge factors. The results indicated notable seasonal fluctuations in groundwater levels, which varied between 4 and 12 meters in the pre-monsoon season and from 3 to 9 meters in the post-monsoon season during the period from 1990 to 2011. Spatial variation maps generated through spline interpolation in ArcGIS depicted changes in groundwater levels over time and concluded that understanding groundwater fluctuations was essential for planning sustainable groundwater management, particularly in regions with complex terrain and poor water quality.

Sajeena and Kurien (2017) analysed the spatial and temporal variations in groundwater levels of dug wells and bore wells in Kadalundi river basin, Malappuram district, Kerala using ArcGIS to evaluate the hydrogeological characteristics of aquifer formations and assess the correlation between groundwater levels and rainfall using visual MODFLOW. The study found that groundwater level fluctuations in lowland, midland and highland areas were generally correlated with rainfall. Hydraulic continuity studies showed that groundwater and surface water were hydraulically connected between aquifers of dug wells and bore wells in most of the study area.

However, in some parts, piezometric water level variations were poorly correlated with rainfall, indicating a lack of hydraulic continuity, making these areas more suitable for deep bore wells and it concluded that understanding local hydrogeological conditions is crucial for effective groundwater management and well placement, particularly in regions with varying groundwater-surface water interactions.

Venkatesan *et al.* (2021) analysed the impact of precipitation variability on groundwater level fluctuations in Vellore district, Tamil Nadu using geospatial techniques. It found that the average annual precipitation in the region was 913.6 mm, with significant seasonal and spatial variations. Precipitation was highest during the southwest and northeast monsoon seasons, with northern areas receiving more rainfall during the southwest monsoon and southern areas receiving more during the northeast monsoon, while post-monsoon precipitation was minimal at around 10.8 mm. Groundwater levels exhibited notable fluctuations, peaking in December and declining by June which indicated a strong correlation with precipitation patterns. It highlighted the significance of comprehending these precipitation patterns for the efficient management of groundwater resources and stressed the vital role of spatiotemporal analysis.

Kumar (2022) carried out a study to analyse groundwater table variations in Thanjavur district before and after the monsoon seasons, focusing on the factors that influenced groundwater levels and quality. It found notable variations in groundwater levels, with the highest decrease reaching 2 meters and indicated that over 50 percent of the region is at risk of excessive exploitation. Geological features, types of soil, elevation and patterns of land use were recognized as essential factors influencing groundwater levels, while quality was affected by saline intrusion and runoff from agriculture. It recommended implementing effective monitoring systems, utilizing efficient irrigation methods and creating structures for groundwater recharge to guarantee the sustainable management of groundwater resources.

Sheeja *et al.* (2022) examined changes in groundwater levels and quality in the coastal aquifers of the Vatakara-Koyilandy stretch in the Kozhikode district, Kerala, India over a 15-year period. The study identified significant alterations in groundwater quality and levels, mainly caused by seawater intrusion and anthropogenic factors.

Hydrogeochemical analyses and spatial variability assessments were applied to investigate these changes. The Piper diagram illustrated shifts in hydrochemical parameters of groundwater sources from 2005 to 2020, highlighting changes in chemical composition. The Gibbs diagram was used to identify the sources of dissolved ions in the groundwater. The spatial variations in water table elevation and salinity were analysed using ordinary kriging interpolation. The findings showed an increase in seawater intrusion, which raised salinity levels in the groundwater, making it less suitable for both irrigation and drinking. It recommended implementing effective management strategies to mitigate seawater intrusion and improve groundwater quality.

Akhtar and Hasnat (2023) examined changes in groundwater levels in the Haryana and Punjab regions of the Indus basin, India from 1996 to 2019. The study aimed to evaluate variations in GWLs using the ordinary kriging method and to assess trends using the Mann-Kendall trend analysis. The results showed significant depletion of groundwater, especially in the southwestern-central and western-northern areas with an average decline of 40.36 cm/year, which decreased to 37.42 cm/year by the end of the study. From 2014 to 2019, the area with high- and low-rate depletion increased by 0.90 percent and 2.17 percent respectively. The kriging method proved reliable, confirming the results. The study concluded that groundwater depletion is a serious issue, particularly in high-depletion areas, and highlighted the need for effective groundwater management strategies. The methods used were helpful in understanding groundwater level trends and will inform future research and policy decisions.

Guchhait *et al.* (2023) conducted a study to assess the impact of groundwater fluctuations from pre-monsoon to post-monsoon on agricultural production in West Bengal, India. It identified a positive relationship between groundwater availability and crop production, with significant fluctuations observed in several districts of South Bengal. In most districts, groundwater levels fluctuated by over 2 meters, indicating that seasonal rainfall significantly influenced groundwater levels and agricultural output. It concluded that groundwater fluctuations were a critical factor affecting agricultural uncertainty in the region, emphasizing the importance of monsoon rainfall in determining crop production.

Choudhary and Singh (2024) conducted a study to analyse spatial and temporal changes in rainfall and groundwater levels in the Bhagalpur and Khagaria districts of Bihar focusing on the impacts of groundwater overexploitation. The study employed GIS tools, graphical plots and statistical methods including the Mann-Kendall and Sen's slope estimator tests, to analyse rainfall and groundwater levels from 1996 to 2020. The results showed a decreasing trend in rainfall at a rate of 25.05 mm/year across the study area. Pre-monsoon groundwater levels declined at rates between 0.005 to 0.102 m/year, while post-monsoon levels increased near the River Ganga. The analysis revealed significant spatial and temporal variations in both rainfall and groundwater levels, highlighting a concerning trend of decreasing rainfall and groundwater depletion.

Dhaloiya and Singh (2024) conducted a study to assess the dynamic behaviour of GWLs in the southwestern districts of Punjab, India focusing on the spatial and temporal distribution of waterlogged and overexploited areas before and after the monsoon season. It analysed 48 years of GWL data (1973-2020) and utilized GIS to map and visualize groundwater level fluctuations across the study area. The results showed that the maximum waterlogged areas occurred in different years, with Fazilka district having approximately one-third of its area waterlogged in 2020. It identified 45 areas at risk of overexploitation, 46 areas considered safe and 9 areas either waterlogged or at risk of waterlogging. It emphasized the need for effective management strategies to mitigate the impacts of waterlogging and prevent further expansion. The detailed maps created in the study could help predict and manage future groundwater resource scenarios.