TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS
DEPARTMENT OF CIVIL ENGINEERING

FINAL YEAR PROJECT REPORT on “DELINEATION OF GROUND WATER RECHARGE POTENTIAL ZONES OF CHITWAN DISTRICT”

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Supervisor:

Assoc. Prof. Dr. Suraj Lamichhane

APRIL 2023

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IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR DEGREE IN CIVIL ENGINEERING

(Course Code: CE755)

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CERTIFICATE OF APPROVAL

This is to certify that this project work entitled “**DELINEATION OF GROUND WATER RECHARGE POTENTIAL ZONES OF CHITWAN DISTRICT.**” has been examined and declared successful for the fulfillment of academic requirement towards the completion of Bachelor Degree in Civil Engineering

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ABSTRACT

This research analyzes the ground water recharge potential and identifies the high ground water recharge potential zones in Chitwan district. The calculation and estimation of groundwater recharge is the way to understand the groundwater reservoir and forecast its potential accessibility. The main objective of this study is to assess the groundwater recharge and its controlling factors at Chitwan District included as Rapti and Narayani catchment basin. Groundwater recharge process is crucial for maintaining the water balance in an area and securing sustainable water supply for drinking, agriculture and industrial purposes and it is also very necessary for the management of both surface and subsurface water resources. Our study uses the application of analytical hierarchical process (AHP) on geospatial analysis for the exploration of potential zones for artificial groundwater recharge. Various aspects of earth surface features such as geology, geomorphology, soil types, land use and land cover, slope, aspect, precipitation, population density, elevation etc. are taken in consideration that influence the groundwater recharge in either direct or indirect way. These thematic layers are prepared and extracted using population data, Landsat 8 image, topographical map, and various other data sources. Weighted analysis and union of data obtained is used for formation of recharge map in this study. A pair-wise matrix analytical method is used to calculate the geometric mean and normalized weight of individual parameters also known as AHP analysis. Further, the normalized weighted layers are mathematically overlaid for preparation of groundwater recharge potential zone map. The results reveals that around 133.17 sq. km (6%) of total area has been identified as high potential zone for groundwater recharge. The forest areas in central part and south western part have high potential for groundwater recharge. Hilly and mountain terrains in north Mahabharata range are considered as unsuitable zone with very low groundwater recharge potential.

Keywords: Groundwater, Potential, AHP, Recharge

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LIST OF ACRONYMS AND SYMBOLS

GIS	Geographic Information System
AHP	Analytical Hierarchical Process
DEM	Digital Elevation Model
LULC	Land Use Land Cover
UNESCO	Land Use Land Cover
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
USGS	United States Geological Survey
SOTER	Soil and Terrain
FAO	Food and Agricultural Organization
ALOS	Advanced Land Observing Satellite
ASF	Alaska Satellite Facility
IDW	Inverse Distance Weighted
ICIMOD	International Centre for Integrated Mountain Development
WSV	Weighted Sum value
λmax	Maximum eigenvalue of the pairwise comparison matrix
CI	Consistency Index
CR	Consistency Ratio
RI	Random Consistency Index
CGWB	Central Ground Water Board, Government of India
GWPRA	Groundwater Potential Recharge Area
CMe	Eutric Combisols
CMg	Gleyic Combisols
RGd	Dystric Regosols
PHh	Haplic Phaeozems
GLe	Eutric Gleysols
DHM	Department of Hydrology and Metrology
GON	Government of Nepal
GWR	Groundwater recharge
ET	Evapotranspiration

P	Precipitation
PET	Potential evapotranspiration
AET	Actual evapotranspiration
GW	Groundwater
SW	Surface water

1. INTRODUCTION

1.1 Background

In the world scenario, some region, have abundant groundwater resources, while others are experiencing significant challenges due to overuse, contamination, or other issues. According to the United Nations, more than two billion people currently living in the countries experiencing high water stress, and by 2050, about five billion people could be affected. This stress is due to population growth, urbanization, climate change, unsustainable water management practices. According to the "Global groundwater sustainability assessment" by Wada et al. (2017), groundwater provides around 25% of the world's total freshwater consumption providing drinking water to over 2 billion people and supporting irrigation for approximately 40% of global food production. According to the World Bank, the world's demand for freshwater is expected to exceed supply by 40% by 2030 highlighting need of sustainable water management practice. In the world scenario, some region, have abundant groundwater resources, while others are experiencing significant challenges due to overuse, contamination, or other issues. Groundwater is the renewable reserve of freshwater in many cases is stored in aquifers. Groundwater is also the primary source of water for river during dry season, particularly when the rainfall is nominal.

According to the Nepal National Water Plan (2018), estimates that around 10% of Nepal's population depends on groundwater for drinking water, while around 30% of the country's irrigated agriculture is supplied by groundwater. According to a study published in the Hydrogeology Journal, the groundwater recharge in Nepal is estimated to be approximately 12.8 billion cubic meters per year. According to a report by the Department of Water Supply and Sewerage, groundwater levels in Kathmandu Valley have been declining at a rate of 0.75 to 1.5 meters per year due to over-extraction and lack of recharge zone particularly in urban areas. Groundwater impacts the socio-economic health of the urban areas. The urbanization process affects the quality and quantity of groundwater. Due to the population growth, forest is converting into agricultural land, residential area, supermarket etc. People use high amount of chemical fertilizer and pesticides in farming which contaminates the groundwater as well as surface water. Such a change has affect directly or indirectly on the socio-economic conditions as well as eco-environment of the surroundings. This is true for Chitwan district, one of the fastest growing urbanization location in Nepal.

According to a study titled "Assessment of Groundwater Resources of Chitwan District, Nepal" by Pandey et al. (2017), total groundwater abstraction in Chitwan district is around 56 million cubic meters per year, with the majority of this groundwater use (around 85%) for irrigation purposes and remaining 15% used for domestic and industrial purposes. According to a study published in the International Journal of Environmental Research and Public Health, the groundwater level in the district has been declining at a rate of 0.5 to 1 meter per year due to over-extraction, particularly in the dry season. Over six million people relay on groundwater as main source of water supply in Chitwan district. Groundwater is obtained from tube wells, hand pumps, dug wells while surface water is obtained from rivers, streams, and ponds. Due to rapid urbanization the catchment is resulting in increase in run-off and decrease in groundwater recharge Thapa et al. (2018). Groundwater level is depleting in Chitwan due to the combination of land use /cover (LULC) change and excessive pumping. Hence due to population growth and urbanization the demand of water is increasing day by day, so the groundwater table of Chitwan is decreasing rapidly. We cannot mitigate the extraction of water but we can increase the recharge of groundwater to balance the extraction. We have to increase the recharge in the location which has high capacity to infiltrate and hold groundwater, but still nobody knows the exact location which has high potential to have groundwater recharge. Our study shows the location which has high potential to have ground water recharge and hence it would be easy to preserve such places to mitigate the scarcity of drinking water in nearby future in Chitwan district.

Many study has been done in national and international level in groundwater recharge potential mapping. In Nepal, several studies have been conducted in Kathmandu Valley, including a study by Lamichhane et.al (2019) that assessed the alteration of groundwater recharge areas due to land use/cover (LULC) change in Kathmandu valley, Nepal. Khadka et.al (2019) that assessed the potential for artificial groundwater recharge using the soil aquifer treatment method. In India, a study by Sharma et.al (2018) assessed the potential for groundwater recharge in western Rajasthan region using the combination of remote sensing and GIS techniques. Kaliraj et.al (2014) assessed the identification of potential groundwater recharge zones in Verigas Upper Basin, Tamil Nadu, and using GIS based analytical hierarchical process (AHP) techniques.

In Chitwan, research has been conducted on ground water recharge potential mapping. They are “Assessment of ground water recharge potential in Chitwan district, Nepal” by Chuju et al. (2015), “Assessment of ground water recharge potential in Chitwan valley, Nepal” by K.Shrestha and Chalise et al. (2014), “Ground water recharge potential mapping of western Chitwan, Nepal using remote sensing and GIS technique” by S.R Ghimire et.al (2014).They has considered various parameters such as: land use land cover, soil, slope, rainfall, drainage and geology. The study used data from multiple sources including remote sensing images and geographic information system (GIS) data to map the recharge potential. The authors identified that the recharge potential is higher in areas with sandy soils, low slopes, higher rainfall, forest cover and areas with impermeable soils, high slope and urban or agricultural land use has lower recharge potential.

Although many research has been conducted on ground water recharge potential in Chitwan, a comprehensive study has not been done yet. So our study on ground water recharge potential on Chitwan district is broad and we have consider the parameters such as: LULC, soil, precipitation, slope, elevation, aspect, river distance population density and road distance. In the present study, we have used nine layers for weightage purpose and these layers have been assigned with appropriate weightage using AHP analysis. This approach is more reliable in delineation of ground water potential zones as these concept deals with systematic allocation of weights through AHP method and weighted overlay analysis technique in GIS platform.

1.2 Statement of Problem

i) According to a study titled "Assessment of Groundwater Resources of Chitwan District, Nepal" by Pandey et al. (2017), total groundwater abstraction in Chitwan district is around 56 million cubic meters per year, with the majority of this groundwater use (around 85%) for irrigation purposes and remaining 15% used for domestic and industrial purposes whose quality is degrading day by day.

ii) According to a study published in the International Journal of Environmental Research and Public Health, the groundwater level in the district has been declining at a rate of 0.5 to 1 meter per year due to over-extraction, and impact of climate change.

iii) The rate of ground water extraction exceeds the rate of ground water recharge which must be balanced to maintain ground water table.

iv) Delineation of ground water recharge zone helps to identify the highly rechargeable zones which will assist for the conservation of those areas and also for the research and studies related to ground water and its preservation.

1.3 Objectives of study

The main objective of this study is to identify and map areas with high potential for ground water recharge.

The specific objectives to fulfill the main objectives are:

i) To generate thematic layer maps for every factors affecting groundwater recharge potential.

ii) To identify layers and its weightage influencing recharge potential.

iii) To delineate ground water recharge potential zones.

1.4 Scope of Study

This study is mainly focused on the mapping of groundwater recharge potential zone and identifying zone with high recharge potential.

The study covers the following scope of works.

i) To evaluate hydrological characteristics of the study area.
ii) To determine climate and precipitation patterns.
iii) To assess Land use and land cover of the study area.
iv) To assess effect of various factors on groundwater recharge potential.
v) To assess groundwater quality and groundwater availability.

1.5 Essence of study

This study helps to evaluate groundwater recharge potential of study area and to locate artificial recharge station. Further this study:

i) Helps to evaluate groundwater availability.
ii) Helps to predict future groundwater availability.
iii) Helps to understand impacts of human activities in groundwater recharge potential.
iv) Helps to develop sustainable groundwater management strategies.
v) Helps in protection of water resources.

1.6 Limitation of study

i) **Data availability:** Limited availability of reliable data on precipitation, groundwater levels, and soil properties can limit the accuracy and precision of recharge estimates. Population data taken is of Census 2011 as of census 2021 is not available. Most of data's used are international data.

ii) **Spatial and temporal variability:** Groundwater recharge rates and patterns can vary greatly in space and time due to factors such as soil type, topography, and weather conditions, making it difficult to obtain a representative picture of the recharge pattern.

iii) **Complexity of the hydrological system:** The hydrological system is complex, and groundwater recharge is influenced by a range of interrelated factors, including geology, land use, and climate, making it difficult to isolate the impact of individual factors on the recharge pattern.

iv) **Cost and logistics:** Conducting field studies to measure groundwater recharge can be expensive, time-consuming, and logistically challenging, especially in remote or difficult-to-access areas.

v) **Lack of understanding:** Despite extensive research, there is still a lack of understanding of some aspects of groundwater recharge processes, such as the role of deep percolation, preferential flow, and the impact of climate change on recharge rates and patterns.

1.7 Organization of the Report

There are six chapters in this project report briefed below in order.

Chapter 1: Introduction

This chapter incorporates introduction with general Background, Statement of problem, Objective of Study, Scope of study, Essence of study and Limitations of the study.

Chapter 2: Literature review

This chapter provides the summary of literature reviewed during the course of this thesis.

Chapter 3: Study Area

This chapter provides description of study area selected for this study.

Chapter 4: Methodology

This chapter contains methodology of research which includes generation of various thematic layers and analysis by AHP method.

Chapter 5: Results and Discussion

This chapter includes the results obtained and their discussion, recommendations and limitation of analysis.

Chapter 6: Conclusion and Recommendations

This chapter includes the conclusion of the study showing how the research objectives were fulfilled by this study and recommendations for the overcoming of limitations for future.

Copyright, Acknowledgement, Approval Page, Abstract and abbreviations, List of Figures, List of Table and Table of Content are given in preface section. References and Annexes are attached at the end of this report.

2. LITERATURE REVIEW

2.1 Selection of Factors Influencing Groundwater Recharge Potential

Groundwater recharge potential is a critical factor in sustainable water resource management as it determines the recharge potential of various zones in area and various studies have investigated the influencing factors for identifying groundwater recharge potential zones. The study by (T. A. Duguma et al., 2021; G. A. Duguma et al., 2021) on the Upper Blue Nile River Basin in Ethiopia identified several factors for assessing groundwater potential zones, including geomorphology, geology/lithology, digital elevation method, land use/land cover, soil texture, lineament density, drainage density, annual rainfall, slope, and soil type. In the article "Flood Susceptibility Analysis in the West Rapti River Basin Using Frequency Ratio Model" by Bhattarai et al. (2022) and Ghimire et al. (2022), factors such as lithology, land use, distance from river, soil texture, slope angle, slope aspect, plan curvature, topographic wetness index, drainage density, altitude, and rainfall were identified as influencing groundwater recharge potential. (S. Shrestha et al., 2020) evaluated groundwater recharge potential in the Far Western Middle Mountain of Nepal and selected drainage density, land use/land cover, lineament density, lithology, slope gradient, and rainfall as the influencing factors. S. Kaliraj et al. (2012) studied the Vaigai upper basin in Tamil Nadu, India, and identified lineament density, drainage density, slope, soil permeability, soil texture, soil depth, aquifer, annual rainfall, land use/land cover, geology, and geomorphology as the influencing factors. A. H. Nasution et al. (2020) studied the groundwater basin of Majalengka Regency and identified lithology, rainfall, land use, soil texture, flow density, slope, and elevation as the influencing factors. R. Palaka et al. (2015); G. Jai Sankar et al. (2015) investigated the Kosigi Mandal in Kurnool District, India, and identified drainage density, land use/land cover map, lineament density map, and geomorphology map as the influencing factors. H. Allafta et al. (2015) studied the Shatt Al-Arab Basin and identified lithology, geomorphology, slope, drainage density, distance from the river, soil, and land use/land cover as the influencing factors. H.D.Bhave et al. (2019) identified slope, soil, geomorphology, lineament, lithology, and land use/land cover as the influencing factors for identifying groundwater recharge potential zones in a watershed in Nagpur, India. Dr. S. V. Lakshmi et al. (2019); V. K. Reddy et al. (2019) studied groundwater potential zones in an unspecified location and identified drainage density, geology, geomorphology, soil, land use/land cover, and rainfall as the influencing factors. (R. Çelik et al., 2019) evaluated groundwater potential in the Tigris River Batman-Hasankeyf Sub-Basin in Turkey and identified geomorphology, geology, lineament density map, slope, rainfall, soil, and drainage density as the influencing factors.

S.lamichhane et al. (2019); N. M. Shakya et al. (2019) in Journal of Hydrology: Regional Studies on topic "Alteration of groundwater recharge areas due to land use/cover change in Kathmandu Valley, Nepal" evaluated groundwater recharge potential considering factors like LULC, Rainfall, Distance from river, Distance from road, Slope, Aspect, Elevation, Soil type, Population Density, Market distance. Considering all the factors selected by various researches for influencing groundwater recharge potential we selected the major factors including LULC, Type of soils, Elevation, Slope, Aspect, Distance from river, Distance from road, Population Density, Rainfall/Precipitation contributing for groundwater recharge potential.

Table 2.1 Analysis of various literatures and researches

Literature review	**G**	**GM**	**Ste**	**DEM**	**S**	**R**	**DD**	**LD**	**TWI**	**LULC**	**WTD**	**DFRo**	**DFRi**	**A**	**PD**
A.D.Duguma et al.	✓	✓	✓	✓	✓	✓	✓	✓		✓					
N.B.Tek et al.	✓		✓	✓	✓	✓	✓		✓	✓			✓	✓	
S.Shobha et al.	✓				✓	✓	✓	✓		✓					
S.Kaliraj et al.	✓	✓			✓	✓	✓	✓		✓					
E.Kusratmoko et al.	✓		✓	✓	✓	✓	✓			✓					
G.Jai Sankar et al.		✓					✓	✓		✓					
H.Allafta et al.	✓	✓			✓		✓	✓		✓			✓		
H.D.Bhave et al.	✓	✓			✓			✓		✓					
S.V.Laxmi et al.	✓	✓				✓	✓			✓					
Al-Ruzouq et al.	✓	✓		✓	✓	✓	✓	✓							
Patra et al.	✓	✓	✓	✓	✓	✓	✓			✓	✓				
Arulbalaji et al.	✓	✓	✓		✓	✓	✓	✓	✓	✓					
Al-shabeeb et al.			✓	✓	✓	✓	✓	✓		✓					
S.Lamichhane et al.	✓			✓	✓	✓				✓		✓	✓	✓	✓
Our Selection	✓			✓	✓	✓				✓		✓	✓	✓	✓

G- Geology/Lithology, GM- Geomorphology, STe- Soil Texture, DEM- Digital Elevation Model, S- Slope, R- Rainfall, DD- Drainage Density, LD- Lineament Density, TWI- Topographic Wetness Index, LULC- Land Use Land Cover, WTD- Water Table Depth, DFRo- Distance From Road, DFRi- Distance From River, A- Aspect, PD- Population Density

2.2 Various MCDM techniques for analysis

As various factors have various weightage for influencing groundwater recharge potential thus a proper calculation of weightage for factors is important which is to be done by Multi Criteria Decision Method (MCDM) which includes various techniques such as:

i. **Weighted Sum Models:** These techniques involve assigning weights to criteria and aggregating the scores of alternatives based on these weights. The Weighted Sum Model (WSM) calculates a weighted sum of the scores, where each criterion is multiplied by its assigned weight. The Weighted Product Model (WPM) calculates the product of the scores raised to the power of their weights. These models provide a simple and intuitive way to combine criteria but assume that the decision-maker's preferences can be adequately captured through linear or multiplicative aggregation.

ii. **Dominance-Based Approaches:** Dominance-based methods focus on comparing alternatives and identifying dominating or non-dominating solutions. ELECTRE (ELimination ET Choix Traduisant la REalité) is a family of techniques that use pairwise comparisons to determine outranking relations. ELECTRE methods assign rankings to alternatives based on their relative performance against each criterion. PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) is another family of methods that uses pairwise comparisons to calculate outranking flows. PROMETHEE methods generate preference rankings and allow sensitivity analysis to assess the stability of the rankings.

iii. **Outranking Methods:** Outranking methods compare alternatives based on pairwise comparisons and outranking relations. These methods aim to identify alternatives that are superior or inferior to others without necessarily providing a precise numerical score. In addition to ELECTRE and PROMETHEE mentioned earlier, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is another popular outranking method. TOPSIS calculates the distances of alternatives from the ideal solution and the worst-case solution and determines the relative closeness coefficient for each alternative.

iv. **Fuzzy Set Theory:** Fuzzy set theory is used in MCDM to handle uncertainty and imprecision in decision-making. Fuzzy AHP extends the AHP method by allowing linguistic variables and fuzzy pairwise comparisons. Fuzzy TOPSIS applies fuzzy logic to TOPSIS, considering fuzzy ratings and fuzzy distances in the decision-making process. These techniques enable decision-makers to incorporate subjective and uncertain information into the analysis.

v. **Data Envelopment Analysis (DEA):** DEA is a nonparametric technique used to measure the relative efficiency of decision-making units. It helps identify the best-performing alternatives and can be used for decision-making purposes. DEA evaluates the efficiency of each alternative by comparing its input-output relationship to that of other alternatives. It can handle multiple criteria and is particularly useful when data on the exact values of criteria are not available or when the criteria are difficult to quantify.

vi. **Utility Theory:** Utility-based approaches use utility functions to model decision-maker preferences and evaluate alternatives. The Analytic Hierarchy Process (AHP) is a widely used utility-based technique. It involves decomposing the decision problem into a hierarchy of criteria and sub-criteria. Pairwise comparisons are made to determine the relative importance of criteria, and a priority vector is derived. Alternatives are evaluated against each criterion, and the priorities are used to calculate an overall score for each alternative. Utility-based approaches provide a flexible way to represent and accommodate decision-maker preferences, but they require the quantification of subjective judgments.

2.3 Selection of approach

As ***Analytic Hierarchy Process (AHP)*** is a widely used multi-criteria decision-making technique that has been applied in various fields, including groundwater management. Several research articles have demonstrated the effectiveness of AHP in groundwater recharge potential analysis. (Patil et al., 2017) used AHP to evaluate the recharge potential of a watershed in India. The study concluded that AHP is a useful tool for identifying potential recharge sites and can help in the sustainable management of groundwater resources. (Kowsar et al., 2019) used AHP to assess the suitability of different sites for artificial groundwater recharge in Iran. The study found that AHP can help in the selection of appropriate recharge sites and improve the efficiency of recharge operations. (Al-Ghuraibi et al., 2019) used AHP to identify the most suitable locations for groundwater recharge in the city of Mosul, Iraq. The study concluded that AHP is an effective tool for selecting appropriate recharge sites and can contribute to the sustainability of groundwater resources. . (R. Palaka et al., 2015; G. Jai Sankar et al., 2015) investigated the Kosigi Mandala in Kurnool District, India, to evaluate the recharge potential using AHP Method. The study found that AHP can provide a reliable and efficient method for identifying potential recharge sites in the regions. Numerous research articles have demonstrated its effectiveness in this field attributed to its flexibility, transparency, consistency, and ease of use thus selection of AHP method is performed in our project for analysis as AHP allows for the incorporation of multiple criteria and sub-criteria in the decision-making process. AHP process proceeds as:

2.4 Basis of comparison

A matrix of pairwise comparisons for each layer against each other layer is created. Comparison is done on the basis of experience and study. We provided different values for the comparison. The values are provided as below:

Table 2. 2 Intensity of comparison Table

Intensity of important value	Definition	Explanation
	Same importance	Two factors contributes equally
3	Little more important	one slightly favor over another analyzed by experience and judgment
5	Much more important	one strongly favor over another analyzed by experience and judgment
7	Very much more important	one very strongly favor over another analyzed by experience and judgment
9	Extremely more important	The evidence favoring one over other is of the highest possible validity.
2,4,6,8	Intermediate Values	When compromise is needed.

2.4.1 Formation of comparison matrix

After preparing comparison matrix for above mentioned nine layers, we prepared normalize matrix. For eg.

Table 2.3 Comparison Matrix

Layers	A	B	C
A	1	3	5
B	0.33	1	3
C	0.2	0.33	1
Total	1.53	4.33	9

2.4.2 Formation of normalize matrix

To prepare normalize matrix, each values of columns are divided by the total values of respective columns.

For eg. All the values of column A is divided by 1.53, column B by 4.33 and column C by 9 in above example.

Table 0.4 Normalize Matrix

Layers	A	B	C	Average
A	0.65	0.7	0.55	
B	0.21	0.23	0.33	
C	0.13	0.07	0.11	
Total	1.00	1.00	1.00	

2.4.3 Determination of averages

Average of each row is computed from the normalized matrix.

Table 2.5 Calculation **of weightage of various layers**

Layers	A	B	C	Average
A	0.65	0.7	0.55	0.623
B	0.21	0.23	0.33	0.256
C	0.13	0.07	0.11	0.103

2.4.4 Formation of consistency matrix

Subsequently, a consistency matrix was created to ensure the reasonableness and consistency of the values used during comparison. The purpose of the consistency matrix is to assess the degree of consistency in the decision-making process.

To prepare the consistency matrix, each column of the comparison matrix is multiplied by each row of the average column of the normalized matrix. For example, in Table-1, Column A is multiplied by the first row of the average column of Table-3, which is 0.633 in the above example. This process is repeated for all columns of the comparison matrix, resulting in the consistency matrix.

Table 0.6 Consistency Matrix

Layer	A	B	C
A	0.633	0.768	0.5165
B	0.208	0.256	0.309
C	0.126	0.0844	0.103

2.4.5 Calculation of consistency index

Now weighted sum value is computed by adding all values of each rows of Table: 4

Table 0.7 Calculation of C.I. and C.R.

Layer	A	B	C	Average (from Table-3)	Weighted Sum value (WSV)	Ratio=WSV/Avg
A	0.633	0.768	0.5165	0.633	1.917	3.02
B	0.208	0.256	0.309	0.256	0.774	3.01
C	0.126	0.084	0.103	0.103	0.314	3.04

$\lambda_{max} = 3.029$

The formula for calculating CI is given by subtracting n from λ_{max} and dividing the result by the difference between n and 1, as follows:

Consistency Index (CI) = $\frac{(\lambda_{max}-n)}{(n-1)}$

Average of ratio of Table: 5 = λ_{max}, where

- λ_{max} is maximum Eigen value of pairwise comparison
- n is no of criteria being compared.

Consistency Index (CI) = $\frac{(\lambda_{max}-n)}{(n-1)}$

$$= \frac{(3.029-3)}{3}$$

=0.0145

Consistency Ratio (CR) = $\frac{CI}{RI}$

Where, RI=Random Consistency Index

Random Index Value is different for different matrix such as;

Table 0.8 Random Index Values

Matrix size/n	R.I.
1*1	0
2*2	0
3*3	0.58
4*4	0.90
5*5	1.12

For 3*3 matrix or n=3, R.I. =0.58

Consistency Ratio (CR) = $\frac{CI}{RI}$

CR = 0.025

Consistency Ratio is checked if CR is greater equal or less than 0.1.

i.e. C.R.≤ 0.1 (acceptable)

C.R. > 0.1 (indicate re-examination)

In above example,

C.R. =0.025<0.1 (acceptable)

Similar procedure was applied for each layers too.

In this way, AHP method was applied.

2.5 Geometric mean

During the initial phase of the Analytic Hierarchy Process AHP method analysis, the parameters were evaluated based on a pre-defined score, which ranged between 0.5 and 1 on a scale. The scores were used to calculate the geometric mean, which was determined by dividing the total scale weight of a particular parameter by the total number of parameters. This calculation is expressed mathematically as follows (as per Rhoad et al., 1991):

$$\text{Geometric mean} = \frac{\text{Total scale weight}}{\text{Total number of parameters}}$$

2.6 Normalized weight

In the context of groundwater recharge, the normalized weight is a crucial parameter for determining potential recharge zones. The second step of AHP analysis involves deriving the normalized weight from the assigned weight of a parameter feature class divided by the corresponding geometric mean. This formula is represented as (after Yu et al. (2002)):

$$\text{Normalized weight} = \frac{\text{Assigned weight of a parameter feature class}}{\text{Geometric mean}}$$

The normalized weighted map serves as an indicator of potential groundwater recharge zones that have been classified into five categories ranging from very high to unsuitable zones. The class with the highest weight is regarded as a very high suitable zone for groundwater recharge, while the least weighted class is considered less or unsuitable for groundwater recharge.

In the current study, the GIS-based AHP method was employed to integrate various thematic layers based on the assigned weights for suitable site selection. As per the guidelines of Central Ground Water Board, Government of India (CGWB, 2007), "the weight of the feature class of individual parameters was assigned on a scale of 1–10. Furthermore, the feature classes of each parameter were quantitatively weighted as poor (weight=1–3), moderate (weight=3–6), high (weight=6–9), and very high (weight=9–10). For instance, the layer with aquifer and more permeable soil type with agricultural land was assigned a weight of 9, while the layer with hard rock with less soil depth and poor permeability was assigned a weight of 1. Similarly, all parameters were assigned a suitable weight and integrated with the geometric mean of the corresponding layer to obtain the normalized weighted output. The assigned weights and the normalized weights of individual parameters are critical in determining the potential zones for groundwater recharge.

3. STUDY AREA

Chitwan district in Nepal is located in the central part of the country and is situated in the Himalayan orogenic belt, which is characterized by complex geological structures and processes. Chitwan district is one of the 77 districts of Nepal, and is located in the southernmost part of Province No.3 with district headquarter as Bharatpur City. It has an area of 2,238.39 Sq.km (864.25 Sq. mi) lies within latitude 27°36′21.60″ north, longitude 84°22′47.28″ east.

Chitwan district in Nepal has a diverse landscape with varying elevations. The district stretches from the low-lying Terai region to the Mahabharata Range and Churia hills in the north. The elevation of Chitwan district ranges from about 100 meters above sea level in the southern Terai region to over 2,000 meters above sea level in the northern part of the district. The Chitwan National Park, a UNESCO World Heritage Site and one of the district's major attractions, has an elevation range of 150 to 815 meters above sea level. Chitwan district compromises of 3 different geological divisions zones.

Terai Alluvial Plain zone is located in the southern part of the district and is composed of alluvial deposits that have been brought down by rivers and streams from the Himalayas. This zone is a plain region covered with dense forests, grasslands, and agricultural lands The Siwalik Range zone runs along the northern part of the district and is composed of sedimentary rocks that were formed during the Tertiary period. Mahabharata Range: The Mahabharata Range zone is a range of low hills that runs parallel to the Himalayas located to the north of the Siwalik Range and is composed of metamorphic and igneous rocks that were formed during the Precambrian and Paleozoic eras.

As of 2021, the population of Chitwan district in Nepal is estimated to be around 579,000 people. The district covers an area of 2,238 square kilometers giving it a population density of approximately 258 people per square kilometer. Population density of Chitwan district is relatively high compared to other districts in Nepal with an average annual growth rate of around 1.6%.

Chitwan district in Nepal has a subtropical climate, with hot and humid summers and mild winters influenced by its proximity to the Indian plains and the Himalayan mountain range to the north. The district experiences four distinct seasons. The summer season lasts from April to June, with temperatures ranging from 30°C to 35°C. The monsoon season lasts from June to September, bringing heavy rainfall to the region. The district receives an average annual rainfall of around 2,500 mm, with 80% of its annual rainfall during monsoon season. The post-monsoon season lasts from October to November, with mild temperatures and clear skies. The winter season lasts from

December to February, with temperatures ranging from 7°C to 23°C. The spring season lasts from March to April, with pleasant temperatures and blooming flowers.

Constituting various watershed area in the district Narayani is the largest river and the source of water for irrigation and hydropower generation. Rapti is another major river originating in the Siwalik Hills and flowing through the Chitwan valley. Reu River is a smaller river in the district, originating in the Mahabharata Range and flowing through the eastern part of Chitwan. Beeshazar Tal is a wetland complex located in the Chitwan National Park which is habitat for several migratory bird species and support the local economy through tourism and fishing activities. Bis Hazari Tal is another wetland area located in the eastern part of the district. Ground water being the dominantly used source of water in this area there are several artificial recharge structures in the districts which includes ponds, dug wells, recharge trenches, and recharge wells.

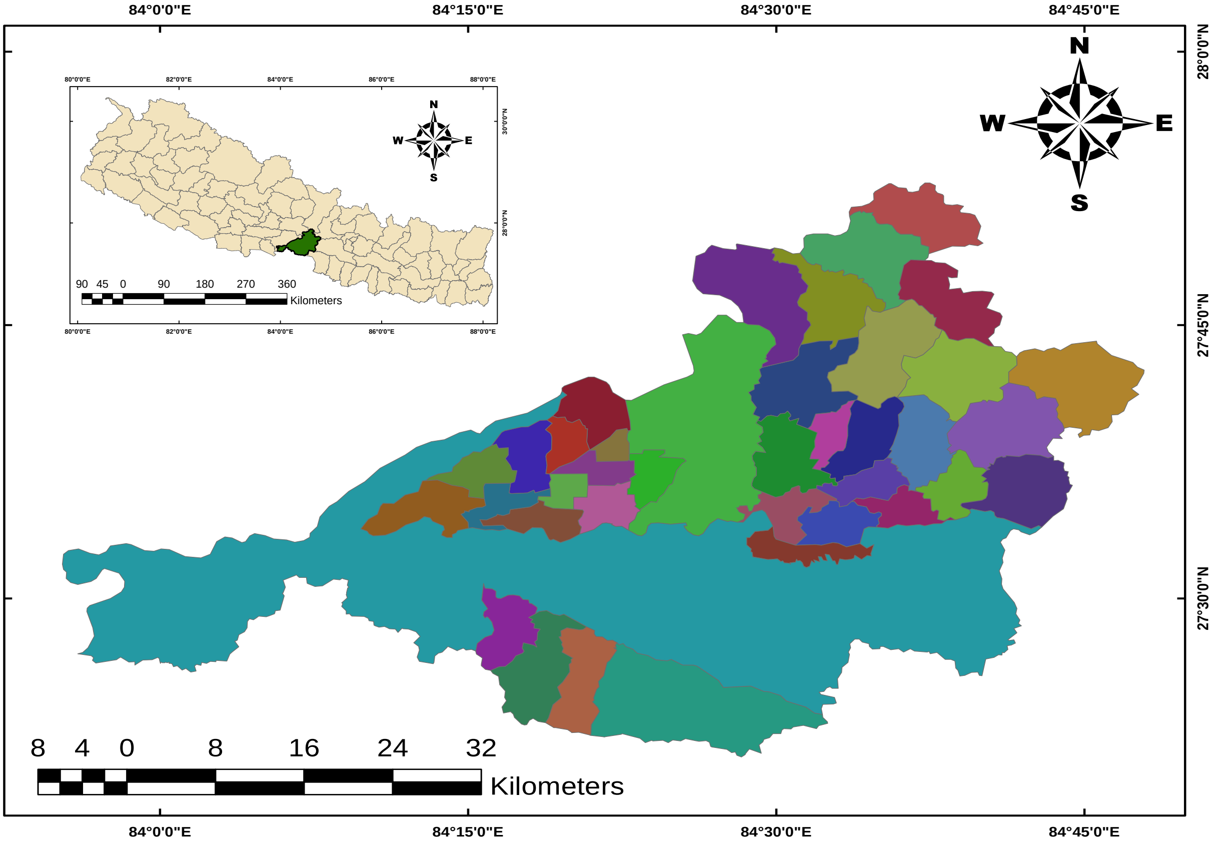


Figure 3.1 Location Map of Chitwan District

4. METHODOLOGY

We collected different data like landsat8 images, precipitation data, DEM data road networks data, and river vector etc. and we processed these data and generated different required layers for our study with the help of ArcGIS. The steps involved in our process is shown by the flowchart below:

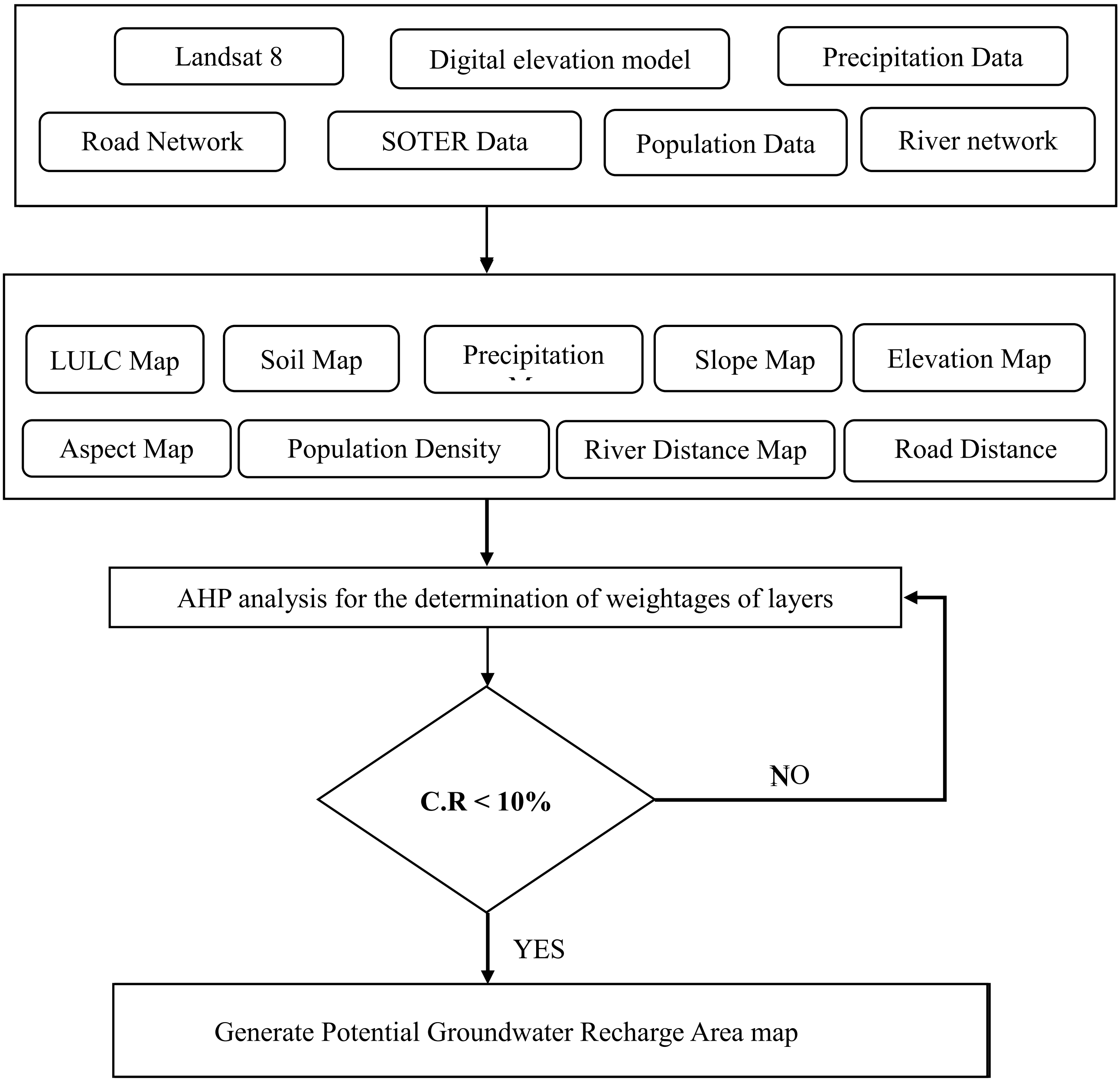


Figure 4.1 Methodological framework

4.1 Preparation of Factors Influencing Groundwater Recharge Potential

4.1.1 Generation of LULC Map

The process of acquiring and analyzing land use and land cover data using Landsat 8 images and Arc Map involves several steps. Firstly, the data acquisition process involves obtaining Landsat 8 images from the USGS Earth Explorer platform by specifying the study area (Chitwan), the year of interest (2022), and a cloud cover range of 0-30%. The suitable image with minimal cloud cover is then downloaded and saved in a folder.

Next, the downloaded Landsat 8 images are added to Arc Map, and the relevant bands are combined using the composite bands tool to create a true-color composite image. The image is then enhanced using tools such as contrast stretch and histogram equalization to improve visibility. The image of our study area (Chitwan district) is clipped using the shape file of Chitwan to isolate the study area from whole image.

Afterwards, the supervised classification method is used to classify the land use and land cover classes using the image classification tool. Training samples are selected from the image using polygons with the same color. Multiple polygons are selected for each class, and these are combined and given a name, such as "built-up area."

The maximum likelihood classification tool is then used to classify pixels with similar colors into specific land use and land cover classes. The resulting land use and land cover map is displayed as a raster image with each pixel assigned to a specific class. To assess the accuracy of the classification, random points are selected in the LULC map, and their validity is verified using ground truth data from Google Earth Pro.

Finally, the land use and land cover map is created by assigning colors and symbols to different land cover classes using the symbology tab in the layer properties dialog box. This map provides valuable information for understanding the land use and land cover patterns in the study area and can be used in various applications, such as urban planning and environmental management.

4.1.2 Generation of soil map

We downloaded the soil map of whole Nepal from soil and terrain database (SOTER). SOTER Nepal is generalized from the original soils and terrain database of Nepal at scale 1:50000, compiled by FAO and Nepal’s survey department. The soil map for our study area i.e. Chitwan is extracted/ clipped by shape file of Chitwan from the downloaded SOTER map of Nepal in ArcGIS.

4.1.3 Generation of Digital Elevation Model Map

Elevation data is obtained from ALOS PALSAR Data using ASF Data Search Vertex (‘search.asf.Alaska.edu\#\). High resolution terrain corrected image is obtained and downloaded for different small sections around the study area. Obtained small section are merged into mosaic map using GIS tools. Study area is extracted from mosaic map using the shape file of required study area in GIS tools.

4.1.4 Generation of Slope Map

DEM generated for required area is taken and launched in area arc GIS Projection of format is checked. Go to spatial analyst toolbar ‘slope’ is selected from ‘surface analysis’ dropdown. New layer is created called slope map which is converted to color coded map based on slope data using symbology taking different color to represent different slope categories.

4.1.5 Generation of Aspect map

With created slope map selected, ‘Aspect is selected from ‘Surface Analysis’ dropdown. New layer of aspect will be created which can be converted to color coded map using arc GIS symbology. Different color can represent different aspects like flat, north, east, west, south aspects.

4.1.6 Generation of Population Map

Population data is obtained for area of interest from national statistical agency which includes data by creating table or spreadsheet for each administrative unit (district, municipality) for area of interest. Population data Imported to ArcGIS is joined to appropriate administrative boundary or grid cell layer in ArcGIS to appropriate administrative boundary or grid cell layer in ArcGIS using ‘join’ function. Population data is symbolized using ‘symbology’ function in ArcGIS represented by different color for different range of population for different range of population density. ‘Population map’ is obtained.

4.1.7 Generation of Precipitation map

Rainfall data for various rainfall station inside or near outside the required area is obtained from Department of Hydrology and Meteorology (DHM). Then the shape file of Chitwan is added to the GIS portal where rainfall data is added for respective coordinate of rainfall station.

The point rainfall data is interpolated to create a continuous surface of rainfall varies. The interpolation is done by using ‘IDW’ tool. Once the interpolation is complete, the raster layer of rainfall values is displayed and suitable color ramp is chosen by the symbology tab.

4.1.8 Generation of Distance from River map

River network of area along with river dataset is obtained from ICIMOD IRDS (‘https: rds.icimod.org’) which was downloaded and was added to map in correct format and projection. River layer is buffered to desired Buffer value which is then converted to raster format. Buffer raster is then selected for ‘Euclidean distance’ in spatial analyst dropdown which forms new map showing distance from river. Obtained map is converted to color coded map based on distance data.

4.1.9 Generation of Distance from Road map

Road network map of area with road dataset is obtained from ICIMOD IRDS (‘https://rdds.icimod.org|”) which was downloaded and was added to map in correct format and projection in ArcGIS. Road layer is buffered to desired buffer value which is then converted to raster format. Buffer raster layer is then selected for ‘Euclidean distance’ in spatial analyst drop down which forms new layer map showing distance from road. Obtained map is converted to require color coded map based on distance data.

4.2 AHP analysis for weightage of layers

The GIS-based Analytic Hierarchy Process (AHP) technique has been employed to conduct a multiple parameter analysis for identifying suitable sites for artificial groundwater recharge in the study area. This report presents the results of the analysis of nine spatial parameters, namely land use, soil, aspect, elevation, population density, distance from river, distance from road, precipitation, and slope, using the AHP approach, which includes geometric mean and normalized weight calculation. The aim of this analysis is to identify potential zones for groundwater recharge.

Saaty's (1990) Analytic Hierarchy Process (AHP) technique has been utilized to identify potential groundwater recharge zones. This approach involves assessing the geometric mean and assigning normalized weights to various parameters to facilitate the decision-making process. To develop the AHP pair-wise matrix in this study, the scale weights of parameters were inputted based on their direct or indirect relationship. The interrelatedness of different parameters with groundwater recharge was integrated to form a cluster of relationships. A rating of 1 was allocated to the parameters that directly affect groundwater recharge, whereas those with an indirect impact were given a score of 0.5. Analytical Hierarchy Process (AHP) for the weightage calculation of layers on the basis of their recharge potential:

At first, we identified 9 different layers and criteria that we want to include in our analysis and we prepared comparison matrix for our nine layers .The layers we included are:

i) Land Use
ii) Type of Soil
iii) Precipitation
iv) Aspect
v) Slope
vi) Distance from river
vii) Distance from road
viii) Population Density
ix) Elevation

4.3 Identification of layers and weightage

It was observed that the mapping of groundwater recharge potential was predominantly influenced by several factors, including Land Use Land Cover, soil, precipitation, aspect, distance from river, distance from road, population density and elevation. While each of these layers was mapped, it was discovered that they did not contribute equally to groundwater recharge. As a result, an AHP analysis was conducted to calculate their respective weights.

4.4 Delineation of groundwater recharge area

To identify potential groundwater recharge sites, a set of nine indicators covering three broad categories (as shown in Figure 1) were selected based on a literature review, expert consultation, data availability, and statistical tests such as the ROC test. These indicators are listed in Table. To estimate the weights for each layer, the AHP method was utilized, which involved a pairwise comparison of each layer against the rest of the layers. This approach has been elaborated in previous studies. The weights factor obtained through this method were used to determine the importance of each layer in identifying potential recharge sites.

4.5 Data standardization

To utilize each thematic layer in the study, each grid of the thematic layers is assigned a unique value. The standardization process is then applied to convert these values into dimensionless values that can be compared across layers. The standardization process involves using equations

(4) and (5) below, which ensure that larger values indicate better conditions and smaller values indicate worse conditions for each grid in the thematic layers (Pei-Yue et al., 2010).

Standardization used for larger the better: $y_i = \frac{(x_i - x_{i,min})}{(x_{,max} - x_{i,min})}$ Eq. (4)

Standardization used for larger the better: $y_i = \frac{(x_{i,max} - x_i)}{(x_{,max} - x_{i,min})}$ *Eq. (5)*

Where, y_i is the standardized value of the thematic grid and i is the index of thematic grid and x_i, $x_{i,max}$, $x_{i,min}$ are the original, maximum and minimum values of the thematic grids respectively.

4.6 Calculation of the Ground Water Potential Recharge Area (GWPRA) index

To obtain a single score for potential recharge area, all the thematic layers were integrated in GIS using equation 6 (Malczewski, 1999). The high potential recharge zone was determined by computing the sum of the product of each weight and its corresponding grid value (Jhariya et al., 2016). The assigned values in each layer grid, as well as the weight factor of each layer, were used to calculate the theoretical potential recharge areas. The higher the value of the grid, the higher the potential for recharge, and vice versa.

$$\text{GWPRA} = \Sigma \frac{x_i w_j}{mn}$$

The formula for calculating the groundwater potential recharge area (GWPRA) in the study area is as follows: $\text{GWPRA} = \Sigma \frac{x_i w_j}{mn}$

Where xi represents the normalized weight of the i^{th} class of the thematic layer, w_j is the weight derived from AHP of the j^{th} thematic layer, m is the total number of thematic layers, and n is the total number of classes in the thematic layer.

5. RESULTS AND DISCUSSION

5.1 Analysis of layers

We prepared different layers and their respective influences on ground water recharge. The relative importance of these layers was quantified and ranked through the study and expert judgment. The comparison and weightage calculation of these layers was done through AHP analysis and given weightage is obtained for respective layers. Precipitation layer gets the maximum weightage of 30.56% whereas population density gets the minimum weightage of 2.2% which depicts that change in precipitation is highly responsible for change of groundwater recharge potential in comparison to change in population density.

Table 5.1 Calculation of weightage of various factors contributing groundwater recharge potential

S.N	Types of Land	Weightage (%)
1	Land Use	14.22
2	Type of soil	21.02
3	Precipitation	30.56
4	Slope	8.6
5	Aspect	5.05
6	River Distance	11.85
7	Road Distance	2.9
8	Population Density	2.2
9	Elevation	3.61
	Total	100

5.1.1 Analysis of LULC map

LULC map is a geographic information system (GIS) based map that depicts different extent, distribution and composition of various land uses and land covers in a specific area. Land use/land cover has a significant role in the runoff, infiltration, and groundwater recharge capacity of any watershed or sub basin, and it also provides soil information such as soil moisture content, groundwater and surface water, and an indicator regarding groundwater potential prospectus.

LULC map of Chitwan district was prepared by using Landsat 8 images obtained from USGS Earth Explorer with the help of ArcGIS. The resolution of the map was 30mx30m. (i.e. each pixel indicates 30m x 30m area in real ground). According to the map, the total area of Chitwan is 2,238.39 square kilometers. Out of this, 55.71% of the area (1,236.374 square kilometers) is covered by forests including Sal, Pine, and Tropical Deciduous forests making it the dominant land use in the region contributing high recharge potential in the area.

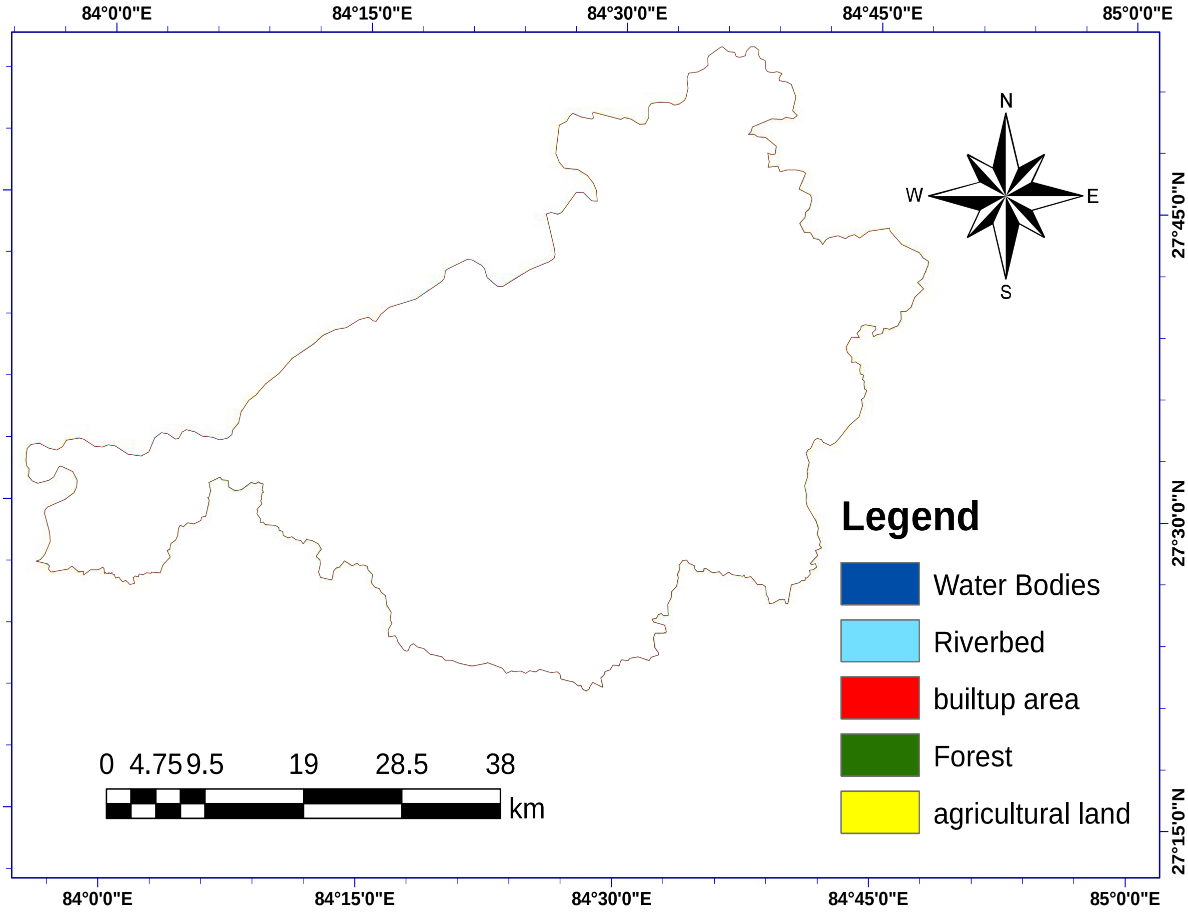


Figure 5.1 LULC Map of Chitwan district (2022)

Agricultural lands, which include cultivated areas, Grassland, pastures, and other types of croplands, make up 39.3% of the total area (872.210 square kilometers) being the 2nd most dominant factor on recharge potential. Built-up areas, which include urban and other types of developed areas, constitute 1.72% of the total area (38.29 square kilometers). The areas like Bharatpur, Ratnanagar and Khairahani were found to be dense built-up areas with high population density and low recharge capacity.

River beds, which include areas adjacent to rivers and other bodies of water, make up **2.57%** of the total area (57.14 square kilometers), while water bodies, which include lakes, ponds, and rivers like Narayani River, Rapti River constitutes **0.70%** of the total area (15.49 square kilometers) with low recharge potential.

LULC layer has weightage of 14.22% from AHP analysis. LULC layer (Forest) has the max weightage for ground recharge potential contributing about 47.87% on 100% weightage of LULC layer and about 6.80% of overall weightage of total analysis whereas max LULC layer (Water Bodies) has the minimum weightage for ground water recharge potential contributing about 4.23% on total weightage on 100% of LULC layer and about 0.60% of overall weightage of total analysis.

Table 5.2 Calculated overall weightage for LULC map

Layers	Weightage of Layer (%)	Classification of layers	Weightage of classification (%)	Overall weightage (%)
Land use	14.22	Water Bodies	4.23	0.60151
		Riverbed	10.92	1.55282
		Forest	47.87	6.80711
		Agricultural Land	28.77	4.09109
		Built-up Areas	8.21	1.16746

5.1.2 Analysis of soil map

Soil map of Nepal was obtained from the Soil and Terrain (SOTER) Database in ISRIC World Soil Information. We extracted a soil map for Chitwan District. . Soil texture generally influences the moisture content in the soil, infiltration rate, hydraulic conductivity, and soil permeability, the grain size of the soil, and the specific composition of the soils, which in turn plays an important role in recharge potentiality.

Figure 5.2 shows that Chitwan has five dominant types of soil including Eutric cambisols(CMe), Gleyic combisols (CMg), Dystric Regosols (RGd), Haplic phaeozems (PHh) and Eutric Gleysols (Gle). Dystric Regosols (RGd) are the dominant soil type in Chitwan district covering around 32.77% (734.5 Sq.km) of total area which have low water-holding capacity and poor infiltration rates limiting groundwater recharge potential., followed by Haplic phaeozems (PHh) with 25.55% (572.6Sq.km) of total area coverage having a moderate to high groundwater recharge potential. CMg - Gleyic Cambisols type of soil covers almost 21.77% (487.97Sq.km) of total area which can become waterlogged and have limited recharge potential. CMe - Eutric Cambisols having a moderate to high groundwater recharge potential occupies only about 13.65% (305.93 Sq.km) of total area where GLe - Eutric Gleysols having moderate groundwater recharge potential covers 6.25% (140 Sq.km) of total area.

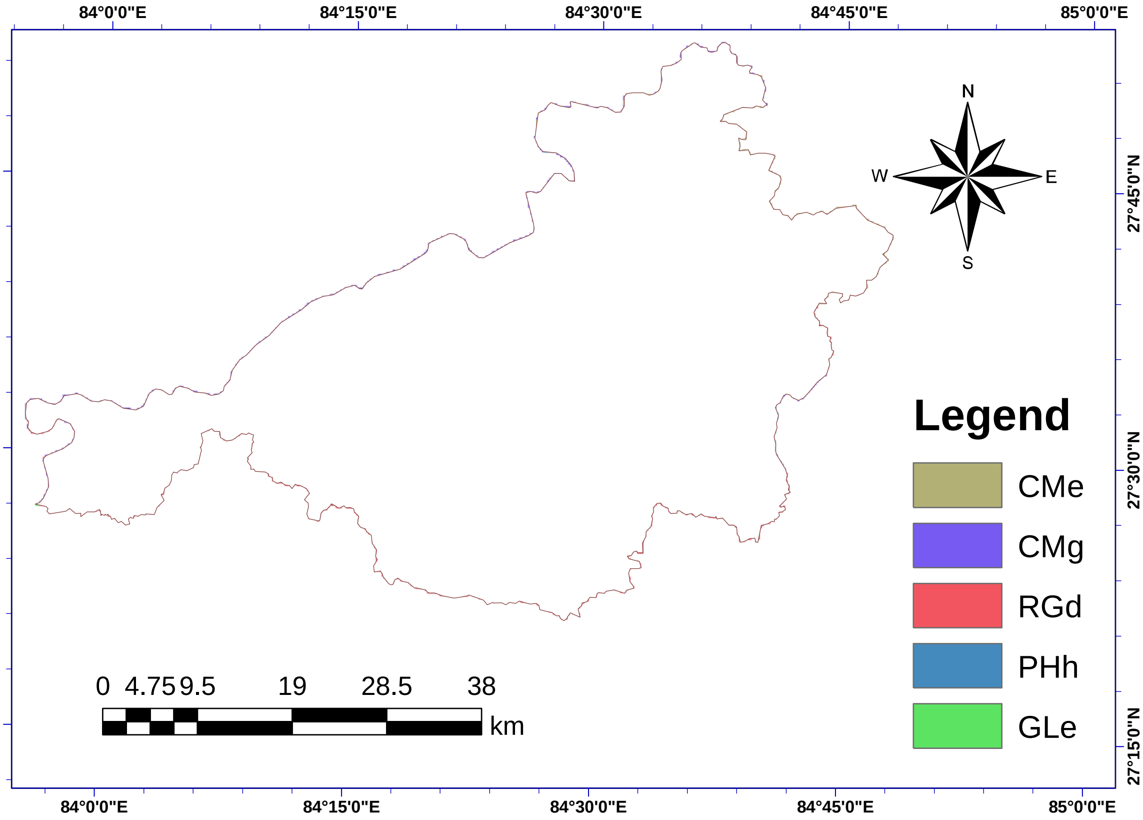


Figure 5.2 Soil Map of Chitwan district

Type of Soil layer has weightage of 21.02% obtained from AHP analysis. Type Of Soil (CMe) has the max weightage for ground recharge potential contributing about 44.49% on 100% weightage of type Of soil and about 9.35% of overall weightage of total analysis whereas type Of soil (RGd) has the minimum weightage for ground water recharge potential contributing about 6.32% on total weightage on 100% of type Of soil and about 1.32% of overall weightage of total analysis.

Table 5.3 Calculated overall weightage of soil map

Layers	Weightage of Layer (%)	Classification of layers	Weightage of classification (%)	Overall weightage (%)
Type Of Soil	21.02	Cme	44.49	9.3518
		Cmg	7.21	1.51554
		Gle	11.18	2.35004
		PHh	30.8	6.47416
		RGd	6.32	1.32846

5.1.3 Analysis of Precipitation map

Precipitation is a critical factor in groundwater recharge because it provides the primary source of water for replenishing the aquifer. Rainfall plays an important role in the hydrologic cycle and controls groundwater potential. Rainfall is the major source of surface and groundwater in this area, and therefore, the intensity of rainfall and its spatial distribution strongly control the recharge volume of the basin, Precipitation map is prepared using precipitation per year data from reference meteorological stations.

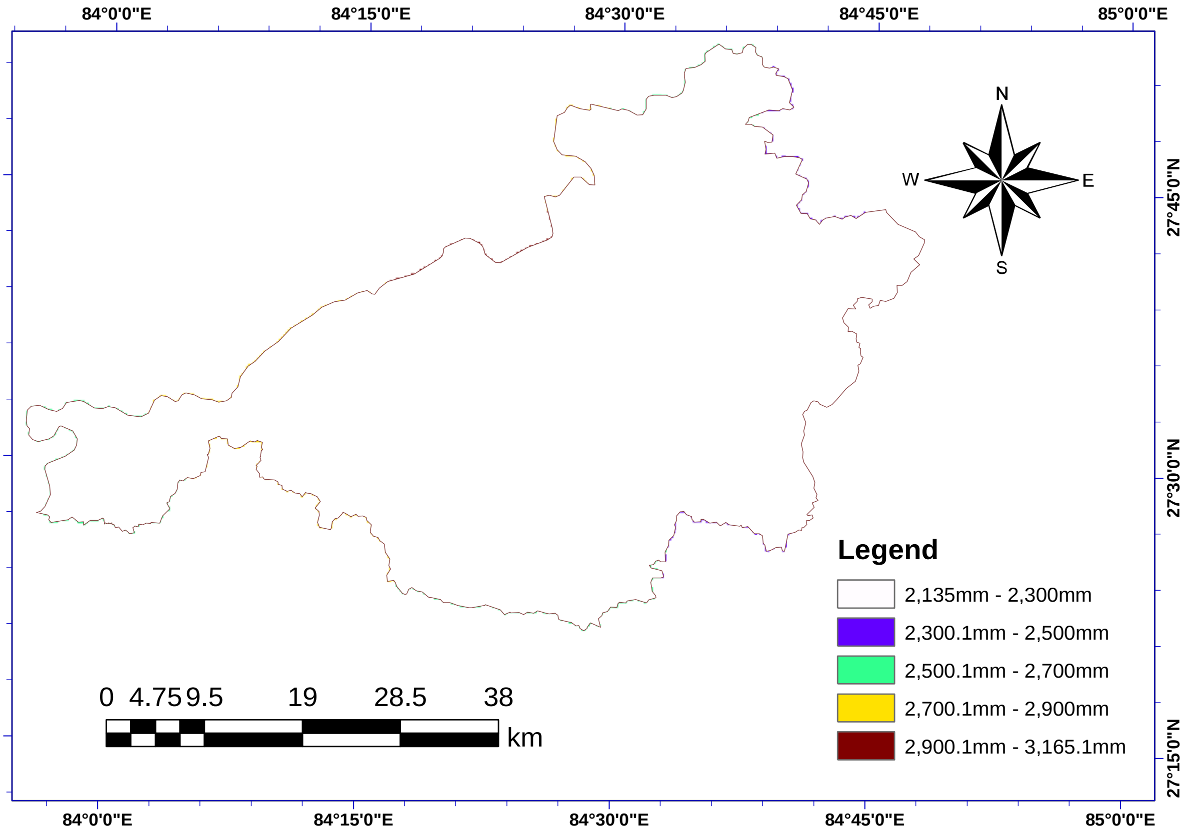


Figure 5.3 Precipitation Map of Chitwan District

The obtained minimum and maximum intensity was found to be 2135 mm and 3165.1 mm respectively. The rainfall intensity was categorized into five classes in discrete form namely 2135.6mm - 2341.5mm, 2341.6mm - 2547.4mm, 2547.5mm - 2753.3mm, 2753.4mm - 2959.2mm, and 2959.3mm - 3165.1mm. Precipitation can replenish groundwater supplies by infiltrating into the soil and refilling aquifers. Heavier and more frequent precipitation generally leads to higher rates of recharge. The precipitation map portrays the different areas with respective rainfall intensity. The area with high intensity has high recharge potential and vice versa.

Precipitation layer has 30.56% weightage obtained from AHP analysis. Max precipitation area (2959.3mm-3165.1mm) has the max weightage for ground recharge potential contributing about

45.3% on 100% weightage of Precipitation and about 13.84% of overall weightage of total analysis whereas Min precipitation area (2135.6mm-2341.5mm) has the minimum weightage for ground water recharge potential contributing about 5.1% on total weightage on 100% of precipitation and about 1.55% of overall weightage of total analysis.

Table 5.4 Calculated overall weightage of precipitation map

Layers	Weightage of Layer (%)	Classification of layers	Weightage of classification (%)	Overall weightage (%)
Precipitation	30.56	2135.6-2341.5	5.1	1.55856
		2341.6-2547.4	7.75	2.3684
		2547.5-2753.3	15.31	4.67874
		2753.4-2959.2	26.54	8.11062
		2959.3-3165.1	45.3	13.8437

5.1.3 Analysis of Slope map

Slope refers to the measure of the steepness or inclination of a surface, usually the ground described as the change in elevation or height over a given horizontal distance. The slope describes the variation of altitude/elevation in a certain area under consideration which influences the runoff. The gentle steepness slopes indicates less speediness of surface water flow and the more groundwater percolation into the ground. Similarly the more steepness of the slope indicates more surface runoff and less groundwater percolation the slope is an essential parameter in groundwater investigation as infiltration is inversely proportional to land steepness. Slope map was prepared by using Digital Elevation Map (DEM).

The slope of terrain in Chitwan district was found to vary from 0° to 590° obtained from slope map. Slope map was classified into 5 classes where 0° to 10° and 10-30° represents the flatter zone that are highly rechargeable. Whereas other classes represents steeper zone. In steeper zone, water can flow rapidly over the surface, reducing the amount of time it spends in contact with the soil and decreasing the opportunity for infiltration and recharge. In contrast, in gentle and flat slope zone, water can infiltrate into the soil and recharge the groundwater system. Various part of Chitwan district contains Chure range, Siwalik hills and Mahabharata range which have steeper slope thus have low ground water recharge potential whereas flat plain lands in district has higher groundwater recharge potential.

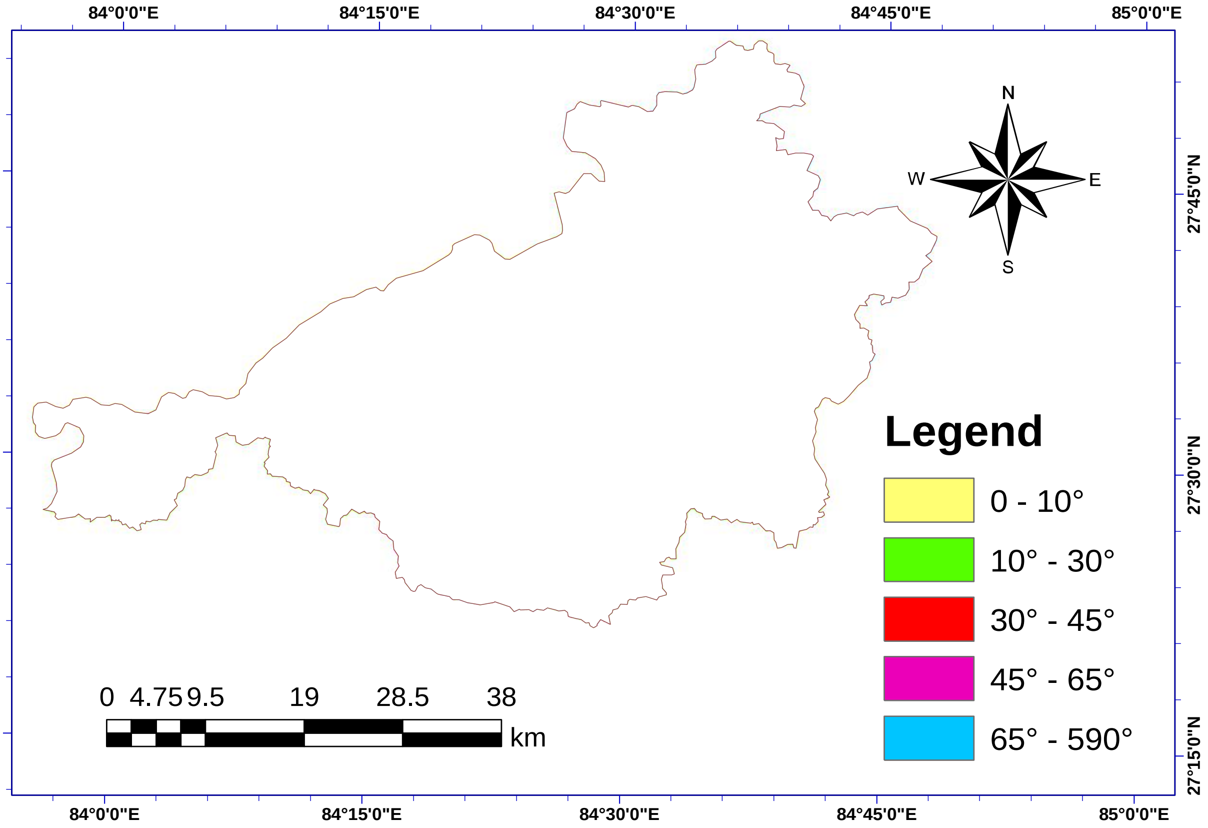


Figure 5.4 Slope Map of Chitwan District

Slope layer has weightage of 8.6% obtained from AHP analysis. Minimum slope (0-10) has the max weightage for ground recharge potential contributing about 42.06% on 100% weightage of slope and about 0.95% of overall weightage of total analysis whereas max slope (above 65) has the minimum weightage for ground water recharge potential contributing about 4.16% on total weightage of slope and about 0.35% of overall weightage of total analysis.

Table 5.5 Calculated overall weightage of slope map

Layers	Weightage of Layer (%)	Classification of layers	Weightage of classification (%)	Overall weightage (%)
Slope	8.6	0-10	42.06	3.61716
		10.1-30	28.32	2.43552
		30-45	17.44	1.49984
		45-65	8.02	0.68972
		65 above	4.16	0.35776

5.1.4 Analysis of Aspect map

Aspect refers to the direction that a slope or surface faces refering to the compass direction that a slope faces measured in degrees from flat (-1), north (0 degrees) to east (90 degrees), south (180 degrees), and west (270 degrees). Aspect of a slope can impact the amount of solar radiation that it receives so that East and south facing areas are drier and have less recharge potential compared to other aspects. Aspect map was prepared by using Digital Elevation Map (DEM) which provides us with the orientation of slope in the land forms of Chitwan district.

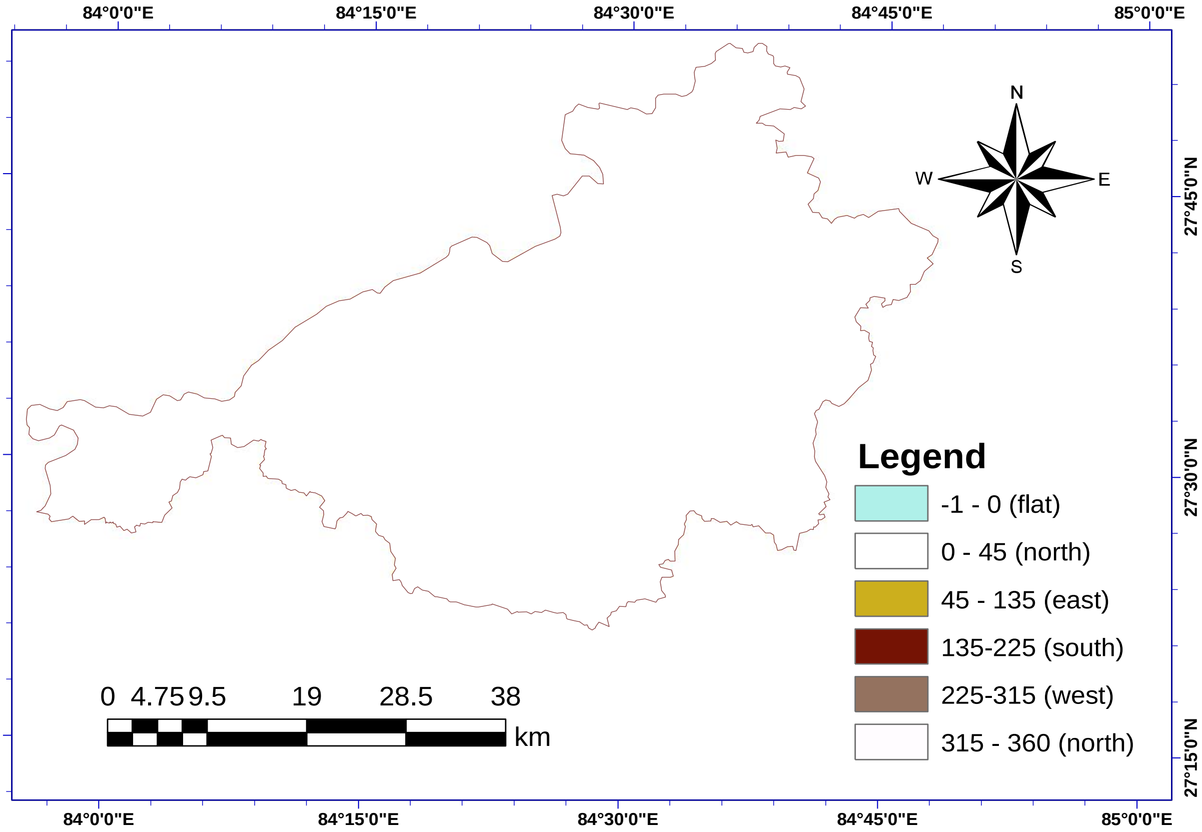


Figure 5.5 Aspect Map of Chitwan District

The map was prepared with five orientations represented as (-1-0) flat, (0-45) and (316 -360) north, (45-135) east, (135-225) South and (225-315) west. Aspect of a slope affects the amount of solar radiation received, with south-facing slopes receiving more solar radiation than north-facing slopes. The terrain with north orientation gets less sunlight thus reduces the tendency of evaporation losses. So, recharge potential is more in north Orientation than South and in west orientation than east whereas the flat zone has more tendency of infiltration than all other orientations.

Aspect has weightage of 5% obtained from AHP analysis. Aspect of map (flat) has the max weightage for ground recharge potential contributing about 42.75% on 100% weightage of aspect and about 2.15% of overall weightage of total analysis whereas max aspect of map (facing south) has the minimum weightage for ground water recharge potential contributing about 4.77% on total weightage on 100% of aspect and about 0.24% of overall weightage of total analysis

Table 5.6 Calculated overall weightage of aspects map

Layers	Weightage of Layer (%)	Classification of layers	Weightage of classification (%)	Overall weightage (%)
Aspect	5.05	Flat	42.75	2.15888
		North	29.5	1.48975
		East	9.65	0.48733
		South	4.77	0.24089
		West	13.34	0.67367

5.1.5 Analysis of Distance from river map

Distance from river map was prepared using concept of Euclidean distance in river channel of Chitwan district. The distance from the river was taken with 750m interval in each range. Areas that are closer to a river tend to have higher recharge potential than those that are farther away, largely because of the greater availability of water and the presence of soils and materials with greater infiltration rates that can store water. There is decrease in recharge potential of the region with an increase in distance from the river and vice versa.

Table 5.7 Calculation of overall weightage of layers of distance from river

Layers	Weightage of Layer (%)	Classification of layers	Weightage of classification (%)	Overall weightage (%)
Distance from river	11.85	0-750	41.35	4.89998
		750-1500	28.99	3.43532
		1500-2250	17.15	2.03228
		2250-3000	7.61	0.90179
		3000 above	4.9	0.58065

Distance from road has weightage of about 2.9% obtained from AHP analysis. Maximum distance from road (above 5000m) has the max weightage for ground recharge potential contributing about 49.18% on 100% weightage of distance from road and about 1.42% of overall weightage of total analysis whereas Minimum distance from road (0-1250m) has the minimum weightage for ground water recharge potential contributing about 4.99% on total weightage on 100% of distance from road and about 0.144% of overall weightage of total analysis.

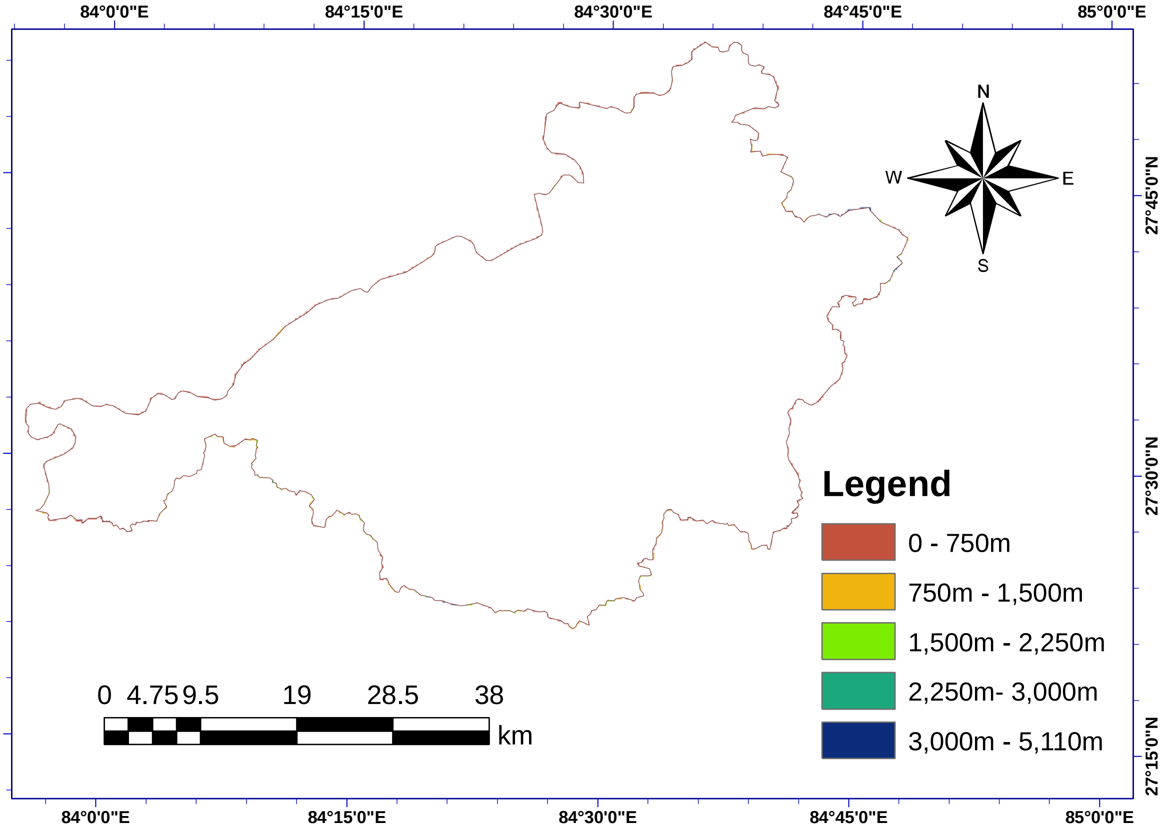


Figure 5.6 Distance from River Map of Chitwan District

5.1.6 Distance from Road map

Distance from road map was prepared using concept of Euclidean distance in road channel of Chitwan district. The distances from road was taken with 1250m interval in each range. The region near to roads are mostly used by the people for built-up and settlement purposes. Roads and other impervious surfaces can cause increased surface runoff, which can lead to erosion and sedimentation, and reduce the amount of water available for groundwater recharge thus areas that are closer to a road may have lower groundwater recharge potential due to factors such as soil compaction, increased surface runoff, chemical contamination, and vegetation loss. But As moving away from the road we found the evacuated, empty lands which have areas for infiltration.

So, there is an increase in recharge potential with increase in road distance and decreases in recharge potential with decrease in distance from road.

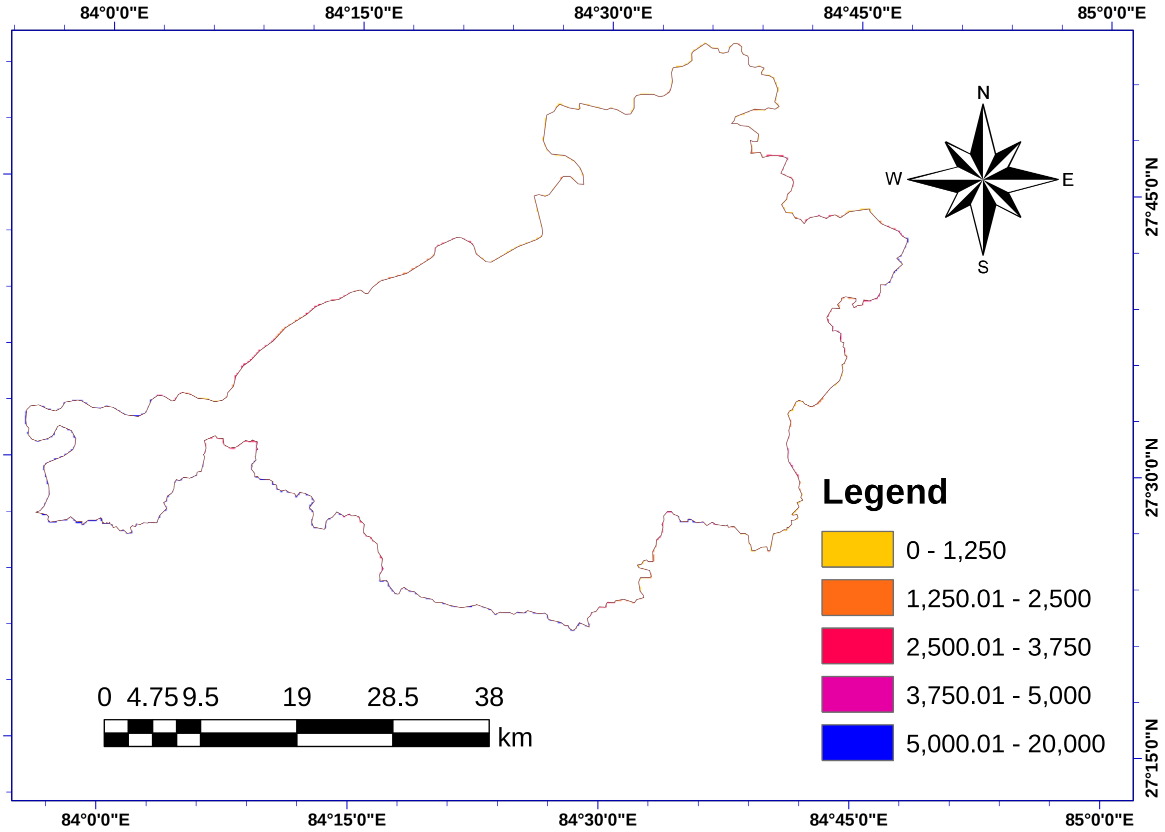


Figure 5.7 Distance from Road of Chitwan District

Distance from road has weightage of about 2.9% obtained from AHP analysis. Maximum distance from road (above 5000m) has the max weightage for ground recharge potential contributing about 49.18% on 100% weightage of distance from road and about 1.42% of overall weightage of total analysis whereas Minimum distance from road (0-1250m) has the minimum weightage for ground water recharge potential contributing about 4.99% on total weightage on 100% of distance from road and about 0.144% of overall weightage of total analysis.

Table 5.8 Calculation of overall weightage of distance from road map

Layers	Weightage of Layer (%)	Classification of layers	Weightage of classification (%)	Overall weightage (%)
Distance from road	2.9	0-1250	4.99	0.14471
		1250-2500	7.24	0.20996
		2500-3750	14.74	0.42746
		3750-5000	23.85	0.69165
		5000 above	49.18	1.42622

5.1.7 Population density

Population density map was prepared using population data obtained. This map shows densely populated area and least populated area. From Map Bharatpur municipality with 2, 03,066 population, Ratnanagar Municipality with 56,000 population, Khairahani Municipality with 48000 population, Kalika Municipality with 36000 population are found to be densely populated area thus have less recharge potential and Chitwan national park area having less population contributes to have high recharge potential. Map is divided into 5 classes named 0, 0-150, 150-450, 450-700 and 700-1234 according to potential density denoted as population per square kilometer. As population density increases, the demand for land for housing, commercial, and industrial purposes also increases leading changes in land use patterns, such as deforestation and urbanization, which can reduce the amount of rainfall that infiltrates the soil and reaches the aquifer causing reduction in recharge potential.

Population density has weightage of about 2.2% obtained from AHP analysis. Population Density (0-1) referring Chitwan National Park has the max weightage for ground recharge potential contributing about 43.31% on 100% weightage of population density and about 0.95% of overall weightage of total analysis whereas max Population Density (above 700) has the minimum weightage for ground water recharge potential contributing about 4.38% on total weightage on 100% of elevation and about 0.096% of overall weightage of total analysis.

Table 5.9 Calculated overall weightage Population density map

Layers	Weightage of Layer (%)	Classification of layers	Weightage of classification (%)	Overall weightage (%)
Population Density	2	0	43.31	0.95282
		0-150	29.83	0.65626
		150-450	15.43	0.33946
		450-700	7.06	0.15532
		700 above	4.38	0.09636

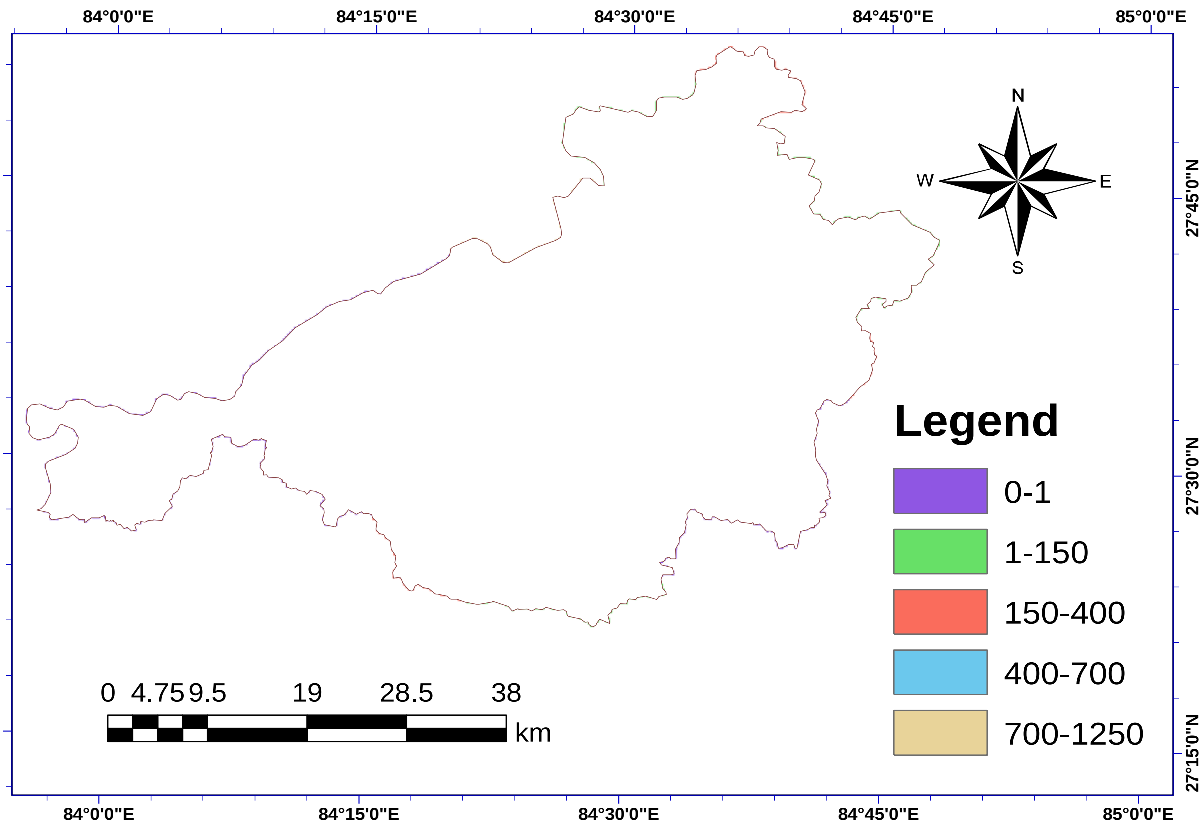


Figure 5.8 Population Density of Chitwan District

5.1.8 Digital Elevation Map

Digital Elevation Map (DEM) was prepared from ALOS PALSAR Data using ASF Data Search Vertex. DEM is a digital representation of the elevation or relief of a terrain or landscape, typically measured in meters or feet above sea level. From map we obtained highest elevation at Chitwan district is 1880 m in Mahabharata Range and lowest elevation of 49m.

Table 5.10 Calculated overall weightage of Elevation map

Layers	Weightage of Layer (%)	Classification of layers	Weightage of classification (%)	Overall weightage (%)
Elevation	3.16	49-225	41.85	1.51079
		225-424	28.61	1.03282
		424-733	16.74	0.60431
		733-1157	8.4	0.30324
		1157-1880	4.35	0.15704

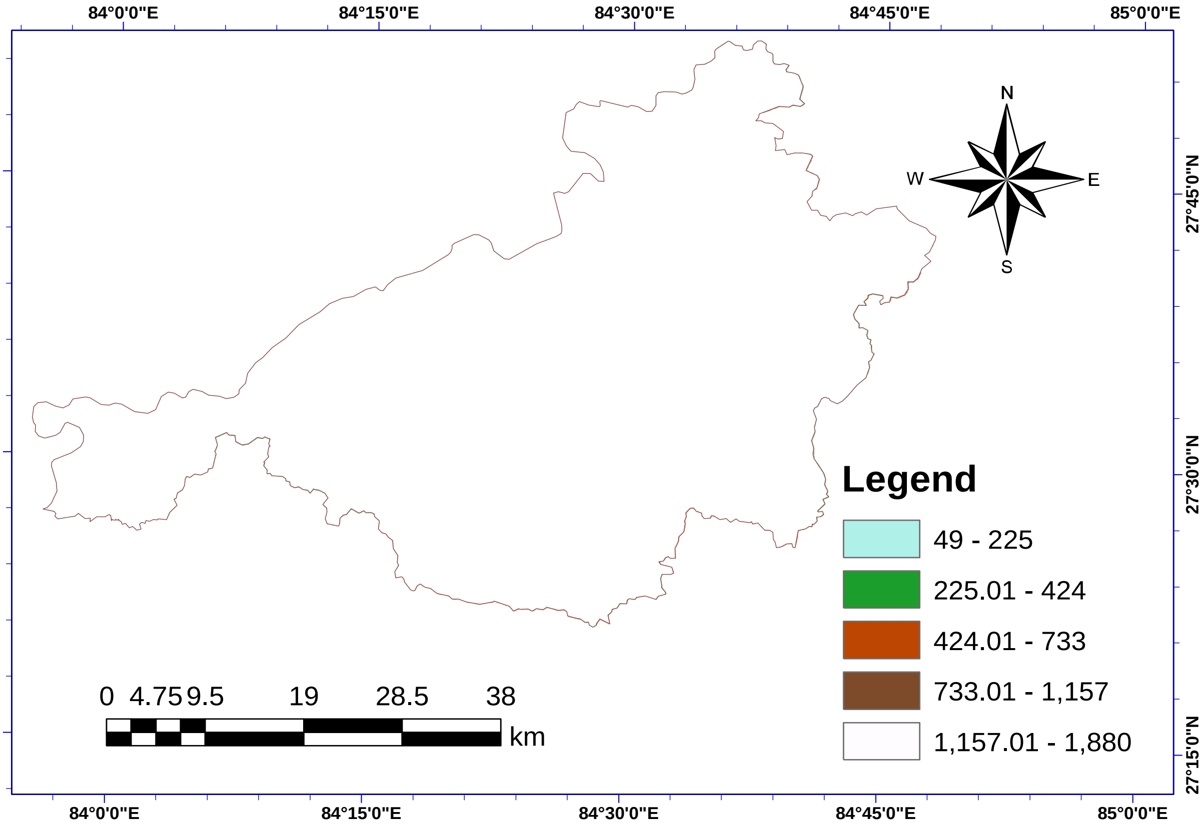


Figure 5.9 Digital Elevation Map of Chitwan District

Map was classified into 5 classes as per elevation as 49-225, 225-424, 424-733, 733-1157 and 1157-1880. The map shows that most of the area lies in the lower region i.e. 49 - 225 m. The lower region contributes more to the recharge of water into the ground. So, most of the area with elevation (49-225 m) and (225-424 m) are more rechargeable than other highly elevated areas from the point of view of elevation. Elevation (49-225m) has the max weightage for ground recharge potential contributing about 41.85% on 100% weightage of elevation and about 1.51% of overall weightage of total analysis whereas max elevation range (1157-1880) has the minimum weightage for ground water recharge potential contributing about 4.35% on total weightage on 100% of elevation and about 0.157% of overall weightage of total analysis.

5.2 Ground water Recharge Potential MAP Analysis

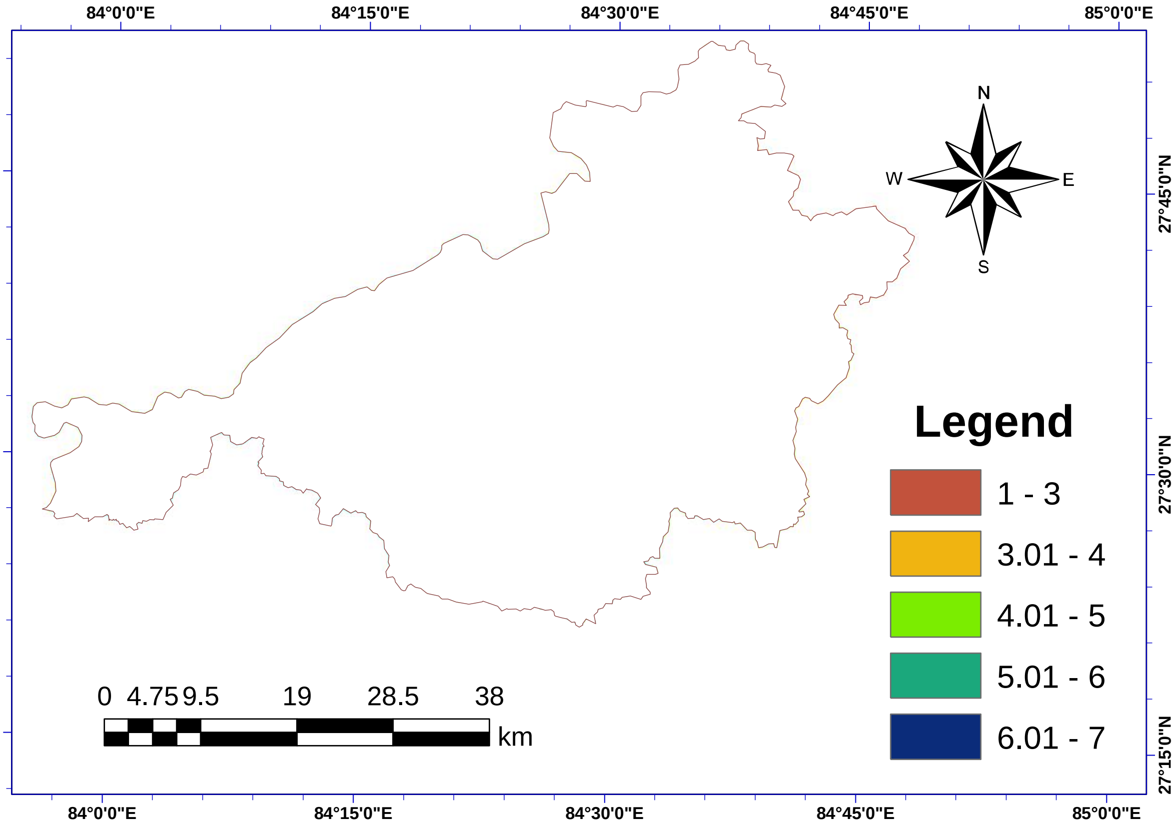


Figure 5.10 Groundwater Recharge Potential Map of Chitwan District

Ground water Recharge Potential Map was prepared by weighted analysis of all 9 layers including Land Use, Type of Soil, Precipitation, Aspect, Slope, Distance from river, Distance from road, Population Density, Elevation using AHP method and union (overlay) tools in GIS. Ground water Recharge Potential Map is a digital diagrammatical representation of ground water recharge capacity of area based on various aspects. Ground water recharge potential map is classified into six various classes based on recharge potential including very low, low, moderately low, moderately high, high and very high.

Table 5.11 Groundwater recharge potential values ranges

Groundwater recharge potential value						
SN	Very low	low	Moderately low	Moderately high	high	Very high
Recharge potential value	1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	6.1-7.0	7.1-8.0

From map we obtained very low recharge potential zone (1-3) to occupy around 6.93% of total area (153.95 Sq.km) and High recharge potential zone (6-9) be 6% of total area (133.17 Sq.km) whereas this district have major moderately recharge potential zone (3-6) occupying about 87% of total area (1932.375 Sq.km) containing low recharge zone (3-4) 16.7% of total area, Moderately Low recharge zone (4-5) 32.35% of total area and Moderately high recharge zone (5-6) 38% of total area. Area with forests and alluvial soil deposit have the max recharge potential whereas higher steeper mountain slopes have low recharge potential.

Table 5.12 Calculation of area coverage of layers of groundwater recharge potential map

Recharge potential	Count	Area (Sq.km)	% of Area
1 to 3 (Very Low)	171053	153.9477	6.936178
3.1 to 4 (Low)	411983	370.7847	16.70586
4.1 to 5 (Moderately Low)	797909	718.1181	32.35511
5.1 to 6 (Moderate High)	937197	843.4773	38.00322
6.1 to 7 (High)	147957	133.1613	5.999638
7.1 to 9 (very high)	0	0	0
Total	2466099	2238.5	100

The above table has shown in bar diagram as:

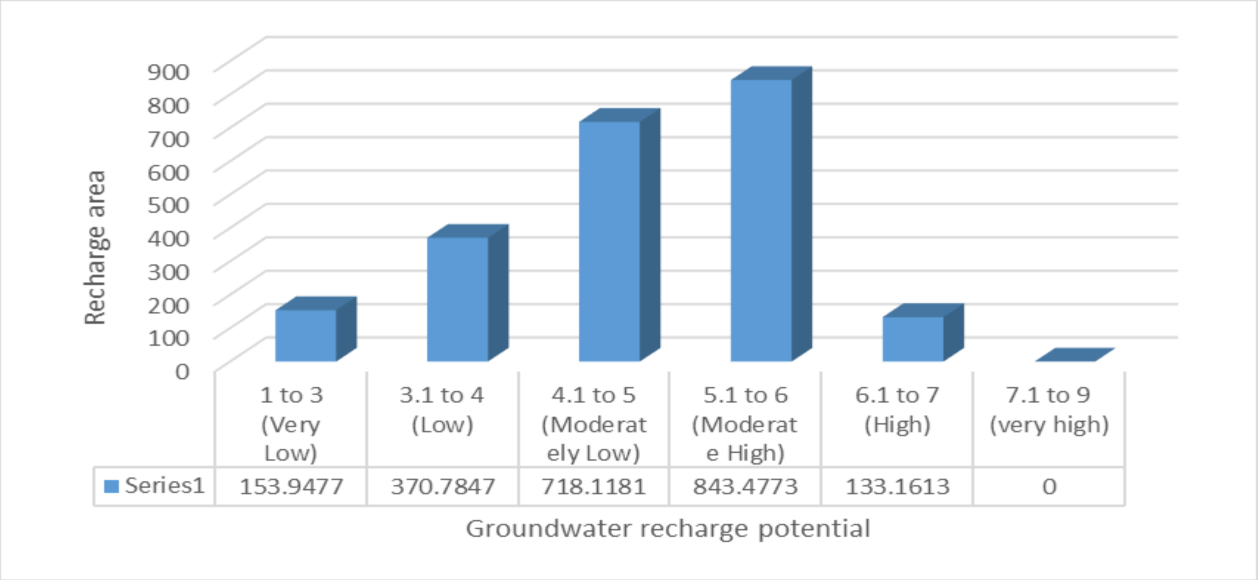


Figure 5.11 Recharge area vs Groundwater recharge potential bar graph

6. CONCLUSION AND RECOMMENDTIONS

6.1 Conclusions

The application of integrated geospatial technology and AHP has proven to be a better tool for the identification of potential groundwater charges zone in Chitwan district. Our study clearly separates the potential zones for ground water recharge by analysing the influencing factors like LULC, Slope, Aspect, Distance from river, Distance from road, Population density, DEM, Type of soil, Precipitation. The results reveals that around 133.17 sq. km (6%) of total area has been identified as high potential zone for groundwater recharge, which is almost the forest portion of our study area. The low recharge potential zone occupy around 153.95 sq. km (6.93%) of the total area, which is the northern steep slope terrain of our study area. The plain and gentle slope in the middle and lower part of study area contribute for high ground water recharge. Haplic Phaeozems (PHh) and Eutric Cambisols (CMe) are considered as suitable soils for ground water recharge, which is mostly found around Ichhyakamana rural municipality and Bharatpur urban municipality areas. The precipitation is high around Bharatpur and Chitwan National Park areas, which contribute for high ground water recharge. Areas that are closer to a river tends to have higher recharge potential than those that are farther away. The areas of Chitwan National Park and Madi urban municipality are closer to the river, contribute to high ground recharge. The Bharatpur metropolitan areas is highly populated and densely urbanized and hence the ground surface of this area is mostly impervious. Due to impervious surface, the surface runoff is high which contribute to low ground water recharge in this area. Mahabharata range having high steep slope hills and mountain have the lowest groundwater recharge potential in the district.

In conclusion, the evaluation of groundwater recharge potential zones is an important step towards sustainable management of groundwater resources. The identification of potential recharge zones can help in the efficient allocation of resources and effective management of groundwater. The evaluation of groundwater recharge potential zones in a particular area can assist in the development of appropriate management strategies for groundwater resources, including the regulation of groundwater withdrawals, recharge enhancement, and the protection of recharge zones. However, it is essential to carry out further studies to assess the quality and quantity of groundwater in these zones and develop appropriate management plans to ensure their sustainable use. Overall, the evaluation of groundwater recharge potential zones is an important step towards achieving sustainable groundwater management and ensuring the long-term availability of this vital resource.

Our study technique is comprehensive multi-parametric and cost effective so has reduced the workload of conventional method. Hence this study is the valuable practical tool for the analysis of the different factors influencing the groundwater recharge and separation of ground water recharge potential zones where results are useful for the planning and management of water supply, irrigation, hydropower, river basin management projects in the study area.

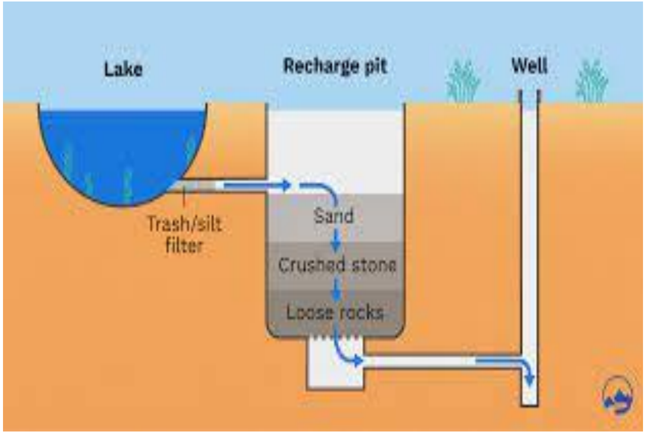
6.2 Recommendations

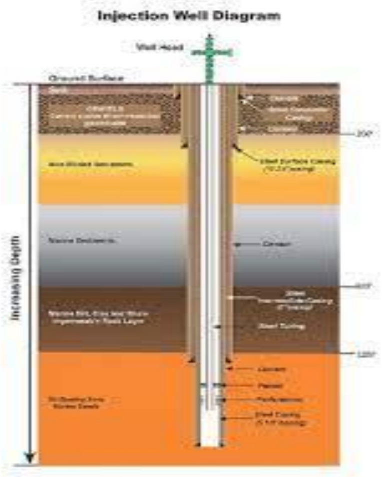
- According to a study published in the International Journal of Environmental Research and Public Health groundwater level in the Chitwan district has been declining at a rate of 0.5 to 1 meter per year thus proper water management efforts should be taken for conservation of recharge zones.
- The government of Nepal has implemented various programs to promote sustainable groundwater management and recharge in Chitwan district, including the National Groundwater Resources Development Board and the Groundwater Resources Management Master Plan which should be promoted.
- Recharge areas can be prioritized for the construction of artificial recharge structures such as check dam, water absorption trenches and farm ponds to store the rainwater and to hold back surface runoff.
- Use of rainwater harvesting and artificial groundwater recharge techniques in Chitwan district is to be promoted to replenish the declining groundwater resources.
- On the basis of the findings, controlled groundwater use should be made in the poor-recharge potential areas of district.
- Water-well drillings should be properly controlled and opened at wide intervals on the field
- According to Pandey et al. (2017), Use of groundwater in Chitwan district is around 56 million cubic meters per year with (around 85%) for irrigation purposes and remaining 15% used for domestic and industrial purposes thus these high recharge potential zones should be protected from urbanization and artificial recharge stations are to be promoted in these areas.
- Further research should be carried out to identify potential recharge zones that were not identified in this study and to determine the feasibility of enhancing groundwater recharge in these zones.

6.3 Selection of artificial recharge station location

1. High and very high recharge zones:

- High groundwater recharge potential zone includes high precipitated, permeable soil and rock formation and forest area in the district thus these location have high natural recharge of groundwater.
- This zone is the suitable location for artificial recharge station in order to enhance recharge through means like infiltration basins and recharge wells.
- Areas in Chitwan national park and Bharatpur municipality are suitable for establishment of artificial recharge station followed by conservation of area from urbanization.





2. Moderate recharge zone:

- Areas where the natural recharge of groundwater is moderate, due to the presence of soils or rock formations with moderate permeability.
- These zone can be suitable for artificial recharge station but requires additional measures like Use of recharge well or injection well to enhance recharge rate.

3. Low recharge zone:

- Low recharge zones may be less suitable for artificial recharge stations, as they may require significant efforts to enhance recharge rates.

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8. ANNEXES

Table A-1: Calculation of overall weightage of different layers

Comparison Matrix

S.N	**Types of Land**	**Land Use**	**Type of soil**	**Precipitation**	**Slope**	**Aspect**	**River Distance**	**Road Distance**	**Population Density**	**Elevation**	**Total**	**Weightage (%)**
1	**Land Use**	1	0.5	0.33	4	3	2	7	3	3	23.83	**14.22**
2	**Type of soil**	2	1	0.5	3	5	3	7	7	6	34.5	**21.02**
3	**Precipitation**	3.03	2	1	5	7	3	9	9	7	46.03	**30.56**
4	**Slope**	0.25	0.33	0.2	1	2	0.5	5	7	3	19.28	**8.6**
5	**Aspect**	0.33	0.2	0.14	0.5	1	0.25	3	3	2	10.43	**5.05**
6	**River Distance**	0.5	0.33	0.33	2	4	1	3	7	5	23.17	**11.85**
7	**Road Distance**	0.14	0.14	0.11	0.2	0.33	0.33	1	3	0.5	5.76	**2.9**
8	**Population Density**	0.33	0.14	0.11	0.14	0.33	0.14	0.33	1	0.5	3.04	**2.2**
9	**Elevation**	0.33	0.17	0.14	0.33	0.5	0.2	2	2	1	6.68	**3.61**
	Total	**7.92**	**4.82**	**2.87**	**16.18**	**23.17**	**10.43**	**37.33**	**42**	**28**	**172.72**	**100**

Normalize Matrix

S.N	Types of Land	Land Use	Type of soil	Precipitation	Slope	Aspect	River Distance	Road Distance	Population Density	Elevation		Total		Average
1	**Land Use**	0.13	0.10	0.11	0.25	0.13	0.19	0.19	0.07	0.11		1.28		**0.14**
2	**Type of soil**	0.25	0.21	0.17	0.19	0.22	0.29	0.19	0.17	0.21		1.89		**0.21**
3	**Precipitation**	0.38	0.42	0.35	0.31	0.30	0.29	0.24	0.21	0.25		2.75		**0.31**
4	**Slope**	0.03	0.07	0.07	0.06	0.09	0.05	0.13	0.17	0.11		0.77		**0.09**
5	**Aspect**	0.04	0.04	0.05	0.03	0.04	0.02	0.08	0.07	0.07		0.45		**0.05**
6	**River Distance**	0.06	0.07	0.12	0.12	0.17	0.10	0.08	0.17	0.18		1.07		**0.12**
7	**Road Distance**	0.02	0.03	0.04	0.01	0.01	0.03	0.03	0.07	0.02		0.26		**0.03**
8	**Population Density**	0.04	0.03	0.04	0.01	0.01	0.01	0.01	0.02	0.02		0.20		**0.02**
9	**Elevation**	0.04	0.03	0.05	0.02	0.02	0.02	0.05	0.05	0.04		0.32		**0.04**
	Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**9.00**	**9.00**	**TRUE**	

Consistency Matrix

S.N	Types of Land	Land Use	Type of soil	Precipitation	Slope	Aspect	River Distance	Road Distance	Population Density	Elevation	Average	Weighted SumValue (WSV)	Ratio= WSV/AVG
1	**Land Use**	0.14	0.11	0.10	0.34	0.15	0.24	0.20	0.07	0.11	0.14	1.46	10.25
2	**Type of soil**	0.28	0.21	0.15	0.26	0.25	0.36	0.20	0.15	0.22	0.21	2.09	9.93
3	**Precipitation**	0.43	0.42	0.31	0.43	0.35	0.36	0.26	0.20	0.25	0.31	3.01	9.84
4	**Slope**	0.04	0.07	0.06	0.09	0.10	0.06	0.15	0.15	0.11	0.09	0.82	9.54
5	**Aspect**	0.05	0.04	0.04	0.04	0.05	0.03	0.09	0.07	0.07	0.05	0.48	9.53
6	**River Distance**	0.07	0.07	0.10	0.17	0.20	0.12	0.09	0.15	0.18	0.12	1.16	9.77
7	**Road Distance**	0.02	0.03	0.03	0.02	0.02	0.04	0.03	0.07	0.02	0.03	0.27	9.33
8	**Population Density**	0.05	0.03	0.03	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.21	9.42
9	**Elevation**	0.05	0.04	0.04	0.03	0.03	0.02	0.06	0.04	0.04	0.04	0.34	9.47

Table A-2: Calculation of weightage of elevation layer

Comparison matrix

		C.I %	**5.48149**	**C.R%**	**4.89419**					
S.N	**Elevation**	**49-225**	**225-424**	**424-733**	**733-1157**	**1157-1880**		**Total**		**Weightage (%)**
1	**49-225**	1	2	3	5	7		18.00		**41.89**
2	**225-424**	0.5	1	3	4	5		13.50		**28.61**
3	**424-733**	0.33	0.33	1	3	5		9.67		**16.74**
4	**733-1157**	0.2	0.25	0.33	1	3		4.78		**8.40**
5	**1157-1880**	0.14	0.20	0.20	0.33	1		1.88		**4.35**
	Total	2.18	3.78	7.53	13.33	21	47.83	47.83	TRUE	**100**

Normalize matrix

S.N	**Elevation**	**49-225**	**225-424**	**424-733**	**733-1157**	**1157-1880**		**Total**		**Average**
1	**49-225**	0.46	0.53	0.40	0.38	0.33	2.09		0.42	1
2	**225-424**	0.23	0.26	0.40	0.30	0.24	1.43		0.29	2
3	**424-733**	0.15	0.09	0.13	0.23	0.24	0.84		0.17	3
4	**733-1157**	0.09	0.07	0.04	0.08	0.14	0.42		0.08	4
5	**1157-1880**	0.07	0.05	0.03	0.03	0.05	0.22		0.04	5
	Total	1	1	1	1	1	5	TRUE		

Consistency matrix

S.N	**Elevation**	**49-225**	**225-424**	**424-733**	**733-1157**	**1157-1880**	**Average**	**Weight Sum Value(WSV)**	**Ratio=WSV/AVG**
1	**49-225**	0.42	0.57	0.50	0.42	0.30	0.42	2.22	5.29
2	**225-424**	0.21	0.29	0.50	0.34	0.22	0.29	1.55	5.42
3	**424-733**	0.14	0.10	0.17	0.25	0.22	0.17	0.87	5.21
4	**733-1157**	0.08	0.07	0.06	0.08	0.13	0.08	0.43	5.07
5	**1157-1880**	0.06	0.06	0.03	0.03	0.04	0.04	0.22	5.10
								ʎmax =	**5.22**

Table A-3: Calculation Of Weightage of Population Density
Comparison Matrix

		C.I %	**4.53**	**C.R%**	**4.04**					
S.N	**Population Density**	**0**	**0-150**	**150-450**	**450-700**	**700-1234**		**Total**		**Weightage (%)**
1	**0**	1.00	2.00	4.00	5.00	7.00		19.00		**43.31**
2	**0-150**	0.50	1.00	3.00	5.00	6.00		15.50		**29.83**
3	**150-450**	0.25	0.33	1.00	3.00	5.00		9.58		**15.43**
4	**450-700**	0.20	0.20	0.33	1.00	2.00		3.73		**7.06**
5	**700-1234**	0.14	0.17	0.20	0.50	1.00		2.01		**4.38**
	Total	2.09	3.70	8.53	14.50	21.00	49.83	49.83	TRUE	**100.00**

Normalized Matrix

S.N	**Population Density**	**0**	**0-150**	**150-450**	**450-700**	**700-1234**		**Total**		**Average**
1	**0**	0.48	0.54	0.47	0.34	0.33		2.17		0.43
2	**0-150**	0.24	0.27	0.35	0.34	0.29		1.49		0.30
3	**150-450**	0.12	0.09	0.12	0.21	0.24		0.77		0.15
4	**450-700**	0.10	0.05	0.04	0.07	0.10		0.35		0.07
5	**700-1234**	0.07	0.05	0.02	0.03	0.05		0.22		0.04
	Total	1	1	1	1	1	5	5	TRUE	

Consistency Matrix

S.N	**Population Density**	**0**	**0-150**	**150-450**	**450-700**	**700-1234**	**Average**	**Weight Sum Value(WSV)**	**Ratio=WSV/AVG**
1	**0**	0.43	0.6	0.62	0.35	0.31	0.43	2.31	5.33
2	**0-150**	0.22	0.3	0.46	0.35	0.26	0.3	1.59	5.34
3	**150-450**	0.11	0.1	0.15	0.21	0.22	0.15	0.79	5.14
4	**450-700**	0.09	0.06	0.05	0.07	0.09	0.07	0.36	5.04
5	**700-1234**	0.06	0.05	0.03	0.04	0.04	0.04	0.22	5.06
								λ_{max} =	**5.18**

Table A-4: Calculation Of Weightage of Distance from River

Comparison Matrix

		C.I %	**4.65974**	**C.R%**	**4.16048**					
S.N	**Distance from River**	**0-750**	**750-1500**	**1500-2250**	**2250-3000**	**3000 above**		**Total**		**Weightage (%)**
1	**0-750**	1	2	3	5	6		17.00		**41.35**
2	**750-1500**	0.5	1	3	4	5		13.50		**28.99**
3	**1500-2250**	0.33	0.33	1.00	3	5		9.67		**17.15**
4	**2250-3000**	0.20	0.25	0.33	1	2		3.78		**7.61**
5	**3000 above**	0.17	0.20	0.20	0.5	1		2.07		**4.90**
	Total	2.20	3.78	7.53	13.5	19	46.02	46.02	TRUE	**100.00**

Normalized Matrix

S.N	**Distance from River**	**0-750**	**750-1500**	**1500-2250**	**2250-3000**	**3000 above**		**Total**		**Average**
1	**0-750**	0.45	0.53	0.40	0.37	0.32		2.07		0.41
2	**750-1500**	0.23	0.26	0.40	0.30	0.26		1.45		0.29
3	**1500-2250**	0.15	0.09	0.13	0.22	0.26		0.86		0.17
4	**2250-3000**	0.09	0.07	0.04	0.07	0.11		0.38		0.08
5	**3000 above**	0.08	0.05	0.03	0.04	0.05		0.24		0.05
	Total	1	1	1	1	1	5	5	TRUE	

Consistency Matrix

S.N	**Distance from River**	**0-750**	**750-1500**	**1500-2250**	**2250-3000**	**3000 above**	**Average**	**Weight Sum Value(WSV)**	**Ratio=WSV/AVG**
1	**0-750**	0.41	0.58	0.51	0.38	0.29	0.41	2.18	5.28
2	**750-1500**	0.21	0.29	0.51	0.30	0.24	0.29	1.56	5.38
3	**1500-2250**	0.14	0.10	0.17	0.23	0.24	0.17	0.88	5.12
4	**2250-3000**	0.08	0.07	0.06	0.08	0.10	0.08	0.39	5.08
5	**3000 above**	0.07	0.06	0.03	0.04	0.05	0.05	0.25	5.07
								λ_{max} =	**5.19**

Table A-5: Calculation Of Weightage of Distance from Road

Comparison Matrix

		C.I %	**3.25**	**C.R%**	**2.90**					
S.N	**Distance from Road**	**0-1250**	**1250-2500**	**2500-3750**	**3750-5000**	**5000 above**		**Total**		**Weightage (%)**
1	**0-1250**	1	0.5	0.33	0.20	0.14		2.18		**4.99**
2	**1250-2500**	2	1	0.33	0.25	0.17		3.75		**7.24**
3	**2500-3750**	3	3	1	0.5	0.25		7.75		**14.74**
4	**3750-5000**	5	4	2	1	0.33		12.33		**23.85**
5	**5000 above**	7	6	4	3	1.00		21.00		**49.18**
	Total	18	14.5	7.67	4.95	1.89	47.01	47.01	TRUE	**100**

Normalised Matrix

S.N	**Distance from Road**	**0-1250**	**1250-2500**	**2500-3750**	**3750-5000**	**5000 above**		**Total**		**Average**
1	**0-1250**	0.06	0.03	0.04	0.04	0.08		0.25		0.05
2	**1250-2500**	0.11	0.07	0.04	0.05	0.09		0.36		0.07
3	**2500-3750**	0.17	0.21	0.13	0.10	0.13		0.74		0.15
4	**3750-5000**	0.28	0.28	0.26	0.20	0.18		1.19		0.24
5	**5000 above**	0.39	0.41	0.52	0.61	0.53		2.46		0.49
	Total	1	1	1	1	1	5	5	TRUE	

Consistency Matrix

S.N	**Distance from Road**	**0-1250**	**1250-2500**	**2500-3750**	**3750-5000**	**5000 above**	**Average**	**Weight Sum Value(WSV)**	**Ratio=WSV/AVG**
1	**0-1250**	0.05	0.04	0.05	0.05	0.07	0.05	0.25	5.08
2	**1250-2500**	0.10	0.07	0.05	0.06	0.08	0.07	0.36	5.01
3	**2500-3750**	0.15	0.22	0.15	0.12	0.12	0.15	0.76	5.13
4	**3750-5000**	0.25	0.29	0.29	0.24	0.16	0.24	1.24	5.18
5	**5000 above**	0.35	0.43	0.59	0.72	0.49	0.49	2.58	5.25
								ʎmax =	**5.13**

Table A-6: Calculation Of Weightage of Precipitation

Comparison Matrix

		C.I %	**=2.48744**	**C.R%**	**=2.22093**					
S.N	**Precipitation**	**2135.6-2341.5**	**2341.6-2547.4**	**2547.5-2753.3**	**2753.4-2959.2**	**2959.3-3165.1**		**Total**		**Weightage (%)**
1	**2135.6-2341.5**	1	0.5	0.33	0.20	0.14		2.18		**5.10**
2	**2341.6-2547.4**	2	1	0.33	0.25	0.20		3.78		**7.75**
3	**2547.5-2753.3**	3	3	1	0.5	0.25		7.75		**15.31**
4	**2753.4-2959.2**	5	4	2	1	0.5		12.50		**26.54**
5	**2959.3-3165.1**	7	5	4	2	1		19.00		**45.30**
	Total	18	13.5	7.67	3.95	2.09	45.21	45.21	TRUE	**100**

Normalized Matrix

S.N	**Precipitation**	**2135.6-2341.5**	**2341.6-2547.4**	**2547.5-2753.3**	**2753.4-2959.2**	**2959.3-3165.1**		**Total**		**Average**
1	**2135.6-2341.5**	0.06	0.04	0.04	0.05	0.07		0.25		0.05
2	**2341.6-2547.4**	0.11	0.07	0.04	0.06	0.10		0.39		0.08
3	**2547.5-2753.3**	0.17	0.22	0.13	0.13	0.12		0.77		0.15
4	**2753.4-2959.2**	0.28	0.30	0.26	0.25	0.24		1.33		0.27
5	**2959.3-3165.1**	0.39	0.37	0.52	0.51	0.48		2.27		0.45
	Total	1	1	1	1	1	5	5	TRUE	

Consistency Matrix

S.N	**Precipitation**	**2135.6-2341.5**	**2341.6-2547.4**	**2547.5-2753.3**	**2753.4-2959.2**	**2959.3-3165.1**	**Average**	**Weight Sum Value(WSV)**	**Ratio=WSV/AVG**
1	**2135.6-2341.5**	0.05	0.04	0.05	0.05	0.06	0.05	0.26	5.07
2	**2341.6-2547.4**	0.10	0.08	0.05	0.07	0.09	0.08	0.39	5.00
3	**2547.5-2753.3**	0.15	0.23	0.15	0.13	0.11	0.15	0.78	5.13
4	**2753.4-2959.2**	0.25	0.31	0.31	0.27	0.23	0.27	1.36	5.14
5	**2959.3-3165.1**	0.36	0.39	0.61	0.53	0.45	0.45	2.34	5.17
								λ_{max} =	**5.10**

Table A-7: Calculation Of Weightage of Slope

Comparison Matrix

		C.I %	**3.96**	**C.R%**	**3.54**					
S.N	**Slope**	**0-10**	**10-30**	**30-45**	**45-65**	**65-160**		**Total**		**Weightage (%)**
1	**0-10**	1	2	3	5	7		18		**42.0593**
2	**10-30**	0.5	1	2	5	6		14.50		**28.32**
3	**30-45**	0.33	0.5	1	3	5		9.83		**17.44**
4	**45-65**	0.2	0.2	0.33	1	3		4.73		**8.02**
5	**65-160**	0.14	0.17	0.20	0.33	1		1.84		**4.16**
	Total	2.18	3.87	6.53	14.33	22	48.91	48.91	TRUE	**100**

Normalised Matrix

S.N	**Slope**	**0-10**	**10-30**	**30-45**	**45-65**	**65-160**		**Total**		**Average**
1	**0-10**	0.46	0.52	0.46	0.35	0.32		2.10		0.42
2	**10-30**	0.23	0.26	0.31	0.35	0.27		1.42		0.28
3	**30-45**	0.15	0.13	0.15	0.21	0.23		0.87		0.17
4	**45-65**	0.09	0.05	0.05	0.07	0.14		0.40		0.08
5	**65-160**	0.07	0.04	0.03	0.02	0.05		0.21		0.04
	Total	1	1	1	1	1	5	5	TRUE	

Consistency Matrix

S.N	**Slope**	**0-10**	**10-30**	**30-45**	**45-65**	**65-160**	**Average**	**Weight Sum Value(WSV)**	**Ratio=WSV/AVG**
1	**0-10**	0.42	0.57	0.52	0.40	0.29	0.42	2.20	5.24
2	**10-30**	0.21	0.28	0.35	0.40	0.25	0.28	1.49	5.27
3	**30-45**	0.14	0.14	0.17	0.24	0.21	0.17	0.90	5.19
4	**45-65**	0.08	0.06	0.06	0.08	0.12	0.08	0.40	5.04
5	**65-160**	0.06	0.05	0.03	0.03	0.04	0.04	0.21	5.06
									λ_{max} =5.16

Table A-8: Calculation Of Weightage of Types of Soil

Comparison Matrix

Types of Soil	**CMe**	**CMg**	**Gle**	**PHh**	**RGd**		**Total**		**Weightage (%)**
CMe	1.00	6.00	4.00	1.50	7.00		19.50		**44.49**
CMg	0.17	1.00	0.67	0.25	1.00		3.08		**7.21**
Gle	0.25	1.50	1.00	0.33	2.00		5.08		**11.18**
PHh	0.67	4.00	3.00	1.00	5.00		13.67		**30.80**
RGd	0.14	1.00	0.50	0.20	1.00		2.84		**6.32**
Total	2.23	13.50	9.17	3.28	16.00	44.18	44.18	TRUE	**100**

Normalized Matrix

Types of Soil	**CMe**	**CMg**	**Gle**	**PHh**	**RGd**		**Total**		**Average**
CMe	0.45	0.44	0.44	0.46	0.44		2.22		0.44
CMg	0.07	0.07	0.07	0.08	0.06		0.36		0.07
Gle	0.11	0.11	0.11	0.10	0.13		0.56		0.11
PHh	0.30	0.30	0.33	0.30	0.31		1.54		0.31
RGd	0.06	0.07	0.05	0.06	0.06		0.32		0.06
Total	1.00	1.00	1.00	1.00	1.00	5.00	5.00	TRUE	

Consistency Matrix

Types of Soil	**CMe**	**CMg**	**Gle**	**PHh**	**RGd**	**Average**	**Weight Sum Value(WSV)**	**Ratio=WSV/AVG**
CMe	0.44	0.43	0.45	0.46	0.44	0.44	2.23	5.01
CMg	0.07	0.07	0.07	0.08	0.06	0.07	0.36	5.01
Gle	0.11	0.11	0.11	0.10	0.13	0.11	0.56	5.01
PHh	0.30	0.29	0.34	0.31	0.32	0.31	1.54	5.01
RGd	0.06	0.07	0.06	0.06	0.06	0.06	0.32	5.00
		CI%= 0.2	**CR% = 0.2**					**ʎ$_{max}$ = 5.01**

Table A-9: Calculation Of Weightage of Aspect

Comparison Matrix

S.N	Aspect	Flat	North	East	South	West		Total		Weightage (%)
1	**Flat**	1.00	2.00	5.00	7.00	3.00		18.00		**42.75**
2	**North**	0.50	1.00	3.00	5.00	4.00		13.50		**29.50**
3	**East**	0.20	0.33	1.00	3.00	0.50		5.03		**9.65**
4	**South**	0.14	0.20	0.33	1.00	0.33		2.01		**4.77**
5	**West**	0.33	0.25	2.00	3.00	1.00		6.58		**13.34**
	Total	2.18	3.78	11.33	19.00	8.83	45.13	45.13	TRUE	**100**

Normalized Matrix

S.N	Aspect	Flat	North	East	South	West		Total		Average
1	**Flat**	0.46	0.53	0.44	0.37	0.34		2.14		0.43
2	**North**	0.23	0.26	0.26	0.26	0.45		1.47		0.29
3	**East**	0.09	0.09	0.09	0.16	0.06		0.48		0.10
4	**South**	0.07	0.05	0.03	0.05	0.04		0.24		0.05
5	**West**	0.15	0.07	0.18	0.16	0.11		0.67		0.13
	Total	1.00	1.00	1.00	1.00	1.00	5.00	5.00	TRUE	

Consistency Matrix

S.N	Aspect	Flat	North	East	South	West	Average	Weight Sum Value(WSV)	Ratio=WSV/AVG
1	**Flat**	0.43	0.59	0.48	0.33	0.40	0.43	2.23	5.23
2	**North**	0.21	0.29	0.29	0.24	0.53	0.29	1.57	5.32
3	**East**	0.09	0.10	0.10	0.14	0.07	0.10	0.49	5.08
4	**South**	0.06	0.06	0.03	0.05	0.04	0.05	0.24	5.13
5	**West**	0.14	0.07	0.19	0.14	0.13	0.13	0.69	5.14
		CI% = 4	**CR% = 4.5**					**ʎ$_{max}$ =**	**5.18**

Table A-10: Calculation Of Weightage of land Use

Comparison Matrix

S.N	**Land Use**	**Water Bodies**	**Riverbed**	**Forests**	**Agricultural Areas**	**Built-Up Areas**		**Total**		**Weightage (%)**
1	**Water Bodies**	1.00	0.33	0.11	0.14	0.50		2.09		**4.23**
2	**Riverbed**	3.00	1.00	0.17	0.25	2.00		6.42		**10.92**
3	**Forests**	9.00	6.00	1.00	2.00	5.00		23.00		**47.87**
4	**Agricultural Areas**	7.00	4.00	0.50	1.00	3.00		15.50		**28.77**
5	**Built-Up Areas**	2.00	0.50	0.20	0.33	1.00		4.03		**8.21**
	Total	**22.00**	**11.83**	**1.98**	**3.73**	**11.50**	**51.04**	**51.04**	**TRUE**	**100**

Normalized Matrix

S.N	**Land Use**	**Water Bodies**	**Riverbed**	**Forests**	**Agricultural Areas**	**Built-Up Areas**		**Total**		**Average**
1	**Water Bodies**	0.05	0.03	0.06	0.04	0.04		0.21		0.04
2	**Riverbed**	0.14	0.08	0.08	0.07	0.17		0.55		0.11
3	**Forests**	0.41	0.51	0.51	0.54	0.43		2.39		0.48
4	**Agricultural Areas**	0.32	0.34	0.25	0.27	0.26		1.44		0.29
5	**Built-Up Areas**	0.09	0.04	0.10	0.09	0.09		0.41		0.08
	Total	1.00	1.00	1.00	1.00	1.00	5.00	5.00	TRUE	

Consistency Matrix

S.N	**Land Use**	**Water Bodies**	**Riverbed**	**Forests**	**Agricultural Areas**	**Built-Up Areas**	**Average**	**Weight Sum Value(WSV)**	**Ratio=WSV/AVG**
1	**Water Bodies**	0.04	0.04	0.05	0.04	0.04	0.04	0.21	5.06
2	**Riverbed**	0.13	0.11	0.08	0.07	0.16	0.11	0.55	5.06
3	**Forests**	0.38	0.66	0.48	0.58	0.41	0.48	2.50	5.22
4	**Agricultural Areas**	0.30	0.44	0.24	0.29	0.25	0.29	1.51	5.24
5	**Built-Up Areas**	0.08	0.05	0.10	0.10	0.08	0.08	0.41	5.03
			CI% = 3		**CR% = 2.7**			**ʎ$_{max}$ =**	**5.12**

Table A-11: Coordinates of rainfall station

ID	Name	Lat	Long	Elevation
62	**P902**	27.62	84.42	256
63	**P903**	27.58	84.53	270
67	**P920**	27.55	84.82	274
68	**P925**	27.43	84.98	332

Table A-12: Precipitation data of year 2020 of Chitwan District

Date	st902	st903	st920	st925
1/1/2020	0	0	0	0
1/2/2020	0	0	0	0
1/3/2020	0	0	0	0
1/4/2020	20	24.2	11.80414	0
1/5/2020	2.8	0	3.613511	0
1/6/2020	0	0	0	0
1/7/2020	0	0	0	0
1/8/2020	0	0	0	0
1/9/2020	5.9	5	4.818015	0
1/10/2020	4.6	2	0	0
1/11/2020	0	0	0	0
1/12/2020	0	0	0	0
1/13/2020	0	0	0	0
1/14/2020	0	0	0	0
1/15/2020	0	0	0	0
1/16/2020	0	0	0	0
1/17/2020	31.5	39.2	43.36214	0
1/18/2020	0	26.2	37.33962	0
1/19/2020	0	0	0	0
1/20/2020	0	0	2.890809	0
1/21/2020	0	0	0	0
1/22/2020	0	0	0	0
1/23/2020	0	0	0	0
1/24/2020	0	0	0	0
1/25/2020	0	0	0	0
1/26/2020	0	0	0	0
1/27/2020	0	0	0	0
1/28/2020	0	0	0	0
1/29/2020	2	0	0	0
1/30/2020	0	0	0	0
1/31/2020	0	0	0	0
2/1/2020	0	0	0	0
2/2/2020	0	0	0	0
2/3/2020	0	0	0	0
2/4/2020	0	0	0	0
2/5/2020	0	0	0	0

Date	st902	st903	st920	st925
2/6/2020	0	0	0	0
2/7/2020	0	0	0	0
2/8/2020	0	0	0	0
2/9/2020	0	0	0	0
2/10/2020	0	0	0	0
2/11/2020	0	0	0	0
2/12/2020	0	0	0	0
2/13/2020	0	0	0	0
2/14/2020	0	0	0	8.370999
2/15/2020	0	0	0	0
2/16/2020	0	0	0	0
2/17/2020	0	0	0	0
2/18/2020	0	0	0	0
2/19/2020	0	0	0	0
2/20/2020	0	0	0	0
2/21/2020	0	0	0	0
2/22/2020	7.3	8.2	8.431527	0
2/23/2020	0	0	0	0
2/24/2020	0	0	0	0
2/25/2020	0	0	0	0
2/26/2020	0	41.2	13.97224	0
2/27/2020	0	3.2	17.10395	0
2/28/2020	0	0	0	0
2/29/2020	0	0	0	0
3/1/2020	0	0	0	0
3/2/2020	0	0	0	0
3/3/2020	0	0	0	0
3/4/2020	0	0	0	0
3/5/2020	0	0	0	0
3/6/2020	0	10.4	0	0
3/7/2020	16.1	15.2	9.274679	0
3/8/2020	0	0	0	1.890226
3/9/2020	0	0	0	0
3/10/2020	0	0	0	3.240387
3/11/2020	0	0	0	0
3/12/2020	0	0	0	0
3/13/2020	0	0	0	0
3/14/2020	0	2	9.636031	0
3/15/2020	0	0	0	0
3/16/2020	0	0	0	5.940709
3/17/2020	0	0	0	0
3/18/2020	0	0	0	3.510419
3/19/2020	0	0	0	0
3/20/2020	0	0	0	0
3/21/2020	2.7	0	0	0
3/22/2020	0	8.2	0	0
3/23/2020	1.5	0	0	5.670677
3/24/2020	0	0	0	0
3/25/2020	0	0	0	7.290871
3/26/2020	0	0	0	0
3/27/2020	0	0	0	0
3/28/2020	0	0	0	0
3/29/2020	0	0	0	51.57616
3/30/2020	0	0	0	0
3/31/2020	0	0	0	9.991193
4/1/2020	0	0	0	0
4/2/2020	0	0	2.409008	0

4/3/2020	0	0	0	0
4/4/2020	0	0	0	0
4/5/2020	0	0	0	0
4/6/2020	0	0	0	0
4/7/2020	0	0	0	0
4/8/2020	0	0	0	0
4/9/2020	0	0	0	0
4/10/2020	0	0	0	0
4/11/2020	0	0	0	0
4/12/2020	0	0	0	0
4/13/2020	0	0	0	0
4/14/2020	0	0	9.154229	0
4/15/2020	2.6	2	9.636031	0
4/16/2020	0	0	0	25.65306
4/17/2020	1.3	0	6.022519	22.41268
4/18/2020	33.4	34.4	0	12.96155
4/19/2020	0	0	14.69495	77.76929
4/20/2020	17.7	59.2	2.168107	34.56413
4/21/2020	5.1	0	14.69495	4.050484
4/22/2020	13.6	19	17.34485	0
4/23/2020	0	0	2.409008	1.620193
4/24/2020	0	19.2	13.97224	8.911064
4/25/2020	11.5	13	8.672427	3.510419
4/26/2020	0	2	0	5.940709
4/27/2020	0	0	0	2.160258
4/28/2020	4.7	8.2	0	3.240387
4/29/2020	3.5	2	1.445405	8.100967
4/30/2020	2.2	1	0	0
5/1/2020	12	11.2	0	27.54329
5/2/2020	0	1	1.927206	3.240387
5/3/2020	0.8	2	0	10.80129
5/4/2020	0	0	6.26342	3.240387
5/5/2020	28.2	14.4	17.58576	5.670677
5/6/2020	4.6	24.4	18.54936	10.80129
5/7/2020	0.8	0	7.467924	25.65306
5/8/2020	9.5	2	8.672427	0
5/9/2020	0	0	0	10.53126
5/10/2020	0	0	0	0
5/11/2020	2	9.4	0	4.590548
5/12/2020	0	0	0	8.370999
5/13/2020	0	0	0	2.160258
5/14/2020	0	0	0	0
5/15/2020	4.8	29.2	0	0
5/16/2020	10.2	2	0	21.33255
5/17/2020	0	0	0	7.560903
5/18/2020	0	0	0	29.70355
5/19/2020	7.4	0	0	11.07132
5/20/2020	0	0	0	6.480774
5/21/2020	0	0	5.540718	0
5/22/2020	0	0	0	23.49281
5/23/2020	0.6	0	0	0
5/24/2020	0	0	0	6.480774
5/25/2020	16.7	15.4	0	5.400645
5/26/2020	7.2	13.4	13.49044	0
5/27/2020	0	3.2	24.57188	0
5/28/2020	1.4	0	10.35873	0
5/29/2020	0	0	9.154229	0
5/30/2020	63.5	26.4	0	3.240387

5/31/2020	123.2	4.4	0	0
6/1/2020	28.6	21.4	17.58576	0
6/2/2020	0	0	0	0
6/3/2020	0	0	0	13.77164
6/4/2020	17.6	0	0	28.08335
6/5/2020	6.7	5.2	10.35873	2.160258
6/6/2020	10.1	10.2	28.66719	3.240387
6/7/2020	3.1	7.2	0	15.12181
6/8/2020	0	0	55.64808	27.27326
6/9/2020	32.8	15.2	0	69.66832
6/10/2020	97.9	24	0	76.14909
6/11/2020	1.1	0	0	56.9768
6/12/2020	0	3.2	4.818015	10.80129
6/13/2020	0.8	0	22.40377	21.60258
6/14/2020	0	0	63.116	0
6/15/2020	7.3	6.2	38.54412	47.25564
6/16/2020	29.1	46.2	40.23043	27.00322
6/17/2020	0	8.2	7.467924	0
6/18/2020	26.1	0	27.70359	32.40387
6/19/2020	0	4.4	7.708824	4.320516
6/20/2020	35	20.2	14.69495	29.43351
6/21/2020	2.6	2.2	4.818015	3.510419
6/22/2020	6.8	4	39.26682	8.370999
6/23/2020	9.7	12.2	30.1126	0
6/24/2020	0	4	0	6.750806
6/25/2020	14.2	22.4	64.0796	27.27326
6/26/2020	6.9	30.2	4.095313	8.100967
6/27/2020	42.9	19.4	0	44.55532
6/28/2020	93.2	10	0	20.79248
6/29/2020	8.5	5.2	7.467924	52.92632
6/30/2020	5.1	13.4	11.80414	2.970355
7/1/2020	0	12.4	0	17.5521
7/2/2020	20.2	2.2	0	4.590548
7/3/2020	2.9	2.2	0	6.210742
7/4/2020	0	3.4	8.792878	12.69152
7/5/2020	0	2	20.47656	15.66187
7/6/2020	28.4	7.4	58.53889	1.890226
7/7/2020	13.2	4.2	29.63079	1.620193
7/8/2020	14.7	17.2	2.890809	44.28529
7/9/2020	56.7	4.2	5.058916	3.510419
7/10/2020	107.3	65.4	36.13511	6.480774
7/11/2020	90.9	41.2	13.49044	7.020838
7/12/2020	40.2	2.2	13.97224	0
7/13/2020	119.4	92.4	30.3535	4.320516
7/14/2020	44.1	25.2	17.82666	3.240387
7/15/2020	1.3	2.4	2.649908	9.181096
7/16/2020	1.3	9.4	0	64.53771
7/17/2020	0	31.4	0	36.72438
7/18/2020	2.2	5.2	6.504321	7.020838
7/19/2020	40.8	15.4	8.913328	0
7/20/2020	88.2	43.4	43.60304	4.320516
7/21/2020	57	102.4	70.10212	10.26123
7/22/2020	4.2	2.2	8.431527	2.700322
7/23/2020	79.4	42.2	18.06756	29.97358
7/24/2020	20.8	49.4	52.03456	14.04168
7/25/2020	5.7	7.4	3.854412	8.370999
7/26/2020	0	0	0	27.00322
7/27/2020	98.6	26.4	0	0

7/28/2020	49.6	58.2	0	0
7/29/2020	12.1	2.2	15.65855	0
7/30/2020	33.7	9.4	0	2.700322
7/31/2020	30.8	28.2	6.745221	10.80129
8/1/2020	53.7	0	50.83006	6.480774
8/2/2020	18.9	11.4	0	7.290871
8/3/2020	0	0	5.058916	3.510419
8/4/2020	0	2	0	51.30613
8/5/2020	45.4	16.2	11.80414	1.620193
8/6/2020	12.1	18.4	15.17675	0
8/7/2020	0	0	0	4.86058
8/8/2020	12.5	0	19.03116	6.210742
8/9/2020	0	4.2	28.42629	13.77164
8/10/2020	2.8	32.4	21.31972	9.721161
8/11/2020	1.6	8.2	38.54412	11.61139
8/12/2020	10	36.4	13.97224	39.15468
8/13/2020	11.2	6.4	0	20.25242
8/14/2020	14.1	11.6	4.336214	21.60258
8/15/2020	33.3	6.4	27.70359	0
8/16/2020	2.6	0	0	0
8/17/2020	0.8	0	5.540718	0
8/18/2020	0	0	3.854412	7.560903
8/19/2020	0	12.2	15.65855	0
8/20/2020	5.8	4.4	43.84394	0
8/21/2020	5.2	36.4	3.854412	11.88142
8/22/2020	6.4	0	0	0
8/23/2020	18.3	0	0	0
8/24/2020	0	0	0	0
8/25/2020	0	0	58.53889	0

8/26/2020	0	0	0	0
8/27/2020	26.8	12.4	9.39513	0
8/28/2020	0	9.4	57.33438	0
8/29/2020	7.2	4.4	0	114.7637
8/30/2020	0	0	0	0
8/31/2020	0	0	0	21.06251
9/1/2020	35	3.2	0	1.890226
9/2/2020	3.4	12.4	1.204504	21.60258
9/3/2020	19.2	0	2.409008	7.830935
9/4/2020	6	4.4	0	0
9/5/2020	0	0	0	11.61139
9/6/2020	0.5	9	0	41.31493
9/7/2020	1.7	21.2	0	26.19313
9/8/2020	51.9	12.4	0	0
9/9/2020	123	77.2	0	0
9/10/2020	0.8	0	0	0
9/11/2020	43.8	26.2	3.613511	0
9/12/2020	14.4	34.9	0	20.25242
9/13/2020	35.3	43.2	24.09008	2.970355
9/14/2020	4.7	1	0	0
9/15/2020	23.4	62.2	2.168107	0
9/16/2020	14.2	5.6	3.854412	0
9/17/2020	40.6	12.4	1.445405	0
9/18/2020	125.7	43.2	0	0
9/19/2020	0.9	2.2	2.409008	0
9/20/2020	0	0	0	0
9/21/2020	0	0	0	0
9/22/2020	0	22.4	13.73134	0
9/23/2020	20.7	19	46.49385	0

9/24/2020	160.4	126.4	55.16627	0
9/25/2020	100.2	81.2	34.44881	0
9/26/2020	17.9	18.4	8.913328	0
9/27/2020	0	0	0	0
9/28/2020	0	0	0	0
9/29/2020	0	0	0	0
9/30/2020	0	0	0	0
10/1/2020	0	0	0	0
10/2/2020	0	0	0	0
10/3/2020	0	9.4	0	0
10/4/2020	0	0	0	0
10/5/2020	0	0	0	0
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10/22/2020	0	0	0	0
10/23/2020	0	0	0	0
10/24/2020	0	0	0	21.87261
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10/27/2020	0	0	0	0
10/28/2020	0	0	0	0
10/29/2020	0	0	0	0
10/30/2020	0	0	0	0
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11/6/2020	0	0	0	0
11/7/2020	0	0	0	0
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11/9/2020	0	0	0	0
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11/11/2020	0	0	0	0
11/12/2020	0	0	0	0
11/13/2020	0	0	0	0
11/14/2020	0	0	0	0
11/15/2020	0	0	0	0
11/16/2020	0	0	0	0
11/17/2020	0	0	0	0
11/18/2020	0	0	0	0
11/19/2020	0	0	0	0
11/20/2020	0	0	0	0

11/21/2020	0	0	0	0
11/22/2020	0	0	0	0
11/23/2020	0	0	0	0
11/24/2020	0	0	0	0
11/25/2020	0	0	0	0
11/26/2020	0	0	0	0
11/27/2020	0	0	0	0
11/28/2020	0	0	0	0
11/29/2020	0	0	0	0
11/30/2020	0	0	0	0
12/1/2020	0	0	0	0
12/2/2020	0	0	0	0
12/3/2020	0	0	0	0
12/4/2020	0	0	0	0
12/5/2020	0	0	0	0
12/6/2020	0	0	0	0
12/7/2020	0	0	0	0
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12/10/2020	0	0	0	0
12/11/2020	0	0	0	0
12/12/2020	0	0	0	0
12/13/2020	0	0	0	0
12/14/2020	0	0	0	0
12/15/2020	0	0	0	0
12/16/2020	0	0	0	0
12/17/2020	0	0	0	0
12/18/2020	0	0	0	29.70355
12/19/2020	0	0	0	31.59377
12/20/2020	0	0	0	0
12/21/2020	0	0	0	0
12/22/2020	0	0	0	4.320516
12/23/2020	0	0	0	0
12/24/2020	0	0	0	0
12/25/2020	0	0	0	0
12/26/2020	0	0	0	0
12/27/2020	0	0	0	0
12/28/2020	0	0	0	0
12/29/2020	0	0	0	0
12/30/2020	0	0	0	0
12/31/2020	0	0	0	0