Ame haGeomorphic Analysis for Effective Planning of Rainwater Harvesting in part of Sirsa Watershed, Nalagarh, Himachal Pradesh

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Abstract: Baddi Industrial Complex is a fast developing industrial hub with more than 10,000 industrial units with 2,500 Pharmaceutical & food processing units and 5,000 small & big units, including textile units. As the water supply in the city and industries is dependent entirely on the development of groundwater resources therefore the sustainability of these resources to meet the stipulated demand in future depends on harnessing of the Rainfall runoff. In order to study the total model of the recharge potential, a detailed study of existing geology, sub surface lithology and the computation of non committed monsoon runoff thus becomes imperative. Geologically, the area is underlain with a thick valley filled with deposits of Pleistocene Period consisting of boulders, pebbles, gravel with intervening lenses of clay/ silty clay. The ratio of the boulder beds to the clay lenses is about 75:25. Therefore, the area has a very high permeability. The major aquifers occur up to a depth of 300m and underlain with Shiwalik rocks having undulating configuration.

Thus, rainwater harvesting has become the obvious management option in the area where the groundwater is continuously being exploited to meet the demand of various user sectors. The continuous development of groundwater has resulted in the decline of the water table near the watershed boundary. The average annual rainfall of the area is 851 mm and most of the water goes off as runoff through the various drains to the river Sirsa which becomes flooded during monsoons. In order to use the surplus monsoon runoff detailed study has been done for the computation of Utilizable Runoff and number of structures which can be planned for its utilization. It is estimated that the total runoff is 18 MCM out of which 12.6 MCM is utilizable potential in an area of 89.63 sq km. In order to effectively plan the rainwater harvesting structures the morphometric analysis has been done by calculating Linear parameters such as number and order of streams, bifurcation ratio, stream length ratio, basin length and areal parameters such as drainage density, frequency (km^2), form factor, circulatory ratio, elongation ratio. In the computation of the number of water conservation/recharge structures, various thematic maps were prepared through visual interpretation of satellite data. The digital analysis has been carried out using GIS software Arc GIS 10 and ERDAS and the Geo-informatics based multi criteria evaluation has been done using Weighted Overlays and AHP methods. It is estimated that it is possible to construct 600 point recharge structures, 60 storage/percolation tanks and about 400 check dams. In order to demonstrate the effective design for recharge structures, a pilot project has been implemented in the Baddi University to showcase the cost effective technology in Rainwater Harvesting using geo textile instead of cost-intensive inverted filter for removing the suspended load in the runoff to be recharged.

Keywords

Rainwater Harvesting structures, Watershed, Utilizable Runoff, Morphometric Analysis, Geoinformatics

1. Introduction:

The Baddi industrial complex area is located at the foot hill of the Himalayas in the Solan district of Himachal Pradesh and it forms a part of Nalagarh Valley. The study area is 39.26 km^2 covering the industrial town of Baddi, under the Nalagarh watershed. The proposed study area is a fast developing industrial hub with polluting and non-polluting industries, along with development of domestic & commercial infrastructures to support the industry .In the industrial complex. There are more than 10,000 industrial units out of which 2500 are the Pharmaceutical and food processing units and 5000 small and big units; some of them are textile units. The water supply to the industrial complex and other allied infrastructure depend entirely on the development of groundwater resources.

The deep tube wells are being constructed by all the industrial units to meet their water demand. The discharge from the industries is polluting the ground water which is the only source of water supply. Nalagarh has been classified under Class IV cities (with population less than 20,000) by High Powered expert committee of Ministry for Urban Development (HPEC, 2011), subsequently there will be further increase in the overall infrastructural development in the area, resulting in pressure on present water resources.

1.1. Location:

The Baddi Industrial area is located in Solan district of Himachal Pradesh. Solan is one of the Southwestern districts of Himachal Pradesh having geographical area of 1,936 square kilometers and located at a distance of 48 kilometers from Shimla. The district lies between North latitude 30°44’53” to 31°22’01” and East longitude 76°36’10” to 77°15’14” and is covered by Survey of India degree-sheets 53A, 53B, 53E and 53F. The district is bounded by Bilaspur district in North-West & Mandi district in the North, Shimla & Sirmaur district in East & South-East respectively. District has inter-state boundary in the South and West with State of Haryana and Punjab respectively (Fig. 1) The Baddi Industrial complex falls in south west of Solan district. The area under investigation covers 39.26 km.

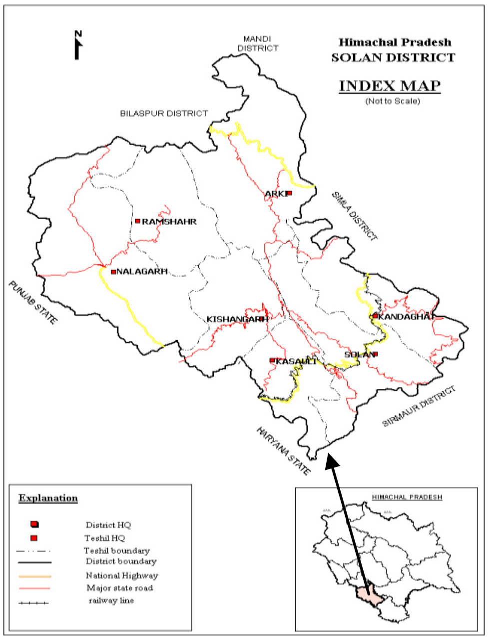

Fig.1: Location Map of Nalagarh

1.3. Climate:

The area has a humid to semi-arid type of climate and experiences three distinct seasons. The monsoon starts towards the end of June and continues till the middle of September. During October and November, the climate is generally pleasant with very scanty precipitation. The winter lasts from December to February. The minimum day temperature is usually around 5º C. A moderate amount of winter rains are received during this period. The spring months of March and April are generally summer months are quite hot days and are oppressive. At Chandigarh (the observatory closest to Nalagarh) the temperature ranges between 30.4^{o}C and 16.5^{o}C. Maximum daily temperature of 38.6^{o}C is observed in June and minimum of 6.1^{o}C in January.

1.3.1. Rainfall:

The different parts of areas do not show any uniformity in the amount of rainfall throughout the year. The study area receives an annual average 1100 mm rainfall which goes up to 1400 mm in the catchment of Balad nadi. The area thus receives about 1.32 million cum. of rainfall which can be harnessed for recharging the aquifers. In order to have the increased sustainability of the aquifers to ensure the availability of ground water to meet the demand for longer period, the present project is of great significance. The five years (1999-2003) rainfall of Nalagarh area under which project area falls is given in Table 1. Due to high porosity and permeability, rainfall is generally absorbed in the soil as the soils are silty sand. Further, study of data of last twenty years has shown maximum rainfall recorded in 1988 as 1641 mm and minimum rainfall recorded as 862 mm in 2006. While, the major share of precipitation, received in the district i.e. around 70% is received from July to September.

Table 1: Rainfall (in mm) for the District Solan

Year	Rainfall in (mm)
1999	1182.9
2000	937.4
2001	856.5
2002	908.9
2003	856.7

Source: State of Environment of the Himachal Pradesh, 2006

1.4. Objectives of the Study:

Strategic planning with sound data base is a pre-requisite for sustainable development of the ground water resources, which further ensures positive impact on socio-economic condition of an area. Baddi industrial area of Solan district is likely to encounter with multiplicity of water problems. In order to study the total model of the recharge potential, the present study entails a detailed study of existing geology, sub surface lithology and the computation of non committed monsoon runoff. In order to use the surplus monsoon runoff available in the watershed a detailed study has been done for the computation of Utilizable Runoff and number of structures which can be planned for its utilization.

In order to effectively plan the rainwater harvesting structures the present study involved morphometric analysis of the watershed by calculating Linear parameters such as number and order of streams, bifurcation ratio, stream length ratio, basin length and areal parameters such as drainage density, frequency (km^2), form factor, circulatory ratio, elongation ratio. In the computation of the number of water conservation/recharge structures, various thematic maps have been prepared through visual interpretation of satellite data. The study concluded with a pilot project demonstration of artificial recharge technology in Baddi University.

1.5. Physiography and Drainage:

The study area is of rectangular in shape and runs parallel to the main strike direction of Siwalik formations. The area is carved between two semi-parallel hill ranges of Siwalik formation in the south western side and the Kasauli formation on the north eastern side. Most of the peaks of the ridge along the northeast flanks of the study area attain heights more than 1000 m above mean sea level (MSL) and the Kasauli Dhar has the highest peak of 1926 m above main sea level. The area under study has higher elevation in north west and south east direction. A topographic contour in the study area is given in Fig.2. Slope of the area is from north east to south west direction.

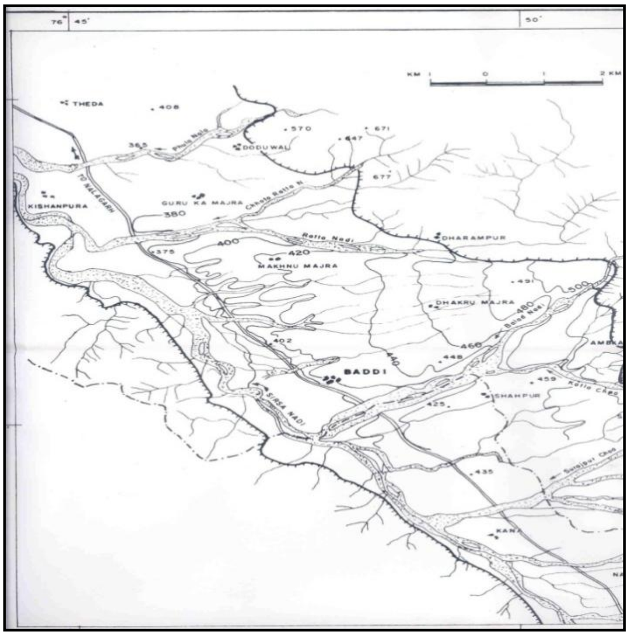

Fig.2: Topographic Map of Study Area, District Solan

Nalagarh valley is mainly drained by the Sirsa nadi which enters the Himachal Pradesh in Solan district near Baddi and flows down to Sutlej river in Punjab. The main tributaries of Sirsa Nadi in the study area are Balad nadi and Ratta nadi along with minor tributaries. Sirsa nadi is a perennial river which flows northwesterly in the study area and joins Sutluj river, a few kms upstream of Ropar. The study area is criss-crossed by a number of small to large khads, which joins the Sirsa river at various places. The catchment area of Balad nadi is 113.22 sq km, Ratta nadi 30 sq km and catchment area of Sirsa nadi 31.11 sq km (Fig.3). in the study area.

The study area of Baddi Industrial Complex lies between Ratta nadi, Balad nadi and Sirsa nadi. Both Ratta nadi and Balad nadi are tributaries of Sirsa nadi. Sirsa nadi forms western boundary of the study area and runs from south east to northwest direction. Ratta nadi forms northern boundary of the project area and runs from east to west direction. It meets Sirsa nadi in north western part of the area. Balad nadi flows from north east to south west direction and forms eastern boundary of the project. These nadies were formed in the last phase of upheaval of Himalayas. All the tributaries khads of Sirsa river flow from north eastern directions and are almost parallel to each other. The tributaries show parallel to sub-parallel drainage pattern. The drainage developed in the area displays dendritic pattern and conspicuously shows bad topography on the road section. A few southwest to northeast flowing seasonal nalas of small magnitude from the outer Siwalik range of south-west flank also meet the main rivers in the valley areas. The valley fill deposits have been deposited in sets of terraces by the Sirsa River. These deposits have been dissected to low lying plain and flood plains by various tributaries, nalas of the Sirsa river. The master slope of study area is towards the northwest direction. However, the ground slope in the southeastern part is from the flanks towards the Sirsa river.

1.6. Hydrogeology

In valley area of Nalagarh, the ground water occurs in porous consolidated alluvial formation (valley fills) comprising, sand, silt, gravel, cobbles/pebbles etc. Ground water occurs both under phreatic & confined conditions. Wells and tube wells are the main ground water abstraction structures. Ground water is being developed in the area by medium to deep tube wells, dug wells, dug cum bored wells. Depth of open dug wells and dug cum bored well in area ranges from 4.00 to 60.00 m bgl wherein depth to water level varies from near ground surface to more than 35 m bgl. Yield of shallow aquifer is moderate with well discharges up to 10 lps.

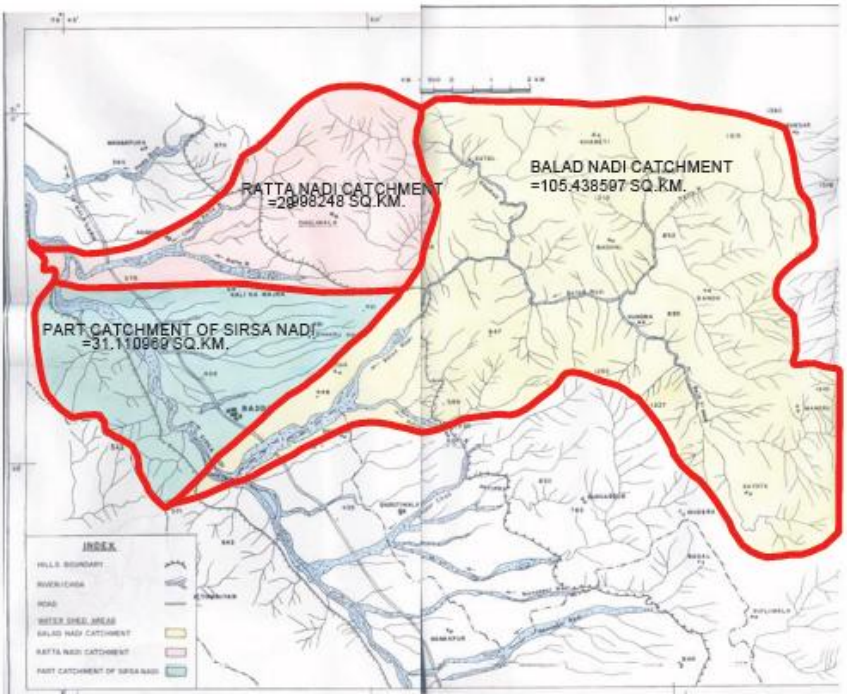

Fig. 3: Catchment Area Of Ratta Nadi, Balad Nadi And Sirsa Nadi District Solan (H.P)

Table 2: Dynamic Ground Water Resources (2004) (Nalagarh Valley) in MCM

Annual Replenishable Ground Water Resources	77.07
Net Annual Ground Water Draft	10.25
Projected Demand for Domestic and industrial Uses up to 2025	6.84
Stage of Ground Water Development	15%

In Nalagarh valley area, there are 12-hydrograph network stations where depth to water level is monitored four times a year and ground water quality once during pre-monsoon period. Depth to water table shows wide variation. During pre-monsoon period (May 2006) it ranged between 3.02 & 38.2 m bgl, while during the post-monsoon period (Nov. 2006) depth to water level ranged from 3.3 to 36.86 m bgl. Deeper water levels are observed mainly in north western part and along the foothills. In major parts of the valley the depth to water level are less than 15.00 m bgl. Fast pace of ground water development is observed in recent years in valley areas and this has resulted in declining water levels; in major part of the valley water level fall ranging from 0.05 to 6.20 metres is observed in the past one decade. There is thus need to initiate water conservation and artificial recharge measures in such areas.

In alluvial areas of Nalagarh valley, though there is scope for ground water development as stage of ground water development is only 15%, (CGWB, 2007) however, there is need to adopt cautious and phased manner ground water development approach in view of depleting water levels in some parts. This decline can be attributed to fast pace of development in recent years, both in agriculture sector and industrial sector. The Fig. 4 shows the location of the wells of the Baddi block.

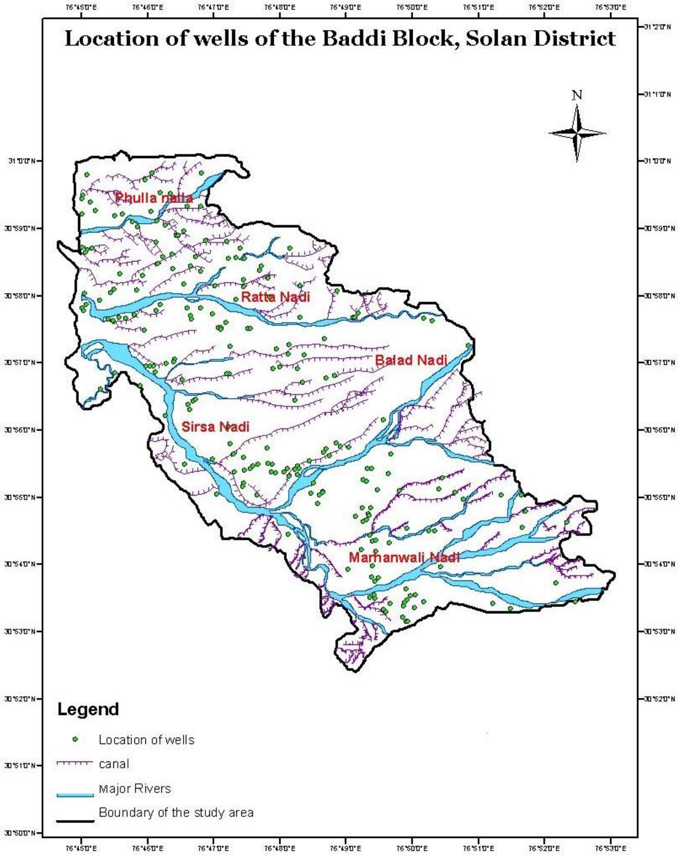

Fig. 4. Map of Locations of wells of Baddi Block

The water supply to the industrial complex and other allied infrastructure depend entirely on the development of groundwater resources. The deep tube wells are being constructed by all the industrial units to meet their water demand without consideration to the sustainability of aquifers. The water table is declining fast and about 11m decline has been observed in the last 10 years.

1.7 Geology

The Nalagarh valley has been carved out in the Siwalik terrain of outer Himalayas and forms a part of Sutlej Sub Basin of Indus Basin. The valley is aligned in northwest - southeast direction in conformity with the trend of main Himalayas in this part. The geology of the area is complex due to the neo-tectonic activity it has undergone. In the terms of absolute relief there is sudden drop from the north-eastern to south-western into the dun. Relief of the dun ranges between 450 and 600 m, however there are large variations between the different areas, related to local and regional tectonic conditions and unequal deposition and erosion. The regional variation in the absolute relief is correlated with regional tectonic frame while in the local areas, variation in deposition have been important. As a result of enechelon, faulting and tilting of the faulted block, the absolute relief within the dun is higher in the north-east and in the south-east than in the north-west and south-west. In this dun a large number of lower order, geologically young tributaries fairly entrenched on the alluvial fans, have further broken the topography and produced a more complicated pattern of variations of local relief as

The lithology of the area comprises valley fill deposits of river terraces of immense thickness. These are horizontally bedded / stratified clay beds with lenses of fine sand and gravel. Geological sequence exposed in the area is given in Table. 3. Geological map of Solan district is given in Fig.5.

Table 3: Geological Sequence of the Study Area.

Formation	Lithology	Age
Holocene deposits	River alluvium and the sediments along the present course	Recent
Pre Holocene deposit (River terraces)	Boulders, cobbles, pebbles with layers / lenses of sand / clay	Upper Pleistocene
Upper Siwalik (Boulder conglomerate)	Boulders, pebbles with sandstone and clay	Lower Pleistocene

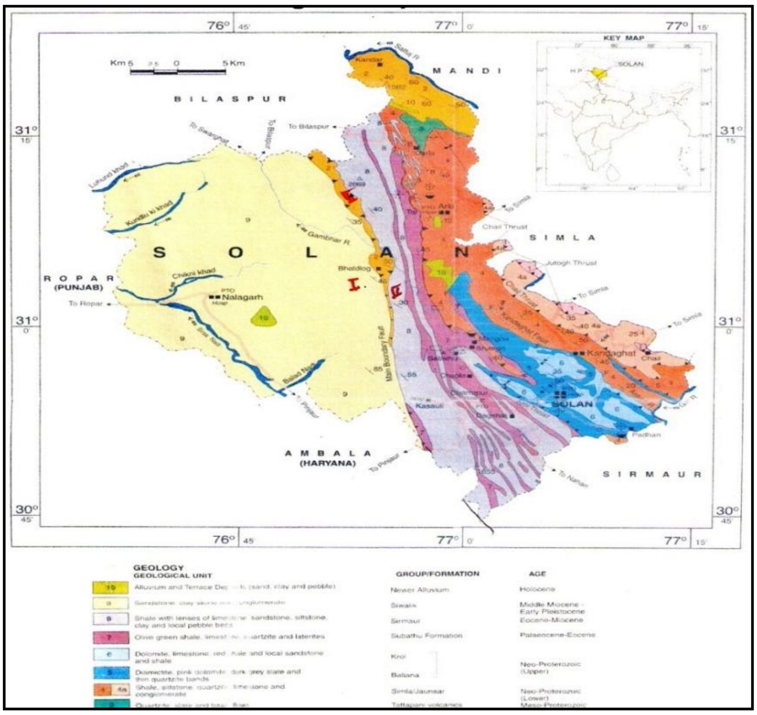

Fig. 5. Geology map of Solan

The valley deposits are mainly fluvio-lacustrine in their characteristic. The deposits along the cutting of the *nalas* show thick clays with beds of boulders, gravels, sands and clay in the valley area. The sediments are more clayey and with lenses of fine sand along the Nalagarh section, which indicates that the sediments have been deposited under fluvio-lacustrine environment and more of the sediments are fine grained and have been contributed by the river Satluj.

The deposits again change to alternate beds of clay and boulders, cobbles, pebbles, gravels, sand and clayey towards the upstream sides of the nalas. The valley fill deposits is more coarse comprising of boulders, cobbles and pebbles etc. towards the peripheral zone of the valley and from the recharge zone. The braided pattern of drainage in these zones also indicates recharge zones of the valley. The sediments continue to become finer until they blend into clay deposits. The horizontal layering of clay deposits also indicates that the deposits are lacustrine in nature. The upper part of the Pinjore - Nalagarh dun along the foot of Himalaya is characterized by alluvial fans and colluvial deposits cris-crossed by a large number of small and large streams or choes. On the other hand, the south-western (lower) parts of dun are characterized by terraces which are open, wide and co-extensive with alluvial fans above.

The growth of kankar was observed in the clay horizons due to leaching of sub-surface water in the zone of aeration. The top of the terrace is covered with materials of cobble grade clays of fine grade.

2.0 Depth to Water Level:

In order to study the variation in water levels, pre-monsoon water levels of the existing 56 groundwater structures were monitored. These include 27 tubewells, 26 dugwells, 2 artificial recharge wells and 1 hand pump. The depth to water level is deep in the vicinity of hills and it is shallow in the low-lying places and terraces. Based on the water levels recorded in the tubewells, the depth to water level map has been prepared (Fig. 6).

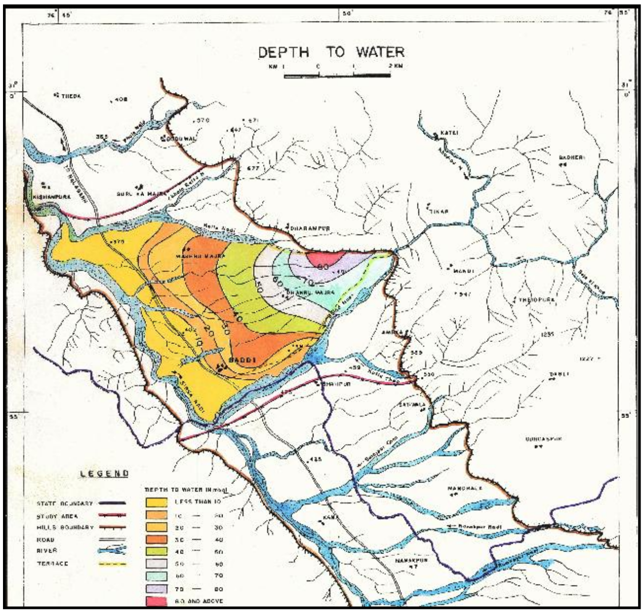

Fig. 6: Depth to Water Level Map of the Area

It is seen from the map that water levels in the area vary between 86 m (Well No. 8) to 2.5 m (Well No 44). Water levels are deep in the north eastern part and decreases towards the south western part of the area.

2.1 Water Table Configuration

Based on the water level data water table elevation map has been prepared. The direction of ground water flow in general is from east to west direction (Fig. 7). However it is observed that from the central part of Balad nadi, near village Koti, the flow directions are towards Ratta nadi in the north of the area and towards Sirsa nadi in the west direction. The water table elevation varies from 448 m a.msl in the east and 360 m amsl in the north west direction.

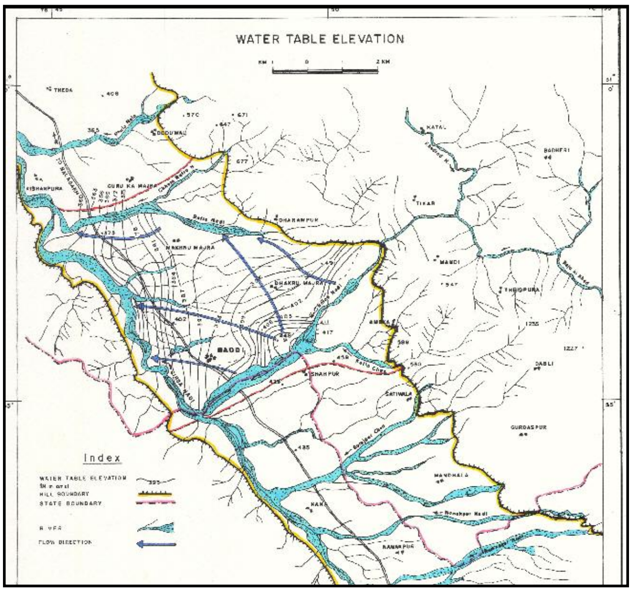

Fig. 7: Water Table Elevation Map

2.2 Allocation of Ground Water Resources for Future Utilization:

The net annual ground water availability is to be proportioned between domestic, industrial and irrigation uses. Among these, as per the National Water Policy, 2002, requirement for domestic water supply is to be accorded priority. The requirement for domestic and industrial water supply is to be kept based on population as projected to the year 2025. The water available for irrigation use is obtained by deducting the allocation for domestic and industrial use, from the net annual ground water availability.

2.3 Recharge from Monsoon Rainfall:

Recharge from rainfall has been computed by using two methods: water level fluctuation method and rainfall infiltration factor method. Recharge computation through water level fluctuation method has been done using the following relation:

$$R^{wtf} = h \text{ X } Sy \text{ X } A + D_G - Rgw$$

Whereas R^{wtf} = possible recharge by water table fluctuation method, h = is the rise in water level in monsoon season, A = Area of computation of recharge, Sy = specific yield, D_G = Gross ground water draft, Rgw = Recharge from ground water irrigation during monsoon season.

The specific yield value in case of valley fill deposits which includes boulders, cobbles, gravels, sand etc. has been taken as 0.16.

Rainfall recharge computed by this method has been normalized on the normal monsoon rainfall using the procedure recommended by GEC-97 using the relation:

$$R_{rf}(\text{Normal wtfm}) = NMR \text{ x } R^{wtf} / AMR$$

Where, R_{rf} (Normal wtfm) = Normalised rainfall recharge

NMR = Normal Monsoon Rainfall

R^{wtf} =Computed Rainfall Recharge

AMR = Actual Monsoon Rainfall in the year of assessment

As there is no draft data available for the last preceding years, hence recharge is normalized for assessment year (2008-2009).

Recharge Computation by Rainfall Infiltration Factor Method during Monsoon is given below:

Rainfall recharge during monsoon period have been computed using, normal monsoon rainfall (data obtained from Commissioner, Revenue department, Govt. of H.P). The rainfall infiltration factor for valley fill have been taken as 0.22 as recommended by GEC 97.

The equation used for computation of recharge is

$$R_{rf}\ \text{(Normal rifm)} = NMR \times A \times RIF$$

Whereas R_{rf} (Normal rifm)= recharge from rainfall by rainfall infiltration factor method, NMR = Normal Monsoon Rainfall, A = Area of valley in Hectare, RIF = Rainfall Infiltration Factor

Percent Deviation

The results from the above two methods (water fluctuation and rainfall infiltration method) have been compared using percent deviation using the following relation:

$$P.\ D = 100x\ \{R_{rf}\ \text{(Normal wtfm)} - R_{rf}\ \text{(Normal rifm)}\} / R_{rf}\ \text{(Normal rifm)}$$

Where, P. D. = Percent deviation, R_{rf} (Normal wtfm) = Recharge from (Normalised as computed water table fluctuation method), R_{rf} (Normal rifm) = Recharge from rainfall as computed by Rainfall infiltration factor method.

After computation of the percent deviation the following criteria as recommended by the methodology (GEC '97) has been to compare the recharge from rainfall:

i) if $-20 \leq$ P. D. $\leq +20$ then R_{rf} (Normal) = R_{rf} (Normal wtfm)

ii) if P. D.< -20 then R_{rf} (Normal) = 0.8 X R_{rf} (Normal rifm)

iii) if P. D. > 20 then R_{rf} (Normal) = 1.2 X R_{rf} (Normal rifm)

2.4 Total Annual Recharge:

Total annual recharge resource was computed as arithmetic sum of recharge from Monsoon, Non-Monsoon Rainfall & recharge from other sources during monsoon and non monsoon season.

Provision for natural discharges has been kept as 10%, as per GEC '97 methodology.

2.5 Total Ground Water Resources of Nalagarh Valley:

Net annual ground water availability has been computed by deducting the unaccounted natural discharge taken as 10 % of the total annual recharge values calculated by rainfall infiltration factor method as per the criteria recommended by GEC-97 for recharge values calculated on the basis of rainfall infiltration method.

Stage of ground water development has been computed using the relation:

$$\text{Stage of ground water Development} = \frac{100x\ \text{Gross ground water draft for all uses}(D_G)}{\text{Annual available ground water resources}}$$

Stage of ground water development of Nalagarh valley in Solan district is 50.85 % and falls under 'Safe' category. Net ground water availability for future use has been computed using the relation

R = A- (B + C)

Where, R = Net annual ground water available for future irrigation use

A = Net available ground water resource

B = Gross ground water draft for domestic and irrigation

C = Allocation for domestic and industrial water supply

2.6. In- Storage Ground Water Resources:

The Baddi industrial complex is part of Nallagarh which covers the area of 23849 hect. Central and state govt. agencies have carried out drilling in Nallagarh valley down to a depth of about 160 meter.

From the lithological logs of various tubewells , it has been observed the aquifer consisting of sand, pebble, gravel, boulder constitute about 27% and clay bed constitute 73% of total aquifer system. Thickness of various granular zones ranges from 2m to 6m, whereas the clay beds ranges from 2m to 20m in thickness. Average depth to water level in the valley is about 20 m. An average specific yield of 16% has been considered uniformly for the study area.

a) Methodology for estimation of In Storage Ground Water Resource

Static Ground Water Resource of the area has been estimated based on the similar approach as adopted for estimation of dynamic ground water resources. The thickness of aquifer material below the zone of fluctuation and specific yield has been used to estimate the resources. The details of the methodology and formulae are given as under:

$I_R = A * H * S_Y$
I_R = In storage resources in ham
A = Area of valley in ha
H = Thickness of aquifer sediments below the zone of fluctuation upto explored depth (explore depth - Pre monsoon water level in m)
S_Y = Specific yield of aquifer in fraction

The salient features of the in storage ground water resource assessment are given in Table 4. The thickness of aquifer sediment has been estimated based on the study of the litholog of the area and only aquifer part has been considered for estimation of resources. Total in-storage ground water resources of Nalagarh valley are 158167 ham.

Table 4: Salient Features of Ground Water Resource Estimation for Nalagarh Valley

Recharge from rainfall during monsoon	6283.55 ham
Recharge from other sources during monsoon	168.43 ham
Recharge from rainfall during non monsoon	1825.88 ham
Recharge from other sources during non monsoon	336.85 ham
Annual Ground Water Recharge	861471 ham
Provision for natural discharge	861.47 ham
Net Ground Water Availability	7753.24 ham
Existing Ground Water Draft for irrigation	2021.11 ham
Existing Ground Water Draft for domestic and industrial water supply	1921.26 ham
Existing Ground Water Draft for all uses	3942.37 ham
Provision for Domestic and Industrial supply to 2025	1921.26 ham
Net ground water availability for future irrigation development	3810.87 ham
Stage of Ground Water Development	50.85
Category	Safe
Total in-storage ground water resources of Nalagarh valley	**158167 ham.**

3.0 Morphometric Analysis

The analysis of drainage morphometry is usually a prerequisite to the assessment of hydrological characteristics of surface water basin. The Sirsa watershed has been analysed through detailed morphometric analysis. In this region, a large number of drainage systems originated from the Sirsa Nadi. Following geomorphologic procedures the catchment area of Sirsa watershed and the surrounding basins were delineated by direct tracing of the drainage tributaries from topographic maps (scale 1:50000). Drainage system boundaries were identified. This was accompanied with a systematic digitizing of the traced tributaries and basin systems in the Geographic Information System (GIS) by using Arc-GIS 10 software. Thus, a drainage system map was produced including the major three catchment areas in the region.

Topographic maps in combination with remotely sensed data, Landsat images were utilized to delineate the existing drainage system, thus to identify precisely water divides. This was achieved using Geographic Information System (GIS) to provide computerized data that can be manipulated for different calculations and hydrological measures.

The obtained morhpometric analysis can help in determining: 1) stream behavior, 2) morphometric setting of streams within the drainage system and 3) interrelation between connected streams. The study utilized an imperial approach of morphometric analysis that can be utilized in assessments of rainwater harvesting structures. [5]

The current study was accomplished using several approaches of drainage system analysis. The study aimed to analyze the major morphometric elements of Baddi watershed in Nalagarh District. It treated the characterization of streams' behavior (e.g. meandering, frequency, etc), their setting with respect to the catchment and their relation to each other (e.g. patterns, junctions, etc). This provided valuable information that can be used in different water assessments and selecting sites for water harvesting. Additionally, the morphometric analysis can be applied to similar drainage systems in the larger watersheds of Himachal Pradesh.

3.1 Materials and Method:

Morphometric analysis of a drainage system requires a delineation of all existing streams and reaches. Of the several methods of drainage system delineation, two procedures have been followed in the present study. These are the manual and automated system delineation.

The manual sampling of drainage network has been adopted from topographic maps, Survey of India open series map No. H43K13 of a scale of 1:50000 in combination with computerized tools, and Geographic Information System (GIS). The digital analysis has been carried out for Landsat Imagery using GIS software Arc GIS 10 and ERDAS Imagine Software and the Geo-informatics based multi criteria evaluation has been done using Weighted Overlays and AHP methods.

For the unconnected drainage systems, satellite images were analyzed using ERDAS Imagine software. These images can provide information on the surface features, and able to detect buried stream networks. This is can be achieved in applying thermal bands with 90m spatial resolution (i.e. capability to distinguish objects on satellite image) in these images. The applied method in stream delineation was done digitally in GIS (*Arc View* software) system. A number of digital applications were undertaken, including band combination, colour slicing, filtering and related measuring tools. Hence, all tributaries of different extents and patterns were digitized.

3.2 Data Analysis and Results:

3.2.1. Drainage Patterns: The arrangement of streams in a drainage system constitutes the drainage pattern, which in turn reflects mainly structural/ or lithologic controls of the underlying rocks [2]. The area of study encompasses a miscellany of drainage patterns; however, dendritic drainage pattern is the most dominant type and occupies more than 95% of the area. Even though, difference in stream lengths and angle of connection, yet they are in general characterized by a treelike branching system, which is a dendritic drainage pattern that indicates homogenous and uniform soil and rocks [8]. All the parameters calculated for the watershed are given in the table 5 and table 6 and a snapshot of Arc view analysis is given in Fig. 8.

3.2.2. Drainage Density (D): Drainage density is a measure of the length of stream channel per unit area of drainage basin. Mathematically it is expressed as: D =□ L (total length of all stream) A (area of the basin). In this study, the drainage density map was obtained using the digital data from the obtained drainage map. This was accomplished using the GIS system (Arc View software), which is capable to measure the actual stream lengths and number. Therefore, the drainage system was classified into frames of definite area (i.e. 5kmx5km). This classification depended on the visual density of streams in the area. Hence, the total length of streams in each frame (i.e. 25km2) was measured using Arc View software.

3.2.3. Drainage Frequency (F): A similar mathematical relation to that applied in drainage density, stream frequency was also done by counting the number of streams in a specified area. In the light of this morphometric relation, several workers used stream frequency rather than drainage density (length density). Therefore, some hydrologic studies consider the density of drainage [6], while others deal with drainage frequency. Stream frequency is expressed by the following equation: F = □ L (number of streams) A (area of the basin).

3.2.4. Meandering Ratio (Mr): It is calculated to express the ratio between straight to curved lengths of the primary (major) stream within the drainage system. It shows how the real stream length is larger than the straight one, which is indicative to stage maturity. [1]

Table 5: Linear Parameters of Sirsa Watershed

Sub - basin	**Stream orders**				**Total Stream No**	**Stream Length**				**Total Stream Length**	**Stream Length Ratio**		
	1	2	3	4		1	2	3	4		2/1	3/2	4/3
1	15	10	2	1	28	10247.019	6454.35	2323.17	4610.15	23634.707	0.629	0.359	1.984
2	5	3	1	1	10	3007.63	2262.92	411.45	644.36	6346.38	0.752	0.181	1.566
3	27	14	3	2	46	16067.428	7461.14	2750.724	12789.75	39069.04	0.464	0.368	4.64
4	6	4	1	1	12	13071.309	6235.68	752.93	3494.81	23554.73	0.477	0.120	4.64
5	3	1	0	1	5	4243.56	3731.57	0	2336.57	10311.7	0.879	0	0
6	17	5	2	2	26	10660.69	5175.724	1573.66	10264.69	27674.76	0.485	0.304	6.522
7	2	2	0	1	5	2088.60	10222.71	0	1647.14	13958.45	4.894	0	0

Table 6: Areal Parameters of Sirsa Watershed

Sub - basin	**Area(A) sq. km**	**Perimeter(mts)**	**Drainage density**	**Stream Frequency**	**Bifurcation Ration (Rb)**			**Mean Rb**
1	7.877140	13,049	0.003	3.554	1.5	5	2	2.833
2	2.278573	6138	0.002	4.388	1.66	3	1	1.88
3	17.932804	24137	0.002	2.565	1.92	4.66	1.5	2.69
4	17.884024	24498	0.0013	0.671	1.5	4	1	2.16
5	8.401141	19434	0.0012	0.595	3	0	0	1
6	15.644203	19518	0.0017	1.661	3.4	2.5	1	2.3
7	12.106949	20546	0.0011	0.412	1	0	0	0.33

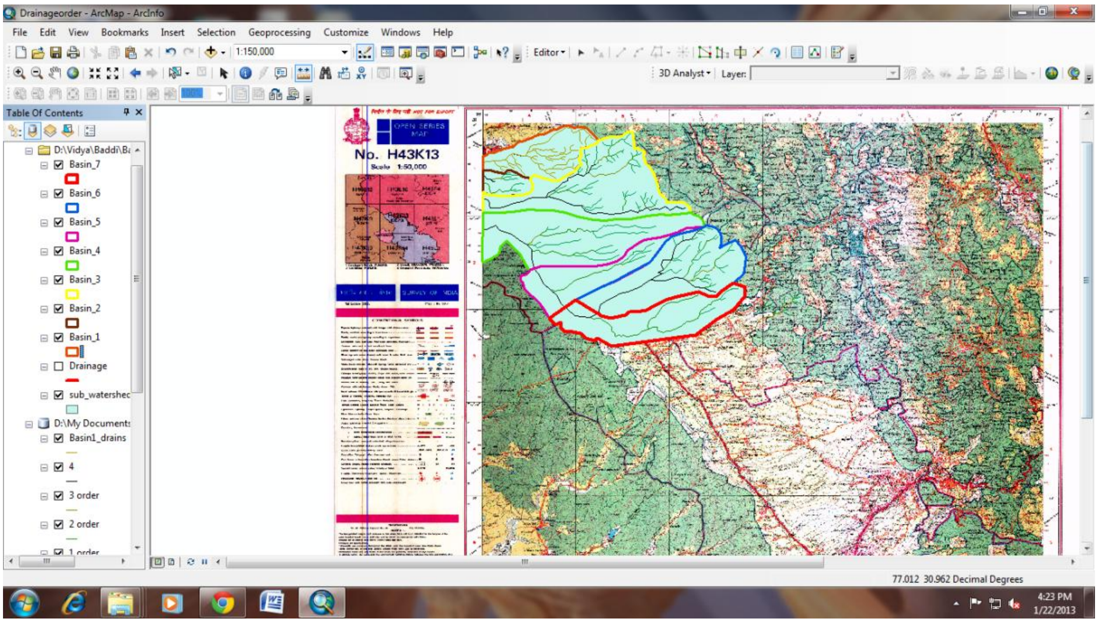

Fig. 8: Snapshot of the Arc View Showing the Division of the Sub Watersheds of the Baddi Watershed.

3.2 Design and Number of Structures:

It is estimated that it is possible to construct 600 point recharge structures, 60 storage/percolation tanks and about 400 check dams. In order to demonstrate the effective design for recharge structures, a pilot project has been implemented in the Baddi University to showcase the cost effective technology in Rainwater Harvesting using geo textile instead of cost-intensive inverted filter for removing the suspended load in the runoff to be recharged.

Table 7: The Runoff Potential Calculation for the Watershed Vis-A-Vis Land Use Category

S no.	Name of the class	Area covered(in hectares)	Area covered in square meters	Runoff Coefficient	avearge annual Rainfall in mm	Intensity of Rainfall in meters	Runoff Potential(C*I*A)in m3	MCM
1	Natural vegetation	1757.73	17580000	0.1	851	0.851	1496058	1.496058
2	Agriculture	3941.64	39420000	0.4	851	0.851	13418568	13.418568
3	Open area	1959.42	19600000	0.16	851	0.851	3335920	3.33592
4	Dry river bed	244.955	2450000		851	0.851	0	0
5	Water body	594.406	5950000		851	0.851	0	0
6	Settlement	737.667	7380000	0.5	851	0.851	3140190	3.14019
				Water available for recharge =			21390736	21.390736

Table 8: Different Recharge structures for the watershed

Watershed no.	Utilizable runoff(mcm)	Sub-surface barriers	Percolation tanks	Check Dam	Point Recharge Structure
1	21.390736	71	106	700	1050

Table 9: Unit recharge/structure/annum

Conservation structure	Unit recharge/structure/annum
Sub-surface	0.3
Precolation tank	0.2
Chek dam	0.03
Point recharge structure	0.02

4.0 Pilot Study Project Implementation:

The study concluded with the implementation of a pilot project of artificial recharge structure implemented in Baddi University, Baddi, Himachal Pradesh. The university has a residential campus spread over 40 acres of picturesque slopes in the midst of Shivalik Hills at Baddi in Solan district of Himachal Pradesh. The structure has been designed near the Pharmacy building of the University and will artificially recharge the groundwater of the campus through rainwater harvesting from adjoining buildings and blocks around the structure. The structure has been designed to receive a flow of 27.3 m^3/hr. Details of the structure are given in Fig. 9 and 10 as below.

Fig. 9 Artificial Recharge Structure Constructed In Baddi University

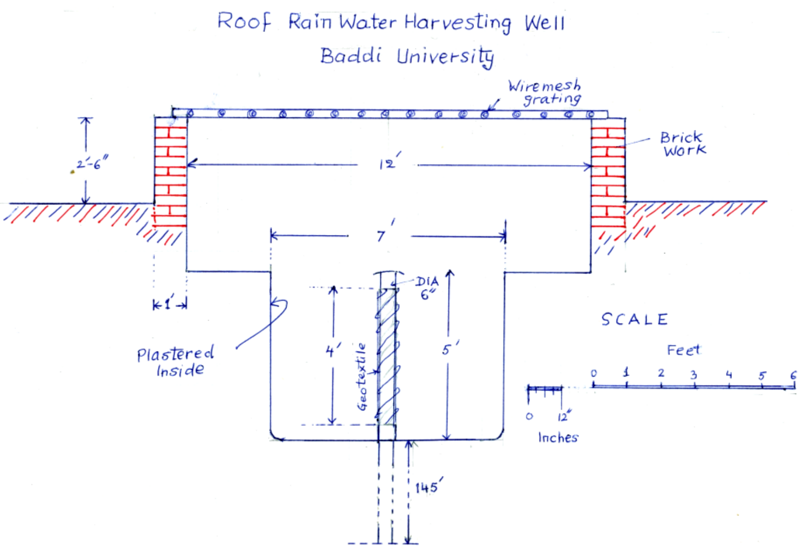

Fig. 10 Design of the Artificial Recharge Structure At Baddi University

4.0 Conclusions:

- This industrial area is highly prone and vulnerable to surface & ground water pollution thus water quality monitoring at close network is essential.
- Proper waste/effluent disposal measures are required to be adopted by industrial units and state authorities needs to check this.
- There is need to protect traditional water harvesting structures like ponds, tanks, talavs to utilized these for rain water harvesting and recharging shallow aquifers.
- In hilly and mountainous terrain, traditional ground water sources viz., springs, bowries etc needs to be developed and protected for better health and hygiene with proper scientific intervention.
- Springs needs to be inventoried & studied for optimum utilization of their discharge either by fracturing, horizontal drilling or by constructing galleries etc.
- Roof top rainwater harvesting practices can be adopted in hilly areas and urban areas, since the district receives fair amount of rainfall. Construction of roof top rain water harvesting structures should be made mandatory in all new construction and rain water harvesting in rural areas should be promoted.
- Traditional water storage systems need to be revived.
- People's participation is a must for any type of developmental activities. So proper awareness for utilization and conservation of water resources is required.

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