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Assessment of Water Resource Sustainability – A Case Study from North India

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Abstract Groundwater utilization has increased dramatically in developing cities of the world over last few decades. The present study was taken up for assessing the sustainability of water resources in a subtropical mountainous Watershed of Dehradun District, Uttarakhand. The study area is the Suswa watershed situated in Dehradun district of North India between 77° 57' and 78° 10' East longitudes and 30° 08' and 30° 27' North latitudes. The study has indicated that the rate of urbanization has increased phenomenally in the study area in the recent decade. The surface runoff estimated for the study area by employing the well known NRCS-CN method is around 22% of annual rainfall in the study area, with the minimum surface water resources availability being about 63 million-m^3 per annum. Ground water estimation for 2005-06 was carried out by using the mass balance based methodology of ground water budgeting practiced by the Groundwater Agencies in India. The stage of groundwater development in the command and non-command areas was found to be 19% and 38% respectively, thus placing the Suswa Watershed under 'Safe' category of development.

A synoptic assessment of ground water quality was carried out by evaluating a groundwater quality index (GWQI) following the approach of Melloul and Collin (1998). For estimating GWQI, seven water quality parameters were selected viz. cadmium, nickel, chromium, total hardness, sulfate, total dissolved solids and total alkalinity.

The relative weights of these parameters were computed by using an analytical hierarchy process. The GWQI contour maps have indicated that, the groundwater of the study area is generally fit for drinking purpose except in few patches of the watershed. For evaluation of sustainability parameters, it was observed that, the deforestation rate in the period of 10 years from 1990 to 2000 was faster than that during the preceding duration of 18 years (from 1972 to 1990). With respect to the water barrier index, computations have indicated that the Suswa Watershed can be put in 'absolute scarcity' category whereas on the basis of IWSS score, the watershed can be classified as 'moderately stressed' to 'highly stressed'. It was found that the ground water resources development is becoming unsustainable in the watershed as well as in the Dehradun city. This study has resulted in formulation of viable guidelines for assessment of sustainability of water resources and is likely to be of the benefit to the planners, hydrologists and decision makers.

Keywords: sustainability indicators, ground water resources, ground water quality index, Dehradun, India.

INTRODUCTION

Water resource systems, that are able to satisfy the changing demands placed on them, now and into the future, without system degradation can be called 'Sustainable'. This paper deals with the basic issues involved in assessment of sustainability of water resources, especially groundwater.

A review of the existing literature indicates that sustainable development of water resources continued to move into the international spotlight amidst warnings that more than a third of the world's population will not have access to sufficient freshwater by 2025 (Gleiek, 2001). Sustainable development is a relatively recent concept that has grown out of concerns about the declining quality of the environment coupled with increasing resource needs as populations expand and living standards rise (Karki, 2008). Godfrey and Smith (2005) reported that in order to address the inadequate level of coverage of safe water supply in developing countries, the UN established various initiatives including the Millennium Development Goals (MDGs). The principal target of the MDGs is to ensure environmental sustainability by halving the proportion of people without access to safe water by 2015. Narula et al. (2001) addressed the emerging concerns regarding water resources sustainability through a case study for Yamuna river basin in India using an area-wide approach. They identified and evaluated three sustainability indicators for analyzing the water sustainability status of the basin. The sustainability indicators used by them were water barrier index (WBI), use-to-resource ratio (URR) and integrated water stress score (IWSS).

The concept of sustainability of water resources has quite varied perceptions to different professionals viz. hydrologists, hydrogeologists, water resources engineers, and sociologists. In case of sustainability of groundwater resources, the concept is largely related to 'safe yield'. Kalf and Woolley (2005) described the progression of the concept of safe or sustainable yield We now understand that the sustainable yield of an aquifer must be considerably less than recharge, if adequate amounts of water are to be available to sustain both the quantity and quality of streams, springs, wetlands, and groundwater dependent ecosystems. Sustainable resource management is managing groundwater for both present and future generations, and providing adequate quantities of water for the environment. Quantifying what these environmental provisions are is presently an urgent research need (Sophocleous, 2000). However, groundwater management all over the world often lacks sustainability as evidenced by falling water tables, drying wetlands, increasing seawater intrusion and general deterioration of water quality. As groundwater cannot be renewed artificially on a large scale, sustainable management of this resource is vital(Kinzelbach et al,2003).

Keeping in view the above, the present case study was taken up for assessing the sustainability of water resource development in a subtropical mountainous watershed of Dehradun district, Uttarakhand with the following objectives:

-To identify relevant sustainability indicators vis-à-vis water resources development for the area of study.

-To assess renewable quantity and quality of surface water and groundwater resources of the study area.

-To recommend suitable options for sustainable water resources development.

The indicators of sustainability employed in this case study are deforestation rate, water barrier index (WBI) and integrated water stress score (IWSS) based on the work of Narula et al. (2001) and Falkenmark & Widstrand (1992). A water quality index based synoptic groundwater quality evaluation was used to assess the sustainability vis-à-vis water quality. The study area, i.e. Suswa watershed covers an area of about 292 km^2 and is situated in Dehradun district of North India between 77° 57' and 78° 10' East longitudes and 30° 08' and 30° 27' North latitudes (Fig.1A and Fig.1B). Its ground elevation varies between 420 m and 2000 m AMSL whereas the annual rainfall varies between 1600 and 2200 mm, most of which falls in the months of June to August. Its land use is characterized by forest and agriculture besides the urban area. As per 1991 and 2001 census reports, total population of Dehradun city was 2,70,000 and 4,47,808 respectively, showing a high decadal growth rate of about 66%. The analysis of land use-land cover changes was carried out by using satellite imageries for the years of 1972, 1990 and 2000. This analysis has indicated that

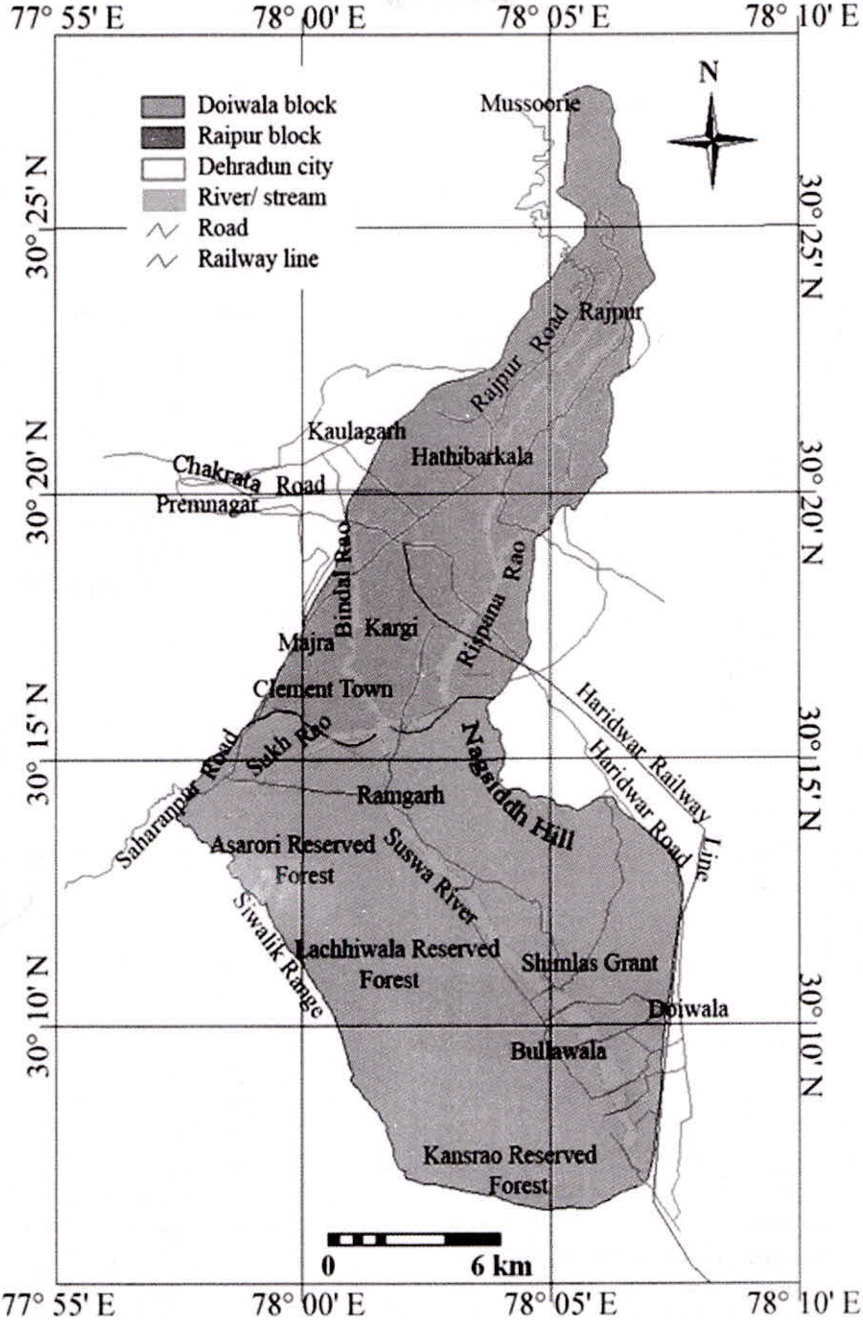

Fig.1 (a). Map of Suswa Watershed, Dehradun District

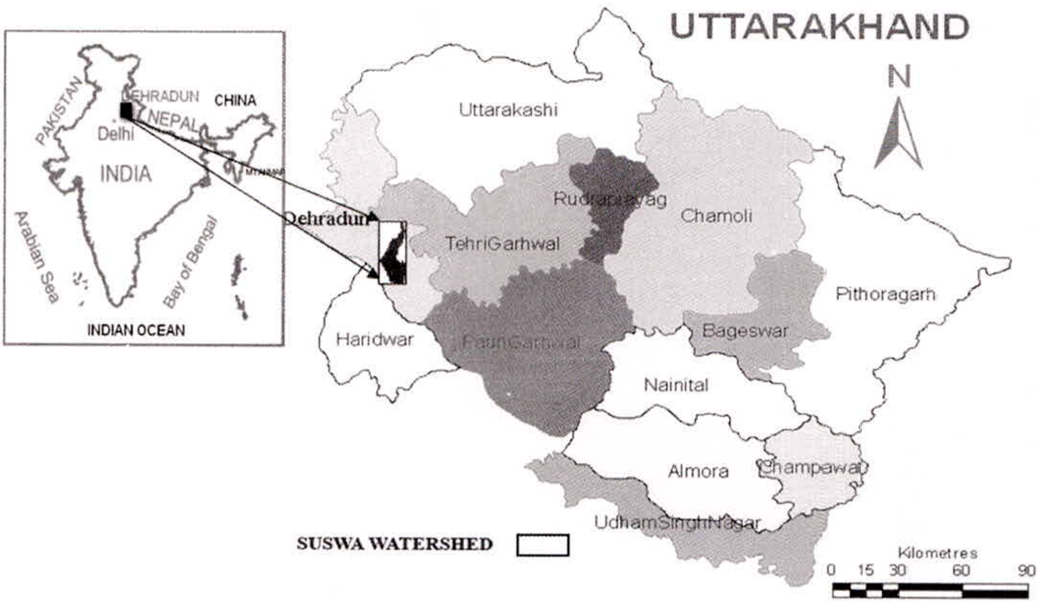

Fig. 1 (b). Location of study area in India

the rate of urbanization has increased phenomenally in the study area in the recent decade.

The evaluation of the relevant sustainability indicators necessitated assessment of the surface water and groundwater resources and their synoptic quality in the study area, besides the details of socioeconomic, deforestation and demographic features.

SURFACE WATER RESOURCES

In order to assess the surface water resources in the study area, an attempt was made to estimate the annual runoff volume for 32 years (from 1973 to 2006) by employing the Natural Resources Conservation Services – Curve Number (NRCS-CN) method. It was revealed that the annual runoff ranged from about 186 mm to 789 mm corresponding to the years 2002 and 1973 against the annual rainfall of 1574 mm and 2915 mm respectively. The average surface runoff depth is about 421 mm resulting from the average annual rainfall of about 2161 mm. By assuming uniform depth of runoff over entire area of Suswa watershed, the average annual runoff volume comes to the order of 122.68 million-m^3.

GROUNDWATER RESOURCE ESTIMATION

The groundwater assessment has been carried out in the present study for the year 2005-06. According to the CGWB guidelines for groundwater estimation (CGWB, 1997) the 'Normal Rainfall' obtained as the average rainfall over a period of sufficiently long years may be considered for computing rainfall recharge. It is observed from the available data that non-monsoon rainfall received in the year 2005-06 is 15% (304.6 mm) of the annual total rainfall of 2044 mm.

The results of computation of groundwater draft and assessment of groundwater recharge along with stage of ground water development are given in Table 1 (Yadav, 2010).

Table 1. GroundWater Draft and Recharge Assessment in Suswa Watershed.

Sr.No.	Parameter	Value/ Description	
1.1	(a)Total area (ha)	29160.00	
	(b)Hilly area (ha) [slope > 20%]	4480.00	
1.2	GW recharge area (ha)	24680.00	
1.3	Poor GW quality area (ha)	0.00	
1.4	Command area (ha)	1996.00	
1.5	Non-command area (ha)	22684.00	
1.6	Current **annual** gross GW draft for all uses in command area,ha-m	300.32	
1.7	Current **annual** gross GW draft for all uses in non command area,ha-m	3874.68	
Recharge from other sources in command area		Monsoon (A)	Non-monsoon (B)
1.8	Recharge from canals,ha-m	21.89	43.78
1.9	Recharge from surface water irrigation,ha-m	228.87	419.60
1.10	Recharge from 'other sources',ha-m	263.26	500.88
1.11	**Annual** recharge from 'other sources' in command area,ha-m	764.14	
Recharge from 'other sources' in non-command area in ha-m			
1.12	Recharge from GW irrigation	180.00	540.00
1.13	**Annual** Recharge from 'other sources' in non-command area.	720.00	
		Command	**Noncommand**
1.14	Rainfall recharge by WTF* method during monsoon season (ha-m)	1001.64	14313.14
1.15	Normal rainfall recharge by WTF method during monsoon season	728.17	10405.29
1.16	Normal rainfall recharge by RIF* method in monsoon season (ha-m)	555.27	6310.46
1.17	Normal rainfall recharge by RIF method in non-monsoon season (ha-m)	177.27	2014.66
1.18	PD* between rainfall recharge estimated for monsoon season by WTF method & RIF method (%)	31.14 (>20%)	64.88 (>20%)
1.19	Recharge from rainfall during monsoon season (ha-m)	666.32	7572.55
1.20	Recharge from rainfall during non-monsoon season (ha-m)	177.27	2014.66
1.21	Annual GW recharge from rainfall (ha-m)	843.59	9587.21
1.22	Net annual GW availability (ha-m)	1607.73	10307.21
1.23	Stage of GW development (%)	16.68	37.59

***Note**: (i) WTF method= Water Table Fluctuation method,
(ii) RIF method= Rainfall Infiltration factor method,
(iii) PD= Percentage Difference.
(iv) Monsoon season is deemed to occur in north India between the months of July and September every year

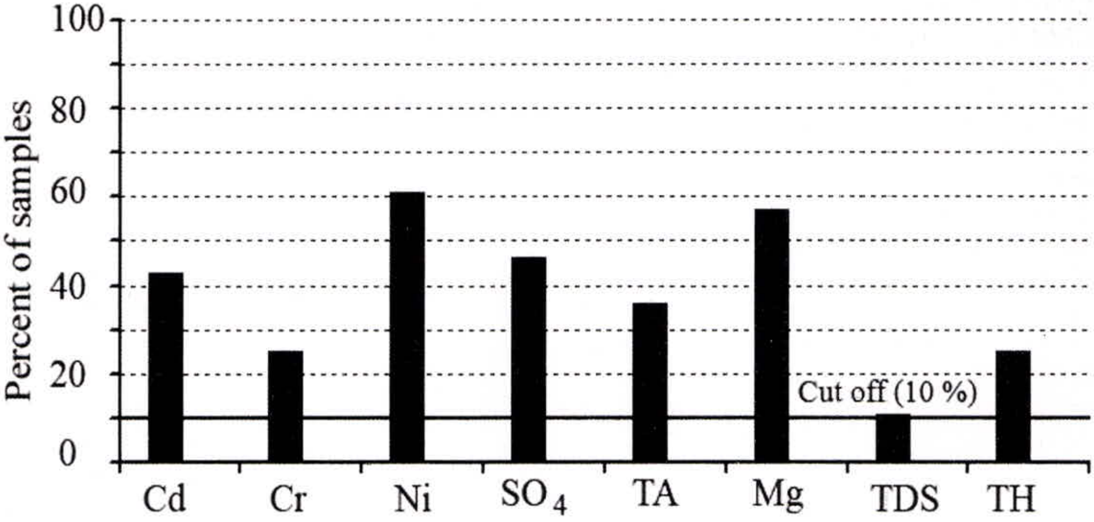

Fig. 2. Percentage of samples exceeding drinking water quality standards

Table 2. Percentage of samples exceeding the drinking water quality standards

Sl. No.	Parameter	Percent of samples exceeding the BIS standards	BIS standards (mg/L)
1	Cadmium	42.9	0.01
2	Nickel	60.7	0.02*
3	Chromium	25.0	0.05
4	Total hardness (TH)	25.0	300
5	Sulfate	46.4	200
6	Total dissolved solids (TDS)	10.7	500
7	Total alkalinity (TA)	35.7	200

EVALUATION OF SYNOPTIC GROUNDWATER QUALITY

A water quality index based synoptic groundwater quality evaluation was used to assess the aquifer water quality in the study area. This involved computation of an Index of Aquifer Water Quality (IAWQ) developed by Melloul and Collin (1998) for assessing the synoptic groundwater quality of Israel's Sharon region. In this approach each value of a parameter, P_i (field data value of parameter i), is related to its desired standard value P_{id} (as per, Indian drinking water standards in the present study). Each relative value, X_i, can be estimated as:

$$X = P_i / P_{id} \quad (1)$$

To express X_i as a corresponding index rating value related to groundwater quality, an index rating Y_i has been assigned to each X_i value.

Operational hydrological experience indicates that $Y_1 = 1$ for $X_1 = 0.1$; $Y_2 = 5$ for $X_2 = 1$ and $Y_3 = 10$ for $X_3 = 3.5$ (usually values of Y_i range between 1 and 10). For any parameter i, an adjusted parabolic function of rates $Y_i = f(X_i)$ can be determined from 2nd order polynomial as in equation (2) (Melloul and Collin, 1998):

$$Y_i = -0.712 X_i^2 + 5.228 X_i + 0.484 \quad (2)$$

Based on the above equation, the corresponding rating Y_i can be estimated for any value of X_i. However, in order to avoid negative values of Y_i (which may result in negative indices), maximum values of X_i have to be restricted to 3.5. Thus, after this transformation of the field data, the IAWQ index formula (equation 3) involves only Y-values, representing input data for the development of IAWQ index formula to numerically assess any groundwater quality situation which is as under:

$$IAWQ = C / n \left[\sum_{i=1}^{n} (W_{ri} . Y_{ri}) \right] \quad (3)$$

where,

C = a constant, used to ensure desired range of numbers (taken as 10);

n = number of chemical parameters involved (i = 1,.n), which is incorporated in the denominator to average the data;

W_{ri} = the relative value of W_i / W_{max};

W_i = a weight for any given parameter;

W_{max} = the maximum possible weight (taken as 5);

Y_{ri} = the value of Y_i / Y_{max};

Y_i = the rating value for the i^{th} chemical parameter [obtained from equation (2)];

Y_{max} = the maximum possible rating for any parameter (taken as 10).

A weight (W_i) is a numerical value given to a parameter to characterize its relative anticipated pollutant impact; lower numerical values define lower pollution potential, while higher values define heightened pollution potential. A W_i value would also be larger if a given parameter were toxic or hazardous to groundwater quality. The values of W_{max} and Y_{max} are incorporated into equation (3), to represent W and Y values as related to a reference level in order to assess the relative level of salinization and pollution, and also to ensure that the ultimate IAWQ value remains within a scale of 1–10. IAWQ values can thus be more readily compared from one site to the other, while providing a means of determining the relative influence of additional parameters upon groundwater quality (Hussain,2005).

For development of the groundwater quality index (GWQI) for the Suswa mountainous Watershed of Dehradun area, Uttarakhand the range of water quality parameters was extended to include major ions and heavy metals. From the point of regional significance, only those parameters were included which reflected violation of the Indian drinking water quality standards of BIS: 10500 (Bureau of Indian Standards, 1991) in more than 10 % of the total samples collected in the study area (Fig. 2). The seven chemical parameters finally selected for estimating GWQI were Cd, Ni, Cr, TH, SO_4, TDS and total alkalinity (Table 2).

The GWQI variation in the Suswa Watershed exhibits a range of values from 0.42 to 2.70 (in pre-monsoon period) and from 0.87 to 3.30 (on a scale of 1 to 10) (in post-monsoon period). The areas with lower GWQI values indicate the better quality groundwater (lowest pollution) and the areas with higher values indicate groundwater affected by increasing salinity concentration.(Fig.3 and Fig.4).

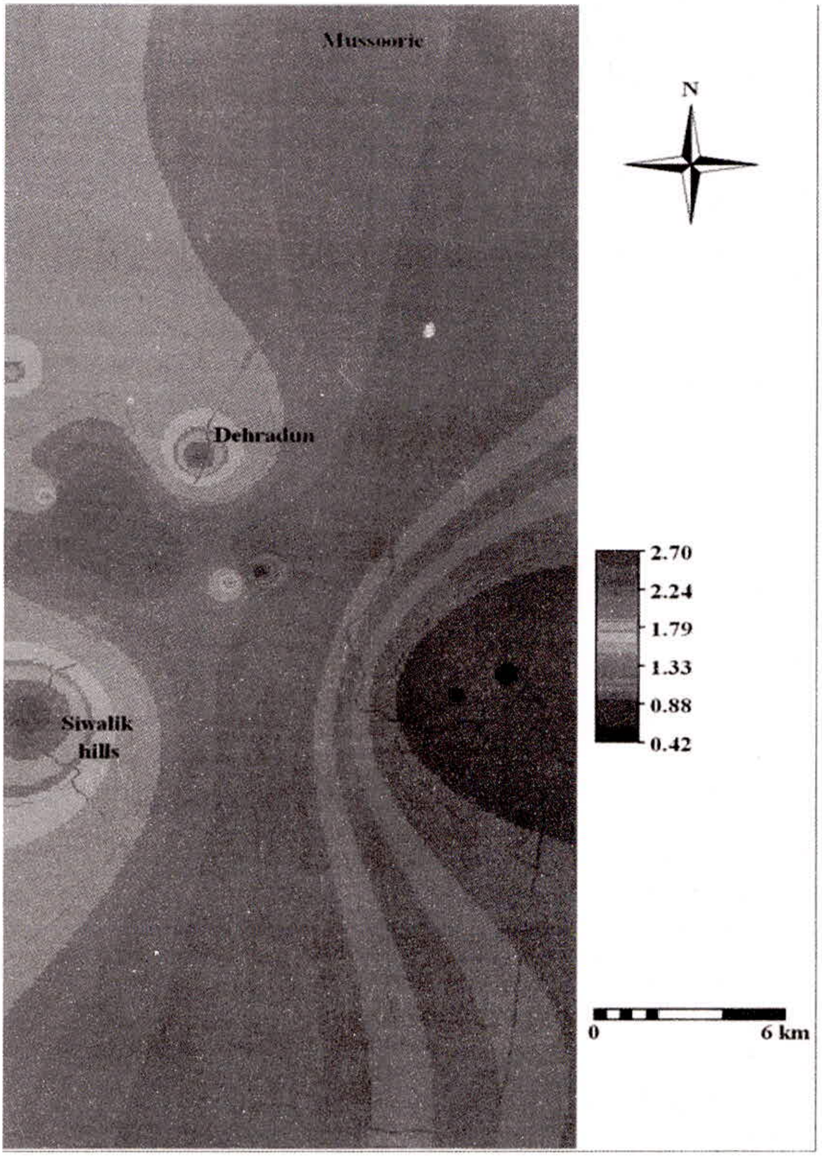

Fig. 3. Groundwater quality index (GWQI) map (Pre-monsoon-2006)

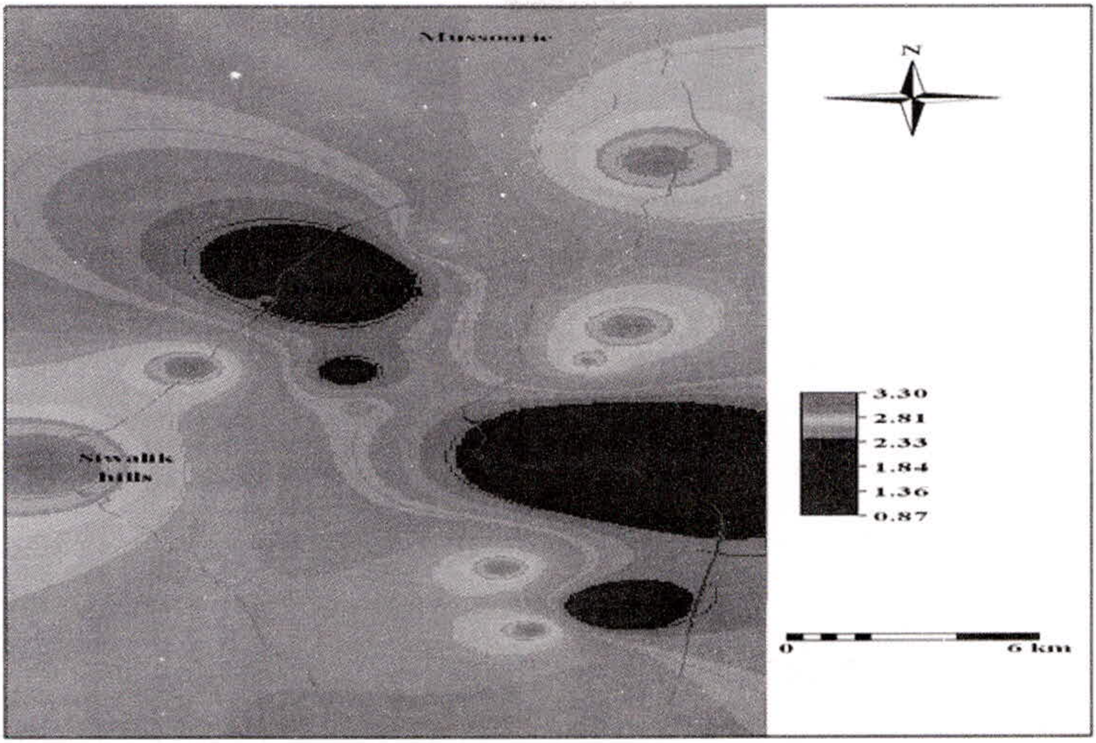

Fig. 4. Groundwater quality index (GWQI) map (Post-monsoon-2006)

SUSTAINABILITY INDICATORS

Forest Area as a Percent of Land Area

Deforestation rate (DR) is the compound annual rate of deforestation in the area of study in percent (between year P to year N):

$$DR(\%) = 100 \times \left(1 - \left(\frac{Forest\ area_{year\ N}}{Forest\ area_{year\ P}} \right)^{\frac{1}{N-P}} \right) \qquad (4)$$

The annual deforestation rate (DR) in the Suswa Watershed is worked out for the periods from year 1972 to 1990 and from 1990 to 2000 by using DR from equation (4) as 0.135 % and 0.888 % respectively. Although, the figures of deforestation rates are minimal, the one in the period of 10 years from 1990 to 2000 is faster than that in the earlier period of 18 years (from 1972 to 1990).

Water Barrier Index (WBI)

This indicator is based on annual per capita availability of renewable water (m^3 per capita per year) as given in Table 3. The water barrier concept is the most widely cited measure of water sufficiency for large regions and river basins. It has been used in a number of sustainability evaluation studies (Falkenmark and Widstrand, 1992). This approach has the advantage of providing a simple view for the basin, thereby stating the category to which it pertains. Notwithstanding the constraint of the size of the study area, this factor has been considered for the Suswa Watershed.

Table 3. Water barrier index categories

(Source: Falkenmark and Widstrand, 1992)	
Index (m^3 per capita per year)	Category/condition
> 1700	No stress
1000 - 1700	Stress
500 - 1000	Scarcity
< 500	Absolute scarcity

In the present study, the minimum and average annual surface water availability has been estimated as 63.19 million-m^3 and 122.68 million-m^3 respectively. Yet, the minimum figure of surface water availability (63.19 million-m^3) has been combined with the net quantity of groundwater available ($11,914.94 \times 10^4$ m^3) to arrive at the total minimum water availability in the Suswa Watershed. Thus, the minimum annual water availability is of the order of 18,23,39,400 m^3. The population for 2005 in the Suswa Watershed (projected from the population of 2001 census) has been worked out as 7,10,938. Finally, the minimum WBI in 2005 is of the order of 256.48 m^3 per capita per year thus placing the Watershed in 'absolute scarcity' category.

Integrated Water Stress Score (IWSS)

This indicator, developed for analyzing the sustainability of water resources, is an outcome of the evaluation of eight parameters listed in the Tables 4 and 5. The values for each of these parameters have been divided into three subgroups in conformity with the approach given by Narula et al. (2001) for Yamuna river basin: acceptable, average, and undesirable. Each sub-group has been assigned a score (referred as a point by Narula et al., 2001), e.g. acceptable is given a score of 1, average has a score of 2, and undesirable has a score of 3. As an example, a high rate of water table decline (more than 0.5 m/ year) falls in the 'undesirable' category and groundwater level decline rate of 0.1 m/ year or less and absence of waterlogging falls in the 'acceptable' category. Based on the summation of scores for each of the parameters, the scores are allotted in the form of integrated water stress and then converted into relative percentage by dividing the watershed score with 24 (8-parameters × 3-sub-groups).

Watersheds with a percentage stress score of more than 60 are classified as 'highly stressed'. In such areas further water development should be restricted or should only take place if it does not pose a further threat to water depletion and deterioration. 'Moderately stressed' watersheds are classified as having percentage stress scores ranging from 40 to 60. In these watersheds, development could be allowed to a certain extent. Watersheds with percentage scores less than 40 were classified as 'low stress' areas with scope for further water use and development. Tables 4 and 5 give the minimum and maximum possible integrated water stress scores for the present study area.

In this study, the lowest possible stress score (Table 4) has been of the order of 41.67 % when only one parameter (e.g. water table decline rate) is considered in 'undesirable' category and other

Table 4. Computations of minimum possible IWSS in the Suswa Watershed

Sl. No.	Eight parameters	Three sub-groups (scores allotted)		
		Acceptable (1)	Average (2)	Undesirable (3)
1	Population density	1	-	-
2	Irrigation intensity	1	-	-
3	No. of industrial facilities	1	-	-
4	Groundwater development	1	-	-
5	Water table decline/ rise	-	-	3
6	Groundwater quality	1	-	-
7	Surface water quality	1	-	-
8	Surface water flow	1	-	-
Sum of scores		7	0	3
Grand sum of scores		10 (7 + 0 + 3)		
IWSS		41.67 [(10 × 100) / 24]		

Table 5. Computations of maximum IWSS in the Suswa Watershed(after Yadav,2010)

Sl. No.	Eight parameters	Three sub-groups (scores allotted)		
		Acceptable (1)	Average (2)	Undesirable (3)
1	Population density	-	-	3
2	Irrigation intensity	-	2	-
3	No. of industrial facilities	-	-	3
4	Groundwater development	1	-	-
5	Water table decline/ rise	-	-	3
6	Groundwater quality	1	-	-
7	Surface water quality	1	-	-
8	Surface water flow	1	-	-
Sum of scores		4	2	9
Grand sum of scores		15 (4 + 2 + 9)		
IWSS		62.50 [(15 × 100) / 24]		

seven parameters are considered as 'acceptable'. Based on the IWSS classification system, the Suswa Watershed can thus be classified as 'moderately stressed'. On the other hand, the Watershed can be classified as 'highly stressed' (with a stress score of 62.50 %) by considering three parameters (e.g. water table decline rate, population density and number of industrial facilities) in 'undesirable' category; one parameter like irrigation intensity in 'average' category and the remaining four parameters in 'acceptable' category (Table 5). Thus, it is inferred that keeping in view the fast urbanization and increasing demands of population, the Suswa Watershed can be classified as 'moderately stressed' to 'highly stressed', confirming the outcome inferred from the WBI approach.

INTEGRATION OF SUSTAINABILITY INDICATORS

The results of the various indicators need to be organized and presented in a format that allows easy communication and unbiased interpretation. A template table has been developed to integrate indicator outcomes and the interpretation of trends (Table 6). After computing the indicators, the table allows to summarize the overall water sustainability condition of the Watershed. Difficulties associated with data acquisition notwithstanding, the indicators discussed above appear to have the capacity for application at watershed scale, helping to identify the priority issues that may require particular focus.

CONCLUDING REMARKS

The sustainability of water resources was evaluated for Suswa Watershed of Dehradun district in Uttarakhand using the relevant indicators of sustainability viz., deforestation rate, water barrier index (WBI) and integrated water stress score (IWSS). The estimates of annual storm runoff indicate that there is a scope for further harnessing the surface water resources as the average annual runoff volume is of the order of 123 million.m^3. The annual groundwater recharge for the year was computed as 11915 ha-m whereas the total draft was 4175 ha-m thus indicating that the groundwater development in the Suswa Watershed is still within safe limits. A synoptic assessment of ground water quality was also carried out by evaluating a groundwater quality index (GWQI).The GWQI index of the watershed varied between 0.42 to 2.70 during premonsoon period and between 0.87 to 3.30 during the postmonsoon period implying that generally the groundwater is within the thresholds of acceptable quality.

It was observed that, the deforestation rate in the period of 10 years (from 1990 to 2000) was faster in the watershed than that during the preceding duration of 18 years (from 1972 to 1990), although it was not alarming. The computations of water barrier index have indicated that the Suswa Watershed can be placed in 'absolute scarcity' category whereas as per IWSS scheme, the watershed can be classified as 'moderately

Table 6. Interpretation and comparison of indicator results

Sl. No.	Criteria (sustainability indicators)	Condition	Trend
1	DR	±	↓
2	WBI	– –	↓
3	IWSS	– –	↓
4	GWQI	±	↔

Condition: ++ very good, + good, ± reasonable, – poor, – – very poor.

Trend: '! improving, "! stable, "! degrading.

stressed' to 'highly stressed'. It is concluded from this study that in the context of declining trend of groundwater levels water, resources development in Dehradun city is becoming unsustainable though the larger Suswa watershed is still manageable.

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