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Assessment of Ground Water Sustainability for a Subtropical Town in Ganga Plain: A Case Study from North-India

D.C.Singhal[1], H. Joshi[1] and Supriya Mishra[2]

[1] Department of Hydrology, Indian Institute of Technology, Roorkee – 247 667, India
[2] Former Faculty, Sharda University, Greater Noida, (Uttar Pradesh), India
[1]E-mail of Corresponding author: dcsinghal7@gmail.com

Abstract

In the present paper, sustainability of groundwater resources of Roorkee town (Haridwar District) in Uttarakhand State of India has been assessed on the basis of certain identified sustainability indicators. A set of sustainability parameters has been identified for the study area in this assessment. These include quantitative assessment of water resources, a water barrier index based on per capita annual availability of water, and an integrated water stress score. For assessment of the quantity of the ground water resources, water level data of the shallow aquifers has been collected by using a ground water monitoring network of 19 open wells. Using ground water estimation methodology of Central Ground Water Board, the stage of ground water development in the study area has been worked out to be about 71%, which put Roorkee town and its suburbs in Safe Category of ground water development. From the data of water quality, Ground Water Quality Index (GWQI) has been calculated and it is concluded that although the ground water quality has degraded significantly between 2005 and 2012, it is still generally suitable for drinking purposes except at few locations. The Roorkee town (and its suburbs) have been put in 'Lower stress' category based on Water Barrier Index (WBI) whereas the area is categorized as "Low stressed" to "Moderately stressed" on the basis of the Integrated Water Stress Score. On the whole, the ground water resources development is still found to be 'sustainable' in Roorkee town and its suburbs. This study has also resulted in formulation of a set of guidelines for assessment of ground water sustainability.

Keywords: Sustainability Indicators, Ground Water Resources, Ground Water Quality Index, Roorkee Town, India.

1. Introduction

The ever growing demand of freshwater for human consumption has become a worldwide cause of concern. Over two billion people around the globe depend on groundwater for their daily supply. A large amount of the irrigation in the world is dependent on ground water, as are large numbers of industries. India, with a population of over 1.20 billion, is the most populous country in the world after China. The urban areas are fast getting densely populated and are expanding rapidly, putting undesirable stress on the natural resources and depleting them. In the present paper, an attempt has been made to evaluate sustainability of a fast growing urban area, Roorkee town and its suburbs using a set of sustainability indicators.

The concept of sustainability of water resources has quite varied perceptions to different professionals viz., hydrologists, hydrogeologists, water resource engineers, and sociologists. Sustainable development is defined as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. In case of groundwater resources, the concept is largely related to 'safe yield' (Hiscok et al., 2002; Kalf and Wooley, 2005). Application of the concept of sustainability to water resources requires that the effects of many different human activities on water resources, and on total environment be understood and quantified to the extent possible (Sophocleus, 1998, 2000). The conventional safe yield approach is limited and restrictive as it fails to address the beneficial impacts of natural groundwater discharge on related groundwater dependent ecosystems, and on the surface water system in general. Alley et al. (1999) suggested that strategies for sustainability of groundwater resources should involve innovative approaches which involve some combination of use of aquifers as storage reservoirs, conjunctive use of surface water and groundwater, artificial recharge of water through wells or surface spreading, and the use of recycled or reclaimed water. Similar to the safe yield, groundwater sustainability is defined in a broad context, and somewhat ambiguously, as the development and use of groundwater resources in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic or social consequences (Alley and Leake, 2004).

The present study has been carried out in the town of Roorkee, a subtropical urban area situated in the northern part of the Ganga alluvial plain of North India situated near the Himalayan foothills. The main source of drinking water in this town and its suburbs is ground water with its domestic and industrial water requirement being fulfilled through municipal water supply supported by private tubewells. The aim of this study is achieved by estimating the quantity and quality of groundwater resources in the study area and estimating the amount of water use to meet the domestic and industrial needs for its population. The assessment of dynamic groundwater resources has been done by using a Mass Balance methodology of groundwater budgeting practiced by the Central Ground Water Board (CGWB), Government of India (GEC, 1997). The estimation of water use in this town is compiled from the data provided by local agencies whereas assessment of groundwater quality has been carried out using the Index of Aquifer Water Quality (IAWQ) proposed by Melloul and Collin (1998).

2. Study Area

The Roorkee town and its surburbs (latitude 29^{o}50' to 29^{o}55' N and 77^{o}50' to 77^{o}55' E) having an area of 78 sq km are situated in the northern part of the Ganga alluvial plain on the right bank of the river Solani, which is a tributary of river Ganga (Fig. 1). The upper Ganga canal flows through the centre of the town dividing it into old part of Roorkee town towards the west and the recently developed areas towards the east. The study area has a gentle slope towards southeast. The Solani river has a southeasterly flow whereas a subsidiary drain in the area flows towards east (Fig. 1).

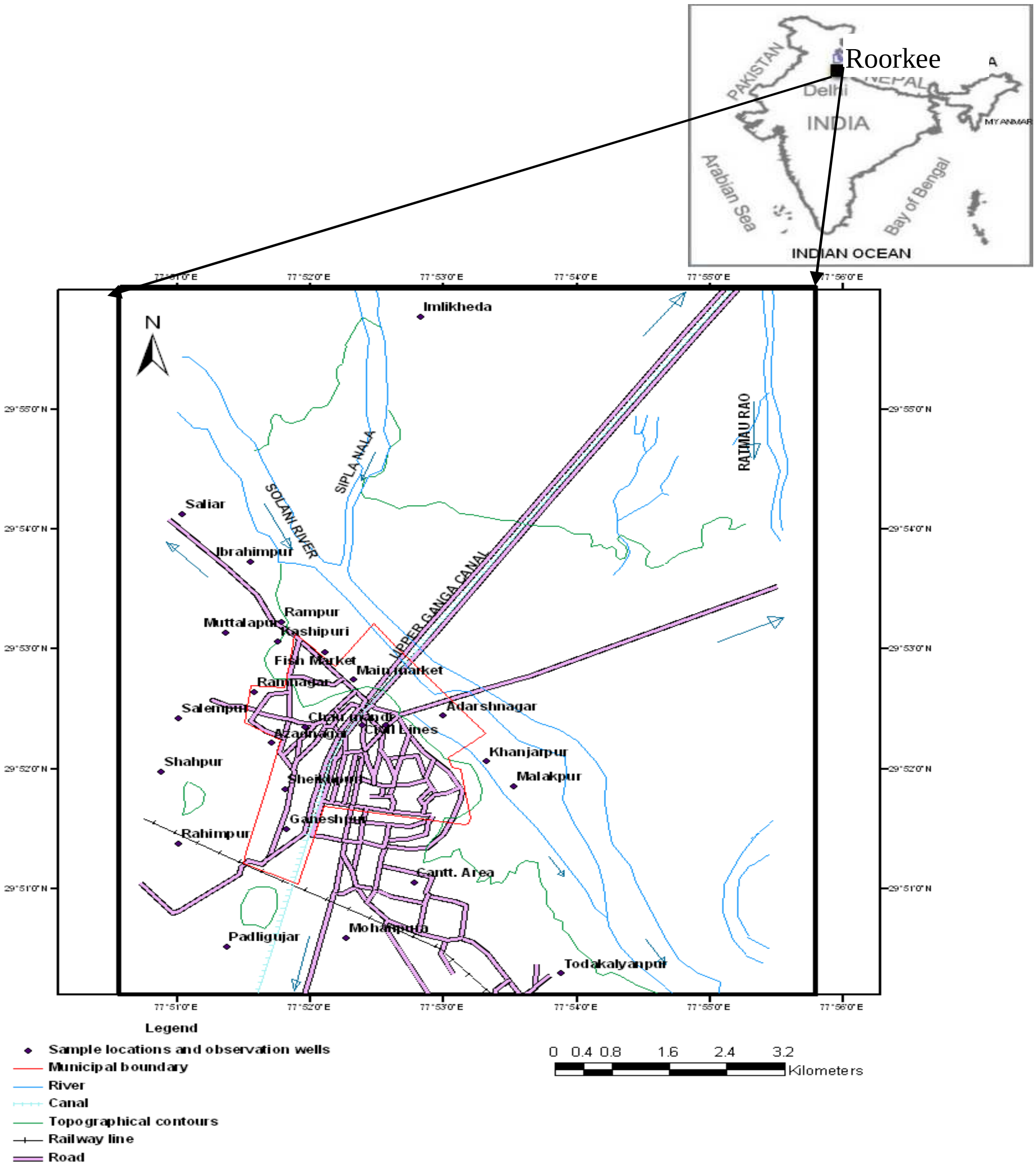


Fig.1.Location map of Roorkee and Suburbs

3. Groundwater Resource Assessment

The assessment of the groundwater resources has been done for year 2004-05 using the methodology of groundwater budgeting (GEC 1997). Calculations of groundwater draft and groundwater recharge calculation along with stage of groundwater development are summarized in Table 1.

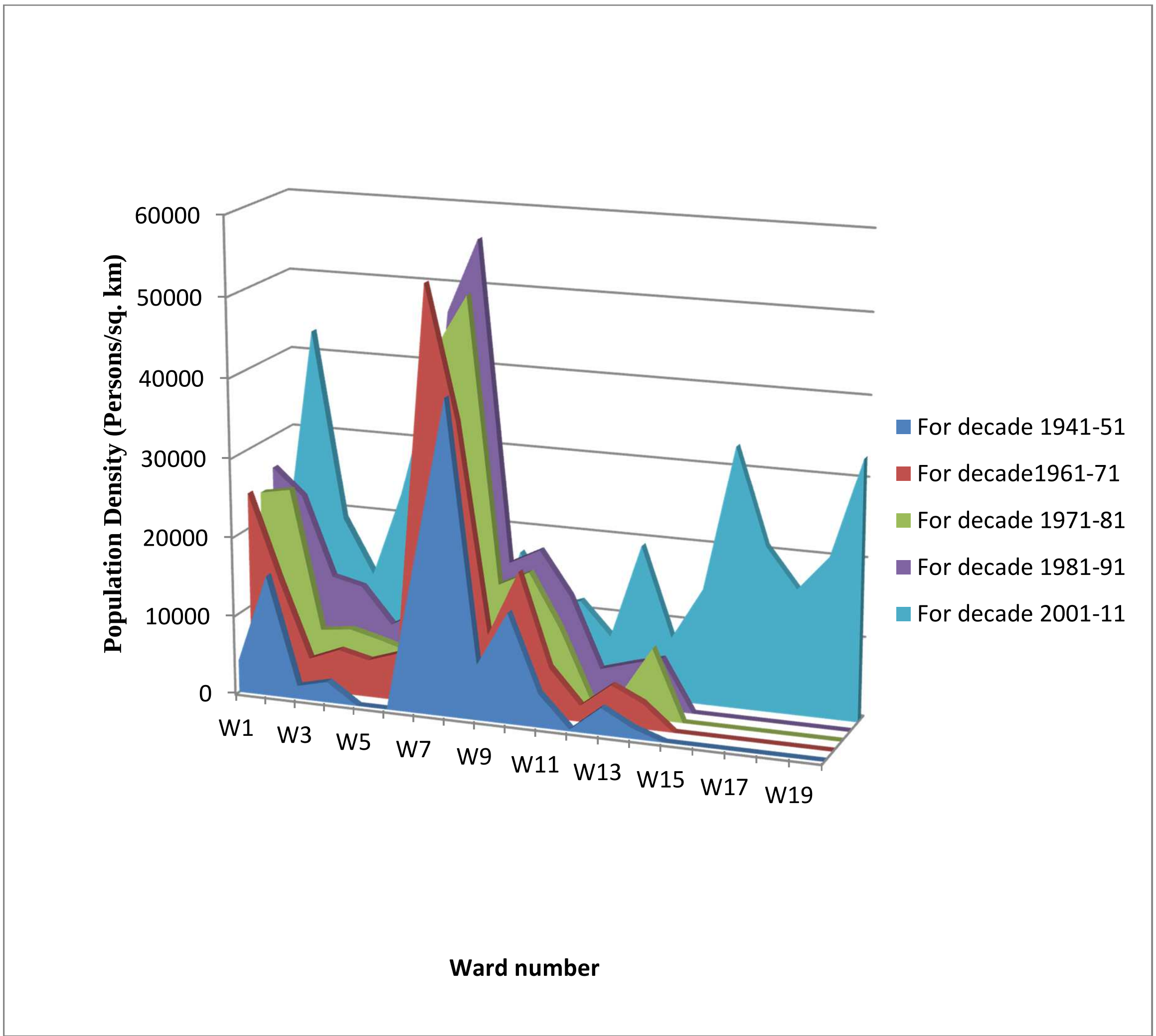
Table 1. Groundwater Resource Assessment (after Mishra 2012)

Sl. No.	Parameter	Value/ Description	
1	(a) Total recharge area (ha), excluding hilly area	7800	
2	Current annual gross groundwater draft for all uses	8580.799 ha-m	
Recharge from 'other sources' in noncommand area (ha-m)		Monsoon (A)	Non-monsoon (B)
3	Recharge from canals	2677	6093
4	Recharge from groundwater irrigation	858.08	1716.16
5	Recharge from 'other sources'	3535.08	7809.16
6	Total Annual Recharge from 'other sources'.	11344.24	
7	Rainfall recharge by WTF method during monsoon season (ha-m)	2868.766	
8	Normalized rainfall recharge by WTF method during monsoon season (ha-m)	3041.08	
9	Normalized rainfall recharge by RIF method in monsoon season (ha-m)	1352.845	
10	Normalized rainfall recharge by RIF method in non- monsoon season (ha-m)	510.78	
11	PD between rainfall recharge estimated for monsoon season by WTF method & RIF method (%)	124.79 (> 20 %)	
12	Recharge from rainfall during monsoon season (ha-m) [1.2xcol. 1.9]	1623.41	
13	Annual groundwater recharge from rainfall (ha-m) [col.1.10 + col. 1.12]	2134.19	
14	Annual groundwater availability (ha-m)	13478.43	
15	Unaccounted losses @10% of col. 1.14	1347.84	
16	Net annual groundwater availability (ha-m)	12130.59	
17	Stage of groundwater development (%) [col.1.2/col.116]	71%	

*Note (i) WTF method= Water Table Fluctuation method,
(ii) RIF method = Rainfall Infiltration factor method,
(iii) PD= Percentage Difference

4. Estimation of Water Supply and Demand

Different sectors of society use water for different purposes: viz. drinking, production of food and energy, etc. The water requirement for these activities varies with climatic conditions, lifestyle, culture, tradition, diet, technology, and wealth. According to 2011 census, Roorkee town has been divided into twenty wards (Fig. 2). The ward wise population density of the town for the period 1941-2011 is shown in Fig. 2. Assessment of actual groundwater extraction (for supply) in Roorkee town (municipal area and IIT Roorkee campus) has been carried out through a dedicated survey (Table 2). Water demand for the Roorkee town has been estimated to be 43.07 MLD for the municipal area and 10.95 MLD for IIT campus adding upto 54.02 MLD. The groundwater extraction in the town totals 52.00 MLD.



1. CHAW MANDI
2. WEST AMBER TALAB
3. SHEKHAPURI
4. GANESH VIHAR
5. PURWA DIN DAYAL
6. EAST CHAWMANDI TALAB
7. NITI NAGAR
8. MALAKPUR
9. SOOTY KANUGOYAN
10. PATHANPURA

11. AVAS VIKAS
12. CIVIL LINE
13. MAQTOOLPURI
14. CIVIL LINE
15. RAMNAGAR
16. RAMNAGAR
17. RAJPUTANA
18. RAMNAGAR
19. PURANI TEHSIL
20 SATTI

Fig.2. Ward-wise population density of Roorkee town (period 1941-2011)

Table 2. Estimation of actual water use/ extraction on the basis of survey

		Number of households/ commercial units	Water use per unit (lpd)	Total water use (MLD)
Households		22681	500 - 1000	12.758
Municipal Water Supply		-	-	21.701
Commercial Units	Industries	46	500 – 3000	0.033
	Hospitals	16	4000	0.048
	Schools (Higher secondary and secondary)	28	2000	0.056
	Colleges/ Research Institutes	12	2000	0.024
	Hotels	8	3000	0.064
	Indian Institute of Technology	1	-	17.325
			Total water use	52.009

5. Groundwater Quality

The data of groundwater quality as available for the year 2005 and that generated for this study for the year 2012 has been analysed. The physicochemical data for the groundwater in years 2005 and 2012 is given in Tables 3 to 6. For comparison with the existing Standards, the values of different parameters laid down by Bureau of Indian Standards (BIS, IS 10500, 1991) have also been given in these tables. A perusal of the data of groundwater quality indicates that the shallow groundwater has total dissolved solids (TDS) in the range of 129 to 1277mg/L in pre-monsoon period, 2005 with the pH varying between 7.1 to 8.3. Further, in pre-monsoon 2012, the TDS range varied between 150 to 2262 mg/L with the pH ranging from 7.1 to 8.07.Thus the TDS of the groundwater was found to exceed the permissible BIS standards (500mg/L) marginally at few locations especially in some central parts of the study area such as Fish Market, Sheikhpuri, Chau Mandi and Kashipuri.(Fig.1).Further, the overall quality of groundwater seems to have deteriorated over the years as reflected from the higher range of total dissolved salts during 2012.This rise in salinity could be ascribed partly to increase in the pollutants in the urban runoff generated from increased industrial activities and which percolated into the shallow groundwater in the study area resulting in the augmentation of overall salinity of groundwater.

Table 3: Physico-chemical analysis of Groundwater Samples (pre-monsoon 2005)

Location	**Temp °C**	**pH**	**Elec. Cond (um/cm)**	**TDS (mg/i)**	**Alkalinity (mg/l)**	**HCO_3 (mg/l)**	**CO_3 (mg/l)**	**Cl (mg/l)**	**Total Hardness (mg/l)**	**Ca (mg/l)**	**Mg (mg/l)**	**SO_4 (mg/l)**	**TP (mg/l)**	**Na (mg/l)**	**K (mg/l)**	**NO3 (mg/l)**
Ibrahimpur	25	7.8	544	357	220	218.7	1.3	16	234	54.4	23.79	49.8	0.0185	66.6	2.4	38.7

Saliar (sewage)	30	7.8	1102	716	418	415.54	2.5	126	306	84	23.31	85.2	1.4565	76.9	20	31.7
Saliar	26.2	7.4	985	640	372	370.66	1.3	77	566	140	52.45	92.19	0.0265	108	10	30.3
Rampur	26	7.5	1277	830	360	358.99	1.0	132	372	93.6	40.79	73.26	0.1457	160	30.8	2.32
Ramnagar (indl)	29	7.6	955	627	256	255.04	1.0	80	322	114.4	8.74	71.2	0.1247	116.9	17.6	0.164
Ramnagar	25.8	7.8	511	333	190	188.88	1.1	19	258	60	26.22	96.31	0.1032	43.2	2.1	ND
Muttalapur	25	7.8	606	392	220	218.7	1.3	132	248	35.2	38.85	55.55	0.1328	56.9	ND	0.184
Kashipuri	25.5	7.5	881	573	220	219.34	0.7	16	390	128	16.99	97.96	0.078	49.7	15.6	0.142
Azadnagar	25	8	452	295	164	162.47	1.5	29	204	52.8	17.48	134.18	0.1779	31.3	4.5	8.43
Sheikhpuri	25	7.2	1100	715	376	375.44	0.6	116	366	120.8	15.54	131.3	0.194	73.5	12.8	16.2
Ganeshpur(R/B)	24	7.1	815	530	264	263.88	0.3	84	446	147.2	18.94	148.17	0.1296	112.3	8.7	26.9
Ganeshpur(L/B)	27	8.3	258	174	70	68.71	1.2	20	134	28	15.54	108.25	0.1312	20.5	2	ND
Salempur	25	7.7	592	389	240	238.87	1.1	21	190	58.4	10.68	126.36	0.1521	57.9	6.1	0.244
Shahpur	36	7.4	856	565	312	310.87	1.1	30	430	81.6	54.88	41.16	0.1602	65.8	3.1	1.11
Padligujar	25	7.1	419	274	146	145.82	0.2	14	160	38.4	15.54	137.47	0.1586	33.8	10.9	13.6
Rahimpur	25	7.8	601	396	218	216.71	1.3	21	286	65.6	29.62	100.01	0.0571	53.7	ND	8.81
Mohanpura	26	7.7	698	459	188	187.12	0.9	40	280	64.8	28.65	114.83	0.078	60.7	12.8	28.6
Todakalyanpur	26	7.1	865	571	202	201.76	0.2	69	340	96.8	23.79	102.48	0.1312	42.8	10.6	12.6
Cantt. Area	24.5	7.8	812	531	250	248.52	1.5	35	212	92.8	2.91	101.25	0.0797	52.6	13.8	25.2
Khanjarpur	25	7.5	913	605	314	313.07	0.9	42	314	92	20.39	80.67	0.128	61.9	15	19.3
Malakpur(GW)	25	7.5	1153	758	226	225.33	0.7	116	400	103.2	34.48	113.19	0.1151	61.6	23.7	40.6
Malakpur(sewage)	34	7.5	1065	707	360	358.93	1.1	54	286	88.8	15.54	194.27	1.9573	84.6	27.5	0.167
Adarsh nagar	28	7.5	840	546	298	297.11	0.9	27	212	71.2	8.25	176.98	0.0297	28	6	2.11
Civil Lines(L/B)	20	8.2	297	184	88	86.7	13	19	140	38.4	10.68	106.6	0.0813	50.1	12	1.25
Canal Water	20	8.3	194	129	70	68.71	1.3	19	100	26.4	8.25	91.78	0.0942	25	9.2	0.485
Civil Lines (R/B)	20	8.2	276	181	102	100.5	1.5	14	144	35.2	13.59	191.8	0.0684	90	13.2	0.341
Fish Market	25	7.8	1008	655	234	232.62	1.4	190	390	100	33.99	9.46	0.107	78.6	7	10.5
Chawmandi	29	7.9	1123	730	342	339.46	1.5	128	396	150.4	4.85	78.2	0.1296	99	11.6	2.99
Main Market	27	7.8	616	401	296	294.25	1.8	60	290	100	46.13	69.56	0.0539	52.8	3.6	11.84

Saraswati temple IIT	25.5	7.7	705	467	220	218.97	1.0	27	158	54.4	5.34	100.84	0.0297	44.5	2.7	2.11
BIS	-	6.5-8.5	-	500	200	-	-	250	300	75	30	-	-	-	-	45

Table 4: Heavy Metal analysis of Groundwater Samples (pre-monsoon 2005)

Location	Cd (mg/l)	Pb (mg/l)	Cr (mg/l)	Zn (mg/l)	Fe (mg/l)	Mn (mg/l)	Ni (mg/l)
Ibrahimpur	0.017	0.0069	0.016	0.051	0.039	0.016	ND
Saliar(sewage)	0.026	0.019	0.03	0.05	0.267	0.134	0.083
Saliar	0.054	0.0048	0.05	0.185	0.135	0.346	0.148
Rampur	0.012	0.00001	0.011	0.136	ND	0.227	0.01
Ramnagar(indl)	0.006	0.0079	0.017	0.101	ND	0.064	ND
Ramnagar	0.005	0.004	0.007	0.081	0.017	0.048	ND
Muttalapur	0.045	0.00004	0.019	0.112	0.056	0.144	ND
Kashipuri	0.022	0.0026	0.011	0.034	0.062	0.007	ND
Azadnagar	0.025	0.0181	0.007	0.129	0.039	0.023	ND
Sheikhpuri	0.019	0.0307	ND	0.14	ND	0.04	ND
Ganeshpur(R/B)	0.01	0.0061	ND	0.068	0.027	0.007	ND
Ganeshpur(L/B)	0.007	0.011	0.001	0.125	0.023	ND	ND
Salempur	0.003	0.0091	0.006	0.253	0.241	0.043	ND
Shahpur	0.01	0.00002	0.007	0.266	0.091	0.051	ND
Padligujar	0.018	0.0058	0.005	0.123	0.04	0.168	ND
Rahimpur	0.017	0.0056	ND	0.067	0.092	0.04	0.007
Mohanpura	ND	0.036	ND	0.228	ND	ND	ND
Todakalyanpur	ND	0.0001	0.004	0.106	0.003	0.027	ND
Cantt.Area	0.006	0.0076	ND	0.168	ND	0.027	ND
Khanjarpur	0.013	0.0012	ND	0.063	0.003	0.018	0.068
Malakpur(GW)	0.015	0.0062	ND	0.045	0.09	0.02	ND
Malakpur(sewage)	0.014	0.0071	ND	0.047	0.128	0.139	0.01
Adarshnagar	0.009	0.0092	ND	0.333	0.385	0.138	0.003
Civil Lines(L/B)	0.015	0.0113	ND	0.122	0.191	ND	0.044
Canal water	0.01	0.0177	ND	0.065	0.042	ND	ND
Civil Lines(R/B)	0.005	0.00019	ND	0.069	0.03	0.021	0.031
Fish Market	0.017	0.0086	0.004	0.461	0.098	0.227	0.007
Chau mandi	ND	0.0189	ND	0.498	0.029	0.139	ND
Main Market	0.003	0.00005	ND	0.486	0.09	0.073	ND
Saraswati temple IIT	0.004	0.00001	ND	0.037	ND	0.065	0.034
BIS : 10500	**0.01**	**0.1**	**0.05**	**5**	**0.03**	**0.1**	**0.2**

Table 5 : Physico-chemical analysis of Groundwater Samples (Pre-monsoon 2012)

Sample Location	F- (mg/l)	Cl- (mg/l)	Br- (mg/l)	NO_3^{2-} (mg/l)	PO_4^{2-} (mg/l)	SO_4^{2-} (mg/l)	EC (us/cm)	pH	TA (mg/l)	TH (mg/l)	TDS (mg/l)	Na+ (mg/l)	NH_4^{2+} (mg/l)	K+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)
Malakpur	0.16	10.89	1.50	0.12	0.00	27.33	556.00	7.96	318.00	264.00	324.00	23.174	0.193	5.636	60.543	21.3889
Khanjarpur	0.26	13.64	2.15	0.16	0.00	27.93	691.00	7.80	356.00	296.00	386.00	39.081	0.182	10.06	26.321	26.339
Adarsh Nagar	0.52	39.04	2.34	0.00	0.00	64.94	962.00	7.52	442.00	404.00	566.00	64.67	0.059	7.924	43.687	47.079
IIT Saraswati Temple	0.14	9.27	1.48	0.00	0.00	33.30	600.00	7.69	306.00	268.00	360.00	30.829	0.156	5.115	41.134	21.386
Saliar	0.43	1.55	1.44	0.16	0.00	4.62	445.00	7.61	274.00	370.00	258.00	30.675	0	2.97	49.107	27.398
Ibrahimpur	0.69	1.18	1.35	0.00	0.00	3.00	438.00	7.85	260.00	182.00	240.00	40.533	0.156	4.866	29.863	25.716
Rampur	0.52	1.42	1.18	0.00	0.00	1.95	427.00	7.63	254.00	182.00	232.00	26.634	0.165	3.642	37.975	25.4888
Muttalapur	0.44	7.23	1.61	0.00	0.00	14.30	512.00	7.61	288.00	236.00	290.00	24.441	0.258	5.096	27.215	31.043
Kashipuri	0.33	214.39	2.89	0.09	0.00	9.16	2103.00	7.35	278.00	372.00	2262.00	41.599	0.306	10.17	158.2	143.678
Ram Nagar	0.35	6.17	1.39	0.00	0.00	11.77	480.00	7.52	290.00	230.00	266.00	21.925	0.207	5.546	60.568	27.471
Salempur	0.34	70.46	1.74	0.00	0.00	36.27	420.00	7.40	326.00	326.00	498.00	45.581	0.237	7.145	42.323	31.783
Azad Nagar	0.37	15.24	1.07	0.00	0.00	8.97	387.00	8.07	208.00	182.00	232.00	15.165	0.286	4.959	32.694	19.374
Sheikhpuri	0.46	31.44	1.06	0.00	0.00	30.19	476.00	7.73	186.00	230.00	320.00	1.0179	0	0.557	4.554	1.73
Ganeshpuri	0.37	32.07	0.97	1.23	0.00	18.53	458.00	7.69	184.00	202.00	308.00	0.974	0	0	5.22	1.338
Padligujar	0.24	18.20	0.94	37.74	0.00	29.64	574.00	7.55	224.00	258.00	394.00	1.271	0	0	6.585	2.127
Rahimpur	0.69	82.29	1.24	2.23	0.00	9.58	377.00	7.58	198.00	176.00	220.00	28.712	0.089	4.642	69.272	22.189
Mohanpura	0.22	12.26	1.14	2.00	0.00	18.35	474.00	7.18	230.00	218.00	282.00	17.256	0.15	2.979	48.85	28.269
Todakalyanpur	0.36	14.64	0.15	22.45	0.00	10.55	365.00	7.74	152.00	154.00	250.00	15.224	0	4.953	59.827	14.374
Fish Market	0.37	118.50	0.45	0.00	0.00	57.51	1076.00	7.33	298.00	496.00	908.00	38.141	0.098	6.972	94.093	62.421
Chaw Mandi	0.30	82.42	0.43	0.00	0.00	33.16	867.00	7.34	340.00	396.00	558.00	38.393	0	8.257	65.715	54.444
Main Market	0.27	17.13	0.00	1.02	0.00	42.13	225.00	7.94	100.00	102.00	150.00	5.836	0	1.429	44.326	10.964
Civil Lines	0.63	2.91	0.39	0.09	0.00	25.65	285.00	7.97	130.00	130.00	168.00	8.853	0	3.519	48.932	14.529
BIS:10500	1.00	250.00		45.00		200.00		6.5-8.5	200.00	300.00	500.00				75	30

Table 6: GROUNDWATER QUALITY DATA OF HEAVY METALS 2012

Sampling Location	Fe (mg/l)	Cu (mg/l)	Mn (mg/l)	Hg (mg/l)	As (mg/l)	Pb (mg/l)	Cr (mg/l)	Al (mg/l)	B (mg/l)	Cd (mg/l)	Zn (mg/l)	Se (mg/l)
Malakpur	1.4038	0.0275	0.1215	0.0068	0.00607	1.8524	0.00302	0.0827	2.4388	0.00513	0.1102	0.00076
Khanjarpur	3.0975	0.0204	0.79804	0.0079	0.0082	0.1614	0.00934	0.1425	3.5385	0.0075	0.166	0.00088
Adarsh Nagar	2.2257	0.0071	0.2643	0.0061	0.0031	0.0067	0.0168	0.0753	4.3433	0.0089	0.4179	0.0023
IIT Saraswati Temple	1.4038	0.0275	0.1215	0.0068	0.00607	1.8524	0.00302	0.0827	2.4388	0.0051	0.1102	0.0007
Saliar	4.0956	0.0554	0.1113	0.0065	0.0061	0.2578	0.0083	0.5971	3.0316	0.0409	2.4571	0.0005
Ibrahimpur	0.4735	0.0088	0.1049	0.0039	0.00091	0.0255	0.0042	0.0684	4.9618	35.2132	0.2389	0.00044
Rampur	1.1815	0.0659	0.0738	0.00356	0.0089	0.1305	0.0049	0.1156	2.7544	0.4186	0.0714	0.00056
Muttalapur	3.7832	0.0168	0.0944	0.003	0.0018	0.0189	0.00463	0.093	1.941	0.02705	0.1455	0.00069
Kashipuri	1.9341	0.01252	0.2105	0.0028	0.0052	0.0128	0.0041	0.218	2.0921	0.0076	1.3967	0.0082
Ram Nagar	1.2056	0.037	0.1703	0.0026	0.0103	0.0229	0.0037	0.1216	1.7259	0.0685	0.4403	0.0007
Salempur	7.1023	0.01311	0.2042	0.0021	0.0039	0.0717	0.0267	0.05	1.5628	0.0269	0.3848	0.0017
Azad Nagar	3.0559	0.0169	0.0897	0.0025	0.0019	0.0695	0.00409	0.1115	1.4228	0.00136	0.1433	0.0007
Sheikhpuri	2.977	44.2	0.0654	0.0106	0.0033	0.0203	0.0097	0.0597	1.5359	0.0015	0.37008	0.0008
Ganeshpir	1.6616	0.0756	0.2443	0.0025	0.00257	0.00536	0.00515	0.03165	1.1771	0.0132	0.2215	0.0007
Padligujar	1.281	0.0209	0.0225	0.0025	0.00318	0.0561	0.0238	0.0591	1.2515	0.00278	0.2814	0.0024
Rahimpur	1.4697	0.00372	0.0901	0.00136	0.00668	0.01359	0.004213	0.1648	1.151	0.0027	1.5263	0.005
Mohanpura	2.1401	0.03377	0.1317	0.001	0.00104	0.01386	0.00569	0.249	2.6479	0.0005	0.6453	0.00073
Todakalyanpur	0.7485	0.0246	0.0308	0.0011	0.012	0.0162	0.0053	0.0737	1.2595	0.0004	0.1115	0.0041
Fish Market	10.24	0.0123	0.283	0.0009	0.0033	0.0216	0.0095	0.1306	2.2793	0.0005	0.9122	0.0018
Chaw Mandi	21.083	0.023	0.214	0.0009	0.003	0.03	0.009	0.063	3.164	0.0006	1.821	0.0011
Main Market	0.754	0.022	0.024	0.001	0.004	0.012	0.004	0.091	2.288	0.0004	0.079	0.0006
Civil Lines	0.549	0.031	0.046	0.001	0.004	0.017	0.003	0.051	1.494	0.312	0.163	0.001

6. Sustainability Indicators

Sustainability indicators are the means to measure the progress towards sustainable development. There are a number of sustainability indicators developed for varying needs throughout the world, but there is a need to adopt the most appropriate ones. From the studies, it has been observed that each situation requires a particular method of assessment and no given set of indicators can be applied uniformly and universally in all areas. The Indicators which have been identified for the present study are as under.

6.1 Water Barrier Index (WBI)

This index has been used in a number of earlier sustainability evaluation studies (Falkenmark and Widestrand, 1992; Gleick, 1993, 1997 and Engleman&LeRoy, 1993). Water Barrier Index (WBI) involves annual per capita availability of renewable water (m^3, per capita per year). The area is defined as being "water stressed" if it has a per capita water availability between 1000 to 1700 m^3 per year or/ and facing "water scarcity" when supplies drop below 1000 m^3 per year (Table 7). For the Roorkee town, the WBI computations have been made by taking net annual ground water availability. The net quantity of ground water available has been estimated to be 12130.59 x $10^4 m^3$. The population for 2005 in the Roorkee town (projected from the 2001 population census) has been worked out as 104312. Thus, the minimum WBI for 2005 is found to be of the order of 1163 m^3 per capita per year. Hence, the study area falls in "Stress category".

Table 7: Water barrier index demarcations (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

6.2 Integrated Water Stress Score (IWSS)

The concept of integrated water stress score has been widely utilized by earlier workers for evaluation of sustainability (Narula et al., 2001) and is an outcome of the evaluation of six parameters, population density, irrigation intensity, number of industrial facilities, groundwater development, water table fluctuation (decline or rise) and groundwater quality. The values for each of these parameters have been divided into three subgroups as per the approach given by Narula et. al. (2001) for Yamuna river basin: acceptable, average and undesirable. Subsequently, each subgroup is assigned a score: acceptable (1) average (2) and undesirable (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/year or less and absence of water logging falls in the "Acceptable" category. Based on the summation of points 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 18 (6 parameters x 3 sub-groups). Areas with a percentage stressed 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" areas are classified as having percentage stress scores ranging from 40 to 60. In these areas, development could be allowed to a certain extent. Areas with percentage scores less than 40 were classified as "Low stress" areas with scope for further water use and development. Tables 8 and 9 give the minimum and maximum possible integrated water scores for the present study area. From Table 8, the lowest possible stress score is 33.33% when all the parameters are considered in "Acceptable" category. On the basis of IWSS classification system, Roorkee area can be classified as "Low stressed". However, the study area can be classified as "Highly stressed" (with a stress score of 55.55%) by considering the parameter of population density "Undesirable" category and two other parameters viz. number of industrial facilities and ground water quality in "Average" category and the remaining four parameters in "Acceptable" category (Table 9). Thus, a refinement in interpretation conclusion can be made keeping in view the fast urbanization and increasing demands of population, and the study area can be classified as "Low stressed" to "Moderately stressed".

Table 8: Computations of minimum possible IWSS in Roorkee and its suburb.

Sl. No.	Six 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	1	-	
6	Groundwater quality	1	-	-
Sum of scores		6	0	0
Grand sum of scores		10 (6 + 0 + 0)		
IWSS		33.33 [(6 × 100) / 18]		

Table 9. Computations of maximum possible IWSS in Roorkee and its suburb.

Sl. No.	Six parameters	Three sub-groups (scores allotted)		
		Acceptable (1)	Average (2)	Undesirable (3)
1	Population density	-	-	3
2	Irrigation intensity	1	-	-
3	No. of industrial facilities	-	2	-
4	Groundwater development	1	-	-
5	Water table decline/ rise	1	-	-
6	Groundwater quality	-	2	-
Sum of scores		3	4	3
Grand sum of scores		10 (3 +4 +3)		
IWSS		55.55 [(10 × 100) / 18]		

6.3 Forest Area

As the present study is related to an urban area (Roorkee and its suburbs), degree of deforestation has been ignored in this work.

6.4 Ground Water Quality Index (GWQI)

Ground water quality index (GWQI) for years 2004-06 & 2012 in the Roorkee and its suburbs is calculated by including few modifications in the original work of Melloul and Collin (1998). For the calculation of GWQI, seven water quality parameters have been selected for year 2005 [viz. Cd, NO_3, total hardness (TH), Fe, Mn, TDS and total alkalinity (TA)] from the quality data (Tables 3 and 4) and twelve water quality parameters [viz. Pb, Cd, Hg, B, Cu, Al, TH, Fe, Mn, Mg, TDS and TA] for the year 2012 (Tables 5 and 6). If the findings (about certain parameter) violate the drinking water quality standards of BIS: 10500 (1991) and WHO (1998) in more than 10% of the total samples collected, that parameter is considered relevant in the area. It may be mentioned that a groundwater sample having the integrated GWQI greater than 2.0 is considered unfit for drinking purposes (Mishra 2012). The GWQI map has been prepared using the GWQI for pre monsoon and post monsoon periods of 2005 and pre monsoon period of 2012 (Fig. 3, Fig. 4 and Fig. 5). From the GWQI maps, the comparison indicates that the GWQI values for pre monsoon period during 2005 are high at few localities like Saliar village in the northwest (Fig. 3). Further, during post monsoon period (2005), the monsoon, 2012 maximum GWQI value (3.25) is observed at several localities, towards northwest as well as in eastern parts of the study area (Fig. 5). Also, it can be noticed that the GWQI values are found to be higher (than the threshold value) in 2012 while during 2005, the GWQI values were within this limit. This indicates that the Groundwater quality is being deteriorated progressively in Roorkee between 2005 and 2012. The reason for the poor groundwater quality at some places during 2012 might be due to increasing urbanization, growth of industries and agricultural activities in the study area. Melloul and Collin (1998) suggested that temporal comparison of GWQI can highlight ongoing increase (or decrease) in the concentration of particular chemical parameter (or combinations of parameters) in groundwater for a region.

6.5 Integration of Sustainability Indicators

The integration of the various sustainability indicators to present the whole scenario has been done in a format that allows easy communication and proper interpretation. Table 10 summarizes the overall sustainability of the resource and indicator trends.

Table 10. Interpretation and comparison of indicator results

Sl. No.	Criteria (sustainability indicators)	Condition	Trend
1	WBI	–	↓
2	IWSS	–	↓
3	GWQI	+	↓

Condition: ++ very good, + good, ± reasonable, – poor, – – very poor.
Trend: ↑ improving, ↔ stable, ↓ degrading.

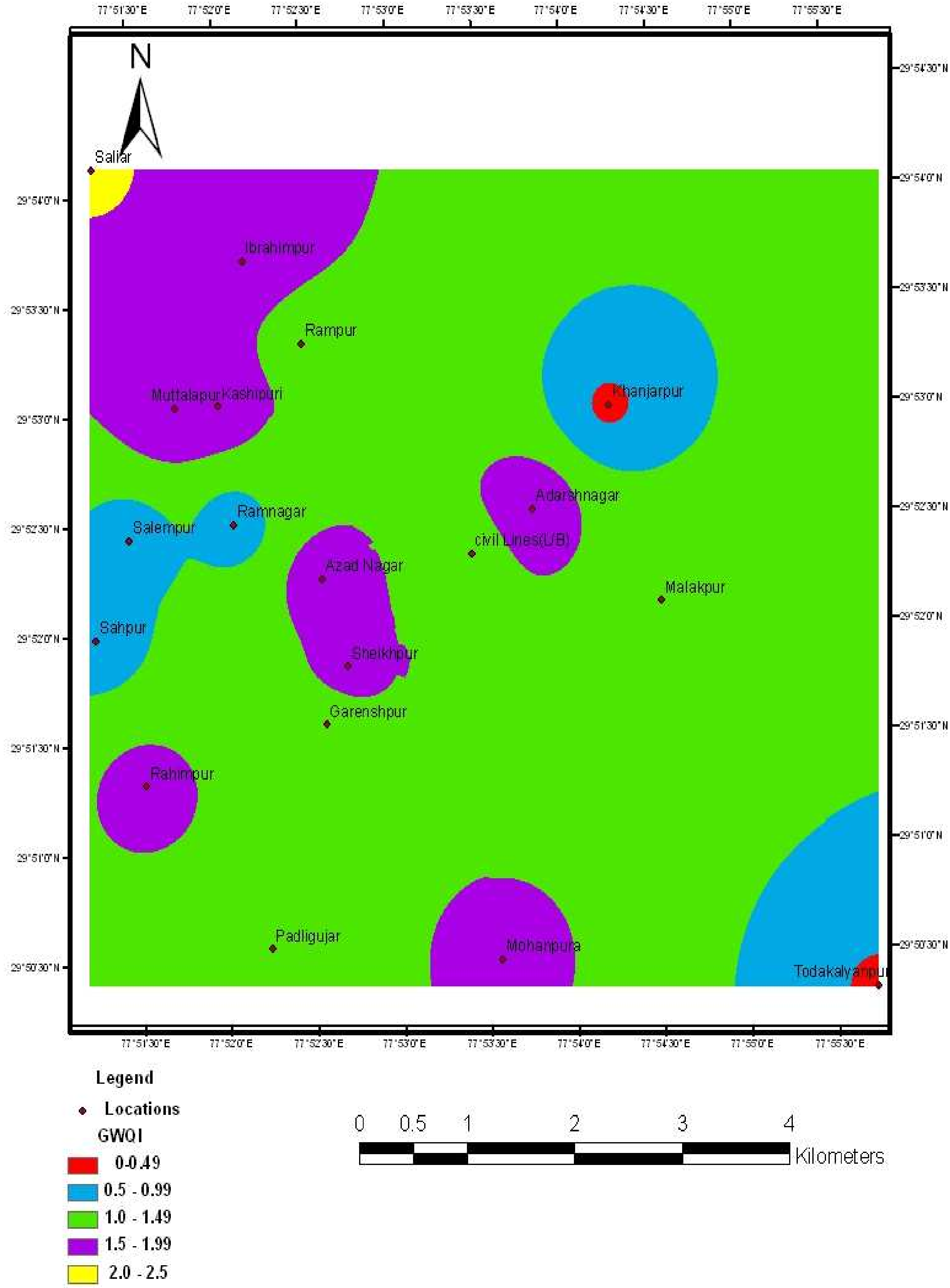


Fig.3. GWQI map for pre-monsoon 2004-06

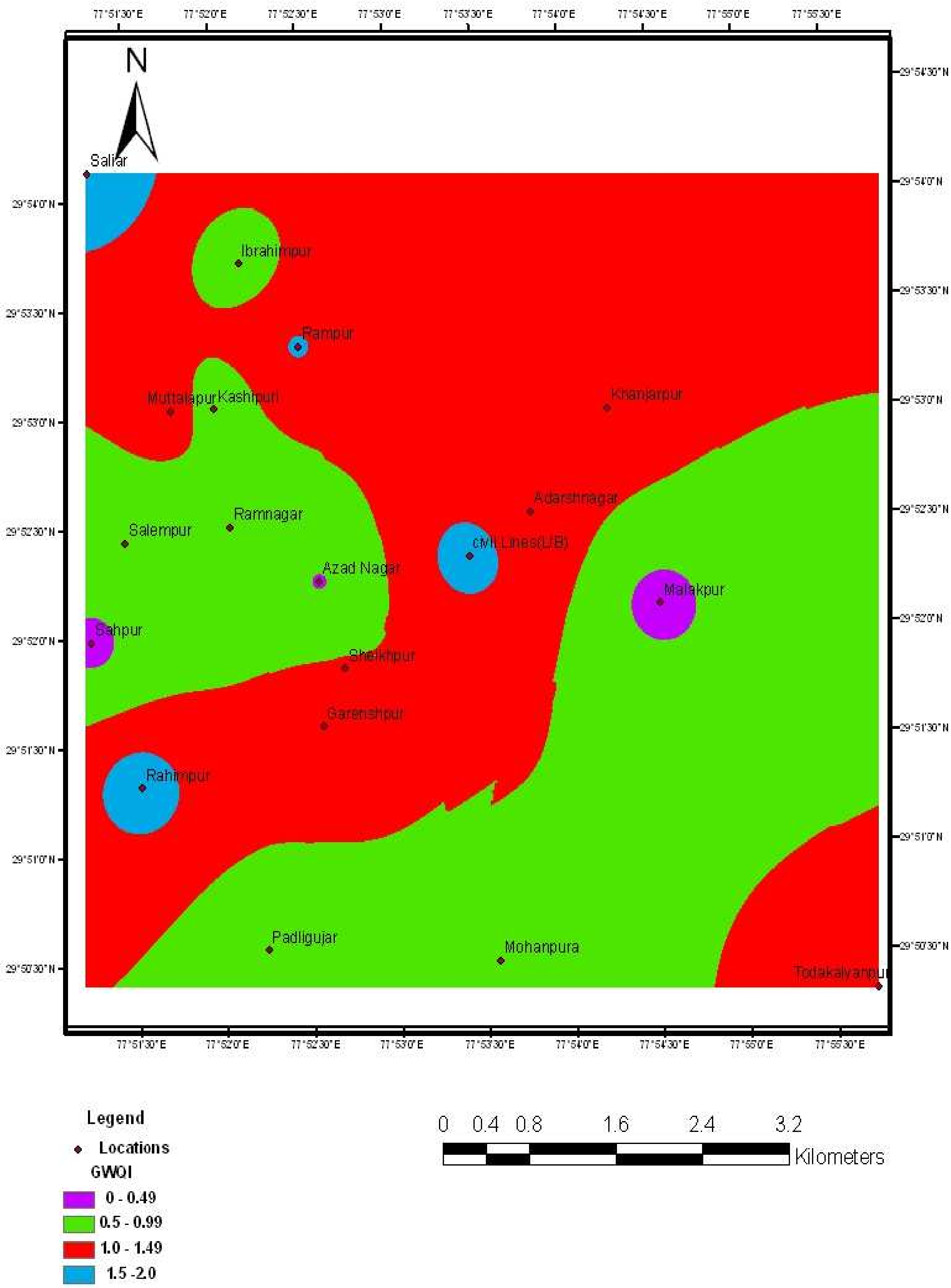


Fig.4. GWQI map for post-monsoon 2004-06

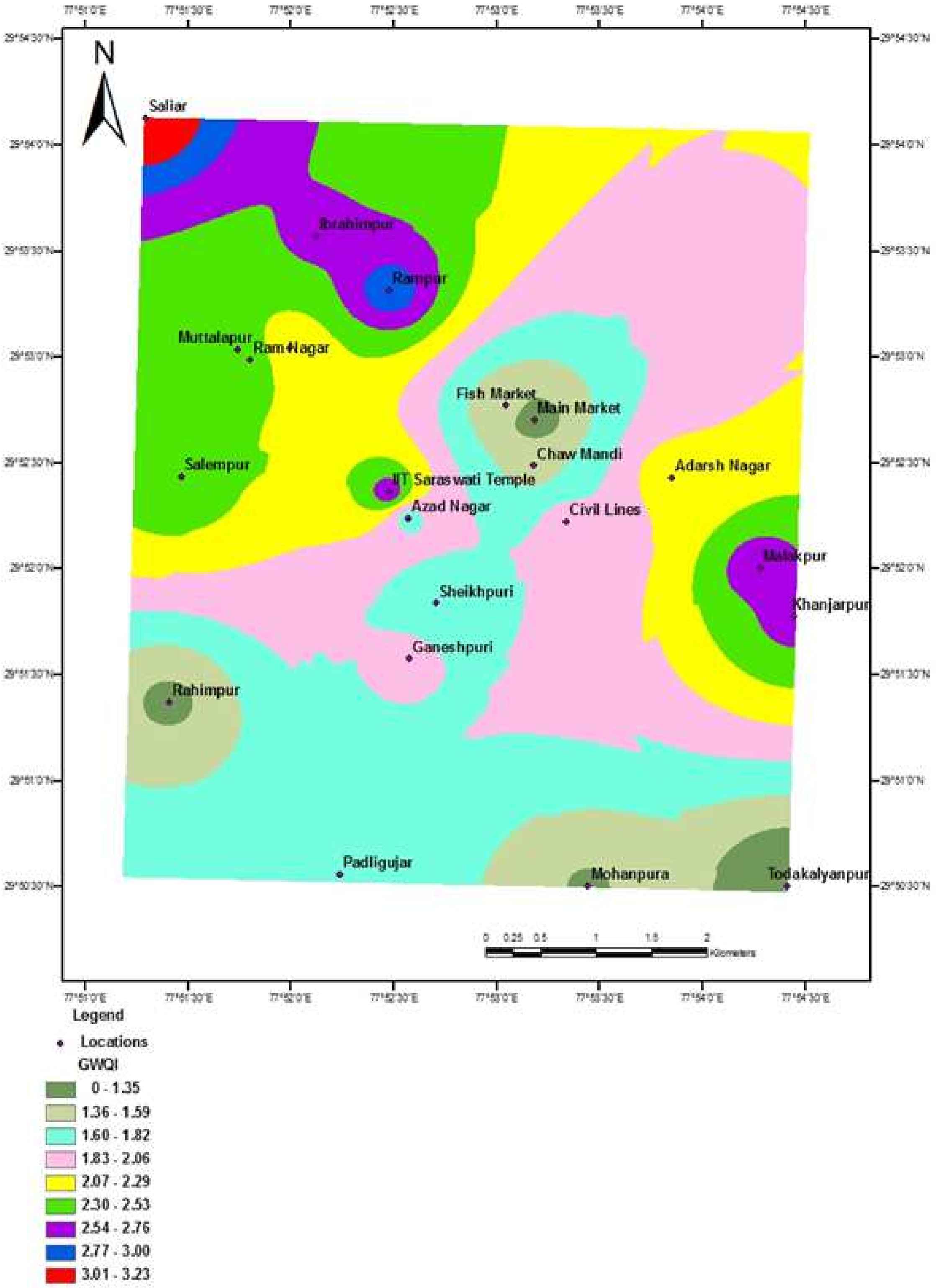


Fig.5. GWQI map for pre-monsoon 2012

8. Concluding Remarks

The groundwater sustainability has been evaluated for Roorkee town and its suburbs. The annual groundwater recharge has been estimated to be 12131ha-m and the stage of groundwater development in the study area is found to be 71%, thus categorizing Roorkee town in the 'Safe' category. It has been observed that water demand for Roorkee town is approximately 54 MLD against the amount of ground- water extraction (for supply) which is estimated to be around 52 MLD. This shows that these values are quite comparable. However, the estimation of Water Barrier Index (WBI) employing a recognized International approach has put Roorkee (and its suburb) in the "Stress" category whereas by using Integrated Water Stress Score (IWSS) approach, the study area has been categorized as "Low stressed" to "Moderately stressed". Assessment of groundwater quality has been carried out by evaluating GWQI which shows that the groundwater quality has degraded significantly from 2005 to 2012, yet the ground- water is generally fit for drinking except at few places in the study area. In the light of the above it is concluded that holistically, the groundwater resources of the study area are sustainable but these are tending towards unsustainability when considered in the light of other environmental factors.

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Corresponding Author

D. C. Singhal

Department of Hydrology, Indian Institute of Technology, Roorkee – 247 667, India

E-mail: dcsinghal7@gmail.com