Trans. Inst. Indian Geographers
Vol. 30, No. 1, 2008

Land Use and Land Cover Related Hydrological Changes in Different Ecosystems of Inter State Chandigarh Region, NW India1*

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Abstract

For assessment of the land use and land cover related hydrological changes, the Inter State Chandigarh Region covering 5,391.50 km2 area and having Chandigarh Conurbation as its core and encompassing four different ecosystems has been taken into consideration.. Settlement pressures, rapidly declining land reserves for extension of agriculture and growing population led to forest destruction in the Natural Hilly Ecosystem of the Siwalik Hills. Meeting highly accelerated timber-fuel-fodder requirements led to marked changes in the vegetal cover. Cessation of inception effect due to forest clearance and gradual reduction in the humus cover resulted in low infiltration and in turn increased surface run off downstream in Semi-Natural Drainage Ecosystem. Thus the barren hills exhibit signs of rapid soil erosion and present 'badland' topography of the Siwalik Hills. The result is sedimentation of stream channels. The rapid siltation process is well illustrated by Sukhna Lake in Chandigarh.

In the piedmont and upland plains the water run off increased since 1950 when the agricultural region with forests in the adjoining Siwalik Hills, was put to totally different use in the developing Heterotrophic Urban Industrial Ecosystem. Constructions related to urban growth progressively sealed off ground surfaces inhibiting infiltration and increasing surface run off. Large scale under ground water extraction led to drying up of water reservoirs at the rate of 0.50-1.5 m/year. Eutrophication of streambeds consequential to increased inflow of city sewerage and industrial effluents was the obvious result.

Major water impact in the Domesticated Agro-Ecosystem resulted from Green Revolution beginning with mid-1960s. There was 215.57% increase in area irrigated from ground water during 1967-68 to 1990-91 period. At some places water table fell by more than 8 m. Significant hydrological events of the Punjab Plain area of the Inter State Chandigarh Region, were the floods of 1988 and 1993.

It may be pointed out that the hydrological spectrum of the region has been adversely effected by rapid land use / land cover changes.

Key Words: Hydrological spectrum, Land use/ land cover changes, Chandigarh Conurbation, Ecosystem, Forest vegetal cover, Soil erosion, Sedimentation, Ground water, Eutrophication.

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* Paper presented during 29th International Geographical Congress at Seoul, South Korea.

Introduction

The importance of forest cover is realized from the fact that the forests are able to store a far greater volume of water than the grasslands. An estimated 17 x 10^6 hectares of moist tropical forests are being cleared annually throughout the world (UNEP, 1993). Consequentially, high run off, soil erosion and stream/ river and lake sedimentation, are the root causes of serious hydrological problems in the tropical and subtropical regions of the world especially in the Asiatic countries. These problems are more serious in the hilly terrains and in their high incidence; the role of human beings is the maximum.

Numerous studies or write-ups have been done the world over, on the land use and land cover related hydrological changes but the significant ones in the recent years have come from Douglas (1976), Gregory (1985), Newson (1992), Walsh, Davies & Musa (1994), and Davis, Rutherfurd & Finlayson (1999).

Nearer home in the Himalayan region, eco-hydrological responses of the Upper Beas Basin (Kulu Valley) in Himachal Pradesh has been studied by Singh (1998) and in the submontane NW Siwaliks (Punjab region) recent note-worthy studies are on soil erosion hazards (Kukal & Sur, 1992), soil erosion management (Kukal, Khera & Hadda, 1993), soil and conservation strategy (Kukal, Sur, Hadda & Bawa, 1994) and rill characteristics (Kukal, Bawa, Khera & Hadda, 1998).

It was almost for the first time that through the reports of State of India's environment by Centre for Science and Environment (1982, 1985, 1991)., comprehensive data are provided about the environmental problems at all-India level in the towns/cities as well as villages. A close scrutiny of the information provided by the above analysts indicates that almost entirely the hydrological problems are related to land use and land cover.

During the last decade or so the author has been engaged in the assessment of the impact and implications of development on various ecosystems of the Inter State Chandigarh Region (Mehta & Y. Singh, 1995; Y. Singh 1990a, b; 1994a, b; 1996; 1997; 2000, 2001, 2002; Y. Singh & Kaur, 1999). The present analysis concerns the hydrological changes in various ecosystems of Inter State Chandigarh Region (ISCR) consequent to changes in the traditional pattern of land use and land cover. The interesting point being that the city of Chandigarh began developing in 1952 *de novo* and gradually developed into full fledged urban conglomeration during the last 50 years. Obviously, the problems of this urban settlement in the environs of Siwaliks and Punjab-Haryana fertile rolling plains are of very recent origin. This facilitates the probes into the causes and concerns as well as possible remedies.

Circumscription of the ISCR

With Union Territory of Chandigarh forming the core, the workable extent of the ISCR extends from 30° 17' to 30° 11' N Latitude and 76° 16' to 77° 29' E Longitude. It covers an area of 5,391.50 km². Originally demarcated area covered only 2,513.5 km² The increased coverage of a landscape of 2,875 km² as has been done by the writer. It was necessary to include the areal spread of different operative ecosystems that cover Chandigarh ecosphere. Thus, the demarcated

ISCR consists in part, the Siwalik Hills and the major sprawl covers the rolling plains. It is bounded by Himachal Pradesh in NE & E and plains of Punjab-Haryana in NW, W & S. Apart from the Union Territory of Chandigarh; the region is constituted in good part, by Punjab-Haryana territories.

Methodology

The present study is based upon both primary and secondary data taken in a spatio-temporal frame of about 25 years period beginning with 1966 when Punjab was re-organised and three governments of Punjab, Haryana and Union Territory came to be accommodated in Chandigarh. The city developed till that time was to be the capital of Punjab alone. The digital maps of 18.56 x 18.56 km^2 sample areas of Chandigarh Siwalik Hills and Chandigarh urban landscape formed basis of primary data collection and the field surveys. The field surveys were also extended to other parts of ISCR. Primary data were collected during 1990-1993 while the secondary data were collected during nineties from various organizations. These sources also supplemented the field study data on hydrological indicators.

Correlations have been drawn with land use and land cover data and the perceptible changes thereto have been assessed. Applications of geographical frame work for data representations and understanding both in space and time were necessary for assessment of the hydrological changes. Modified NRSA (1989) land use classification has been adopted for quantification of urban sprawl and resultant wastelands.

Land Use And Land Cover Changes

Major changes in the land use / land cover that various ecosystems have experienced during the last fifty years, consequent to the development of capital city of Chandigarh, are enumerated below:

1. Vegetational Changes in Natural Hilly Ecosystem (NHE)

A. Forest Cover

Assessing the forest cover changes in Siwalik Hills which constitute the Natural Hilly Ecosystem (NHE) of ISCR, Mehta & Y. Singh (1995) and Y. Singh (2001) have pointed out that:

(1) By and large, the forest area experienced wide fluctuations between 1966-91. As much as about 10% of the forest area of Siwalik region of Punjab and Haryana has been deforested during 1966-86 and the land diverted to other uses as agriculture and habitation.

(2) Forest density classes underwent marked changes. The NHE was left covered with nearly 10% dense forests and in 1983 forest in these hills was turned into open forests.

(3) Overall forest area in Chandigarh and Morni Siwalik Hills during 1983-86 decreased further by 7.76% and 12.35% respectively

B. Quality of Vegetation

The quality of forests improved greatly with area under dense forest.

The years 1988-91 showed much better performance for Chandigarh Siwaliks although area under forests increased by just 1.29%, the dense forest area increased by 2.81% and there was a marked increase in the area under Open Forest. However, the

Table 1: Urban Sprawl of HUIE of Chandigarh*

1.	Chandigarh Conurbation	12,436.95 ha
2	Culturable Waste interspersed with Cropland (in between Chandigarh and SAS Nagar)	753.14 ha
3.	Urban Peripheral Zone	
	(a) Rural Settlements	118.32 ha
	(b) Suburban and Fringe Settlements on agricultural land (Mixed Built-Up Land)	2,790.88 ha
	(c) Barren Land	1,259.78 ha
	(d) Culturable Waste interspersed with cropland	5,216.61 ha

*Based on IRS IA LISS 2 (June, 1988) and Y. Singh (2004)

Scrub Forest area increased by 59.64%. In Morni Siwaliks, the dense forest increased total forest area increasing by 1.25%

Siwaliks are sparsely forested especially on the SW aspects Whatever plant wealth is present that is located either on the N & NE aspects or in the deep gulleys of the *'choes'* (seasonal streams). The *dun* side supports thick stands of *Acacia catecchu* (*katha*) trees, as well as several spiny and non-spiny dry deciduous species, which at places form impenetrable thickets. Forest canopy over, a greater area of Chandigarh Siwalik Hills, is thin. The ground grass and leaf litter cover is poor. Most of the trees have stunted growth. The periodic extraction of *baggar* or *babbar* grass (*Eulaliopsis binnata*) lays bare large forestlands, which become open to degradation due to soil erosion.

2. Growth of Chandigarh Urban Ecosystem (Cue) and Heterotrophic Urban-industrial Ecosystem (Huie)

Chandigarh CUE quickly passed through the Town Group (1961 Census) and Urban Agglomeration (1971 Census) stages with the development of the satellite towns of SAS Nagar and Panchkula. It achieved the status of Chandigarh Conurbation in early 1990s since its population kept on increasing incessantly due to its accelerated urbanization and industrialization processes. This and spill over urbanization were responsible in shaping it into Conurbation (Table 1).

The results of the land use analysis of Chandigarh conurbation are given in table 2. It indicates that the built-up land constitutes 66.79%, vacant land 25.80% and evergreen vegetation 7.40% with maximum per cent evergreen area being present in SAS Nagar. Vacant land is either land allotted for urbanization or wasteland while evergreen / vegetation indicates parks, roadside plantations or natural vegetation groves. Culturable waste area of 753.16 ha lying between Chandigarh and SAS Nagar comes only to 6.18% of the total urban area of Chandigarh Conurbation.

Based on recent information, today the built-up land is nearly 79.96% (10,797.79 ha) of the total earmarked urban zone area of the HUIE (13,503.37 ha). Also in the urban peripheral zone of HUIE, a large part of it is built up which comes to around 3,589.30 ha. This built up area surrounding urban zone

Table 2: Land Use data for Chandigarh Conurbation* (in hectares)

S. No.	City / Town	Chandigarh	Manimajra	Panchkula	SAS Nagar	Total
1.	Total Area (12,436.95 ha)+	7,082.14	801.00	1,942.54	2,347.27	12,172.95
2.	Built-up	5,428.58 (76.65)	285.16 (35.60)	1,285.34 (66.17)	1,131.43 (48.21)	8,130.51 (66.79)
3.	Vacant Land	1,051.84 (14.85)	515.84 (64.40)	596.20 (30.69)	977.96 (41.66)	3,141.84 (25.81)
4.	Evergreen/ Vegetation	601.72 (8.49)	-	61.00 (3.14)	237.88 (10.13)	900.60 ((7.40)

* Chandigarh Air Port: Built-Up Area: 264.00 ha
* Based on IRS IA LISS 2 (June 1988) and Y. Singh (2004). Figures in bracket indicate percentage

in large part includes suburban and fringe settlements on agricultural lands and a small measure of it is rural settlements.

All these land use details show highly accelerated rate of conversion of agriculture land to non-agricultural uses (e.g. Zirakpur and Kharar areas). The Union Territory of Chandigarh the rural area is greatly reduced from 71.57% (1961) to 31.58% (1991) because the urban area is still fast expanding (Singh Y 2004). Although, no new urban sectors are planned yet the agriculture land of UT villages is being gradually acquired for meeting the growing needs e.g. for the establishment of the Botanical Gardens and for the construction of settlement colonies needed for the urban labour.

3. Domesticated Agro-ecosystem (DAE)

(a) From 1967 to 1991 there is noticeable change in agricultural land use over the years and the land entirely used for non agricultural purposes (mainly urbanization) has increased by 164%, fallow land dropping by 55.33% and non productive area increasing by 63.17%.

(b) Through extensive use of HYVs, fertilizers, ground water irrigation and mechanized farming there was emphasis on multi-cropping and the area sown more than once increased by 58.20%. Net cultivated area increased only 2.4%. The result was 250.35% and 850.09% increase in production of wheat and rice.

(c) Ground water irrigation area increased by 215.57%.

(d) Forests constitute the most vital class of agricultural land use but the area under agro-forestry did not change much in DAE. From 1967 to 1991 agro-forestry area increased by only 6.25%. The land in Chandigarh urban areas has been mostly utilized for public parks and out side in rural area the land on *'choe'* margins and even on the *'choe'* beds has been put to agriculture by the villagers.

4. Semi Natural Drainage Ecosystem (SNDE)

Writer's field studies indicated that SNDE covers only 197.75 sq. km area in contrast to 684.758 sq. km area of NHE from where the SNDE originates. The drainage system during the last 50 years period of development of Chandigarh and the consequential stress on natural systems has undergone tremendous change due to (i) badland topography of the Siwaliks Hills, (ii) sedimentation of seasonal streams in hill-foot plains, and (iii) eutrophication of stream beds due to discharge of city sewage, waste waters and industrial effluents. The result is the rise in stream bed level due to siltation. The flooding in rainy season is a normal feature year after year (Figs. 1-2). During minor floods there is deposition of fertile alluvium in the fields adding to soil fertility and moisture content but often-large tracts lying in Punjab, experience major floods causing damage to crops, village and urban properties, and communication systems. ISCR experienced two major floods in recent years i.e. 1988 and 1993 (Fig. 3). In the Punjab area of ISCR, Rajpura and Fatehgarh Sahib tehsils and Ropar and Kharar tehsils suffered considerable damage during these floods (Y. Singh, 2000).

According to Y. Singh (1996) the present average soil loss of 367.5 tons/ha/year from catchment areas of certain streams of Chandigarh Siwalik Hills is alarmingly high. Longitudinal profiles of Manakpur choe, Sugh Rao, Jaintia Devi Ki Rao, Budhki and Siswan *Nadis* (streams) of Piedmont plain near Chandigarh lack the concavity slope which enables streams to transport the load and instead these present planar to plano-convex curves of their beds (Y. Singh, 1994a).

Effects on Hydrological Spectrum

The badland topography of the Siwalik Hills, the forest cutting, the thinning of canopy and continuous lopping / pruning of vegetation have been responsible for deleteriously effecting the water regime in several ways. Lack of proper humus layer decreased the infiltration rate of water and enhanced the run off resulting in speedy soil erosion and siltation of stream or *choe* beds and other water bodies. Due to siltation, during the period 1958-78, there was an average annual loss of 2.91% in the water storage capacity of Sukhana lake and in 1988 the water storage capacity declined merely to 34.06% of the original (Y. Singh 1994, 2002).

The existence of water springs and fresh water channels, which were so common in the Siwalik Hills and adjoining piedmont plain before the upcoming of Chandigarh, has been completely obliterated or wiped out now. Earlier, up to the end of 1950s quite a many of the streams (e.g. Attawa and Kanthala *choes*) in the region used to carry neat and clean water at least for the foothill or piedmont portion of their length. Fresh water channels of Manimajra and Panchkula were a significant part of the landscape. Till about the end of 1980s the region had adequate ground water flow regime (Fig 4). The area cultivated the best rice qualities of that time. Now, either the streams are completely dry immediately after the rains due to quick water run off or they carry dirty and unclean urban waters. The result is that there is little recharging of the ground water from the streambeds, which remain dry during the most part of the year. Even when there is recharging of ground water from wet streambeds, this pollutes the subsoil or ground water due to the presence of contaminants in sullage waters. The quality of ground waters of Chandigarh Urban Ecosystem (CUE) has progressively deteriorated, even becoming unfit for drinking through the use of hand pumps which are the only source of water supply in the villages of U.T. Chandigarh and the adjoining Punjab-Haryana plains.

Presence of city waste waters in the streams and the use of sewage waters for agricultural purposes in the villages adjoining U.T. have progressively decreased the water percolation from soils because of clogging of soil voids by accumulation in the fields of suspended particulate matter present in the city sullage and waste waters.

In the urban areas, the soil surface fit for infiltration of water during or after the rains has greatly been reduced because of the fact that from the constructed area, hard soil surface, and the metalled road surface, there is abnormally quick water run off.

HUIE has as much as 79.96% built up area and evergreen vegetation area constitutes only 7.24%. Eventually, because of very low infiltration rate due to cessation of inception effect on reduction of humus cover in the drainage basins and hardening of land surface in urban areas, the subsoil/ground waters are not recharged at the same rate at which these are pumped out for meeting the urban water requirements. The result is that CUE is always facing water shortage during summers in spite of several water augmentation schemes put in use from time to time, even using Bhakra Main Line Canal waters for domestic use. Deep tube wells which in the early formative years of Chandigarh used to supply most of the water requirements, have fallen much short of the needs of the people. Y. Singh (1994b) estimated that in 1993 water availability was hardly 46% of the total water requirements of U.T. Chandigarh. Water table kept on falling gradually and several tube wells became inoperative over the years due to this cause. The strategy adopted for future years is based on extracting water from deep lying ground water acquifers, about 185 m deep.

In DAE due to diversion of land for urbanization, the quantities of infiltrated waters have been greatly reduced. Above all, there have been tremendous pressures on the use of ground water for irrigation of agricultural crops especially paddy crop which is raised generally in standing water, at least in the early phase of growth and that too in the summers. In the DAE during 1967-68 to 1990-91 the net irrigated area increased by 161.00% and this comes to nearly 68.43% of the net sown area while during the same period area under paddy cultivation increased by 209.55% resulting in overdraft of the ground waters because tube well irrigated area has increased by 215.57% (Y. Singh, 1994b).

Chandigarh U.T. experienced a decline of 1-3 m in water table while in most of the Punjab area of DAE during June 1974 to June 1988 due to overdraft of ground water decline of 3-6 m was observed. However, the rate of decline in ground water level in sweet water zone of Punjab averaged 0.20 m per year during 1979-1991 (Singla, 1992). An average fall of 11 m was registered in Sukhna and Patiali Ki Rao well fields of Chandigarh up to 1976. At prevailing rate of draft of ground water in 1991 in U.T., a further drop of 5-15 m in ground water table occurred. As estimated by Central Ground Water Board in 1981, the rate of decline of ground water table in different parts of well fields of Chandigarh was 0.5-1.5 m per year (Singh 1994b). Though these figures about the fall in ground water table are for different periods they indicate that the situation is alarming. The end result is short supply of ground water in the ISCR both for CUE and DAE. Also pollution of subsoil and ground waters is increasing at alarming rate especially in the peripheral region of Chandigarh where sewage waters are used for raising crops.

One of the major deleterious effects of development (officially termed as planned but due to laxity in enforcement of laws, it often becomes unplanned in certain sectors) in Chandigarh is that there is shortage of ground water within and its pollution particularly in the periphery of HUIE of the ISCR. As a matter of fact the main causal combined factor for adverse changes in the hydrological spectrum in the ISCR, is the ecological destabilization of all the four operative ecosystems. These often overlap in operation. Rapid land use/ land cover changes have caused marked distortions in the functioning of various ecosystems.

Discussion

It is evident that land cover and land use changes in the NHE, HUIE and DAE of the ISCR have greatly affected the hydrological spectrum. Marked effects are evident for land cover changes in the Siwalik Hills.

The rocks and soils of the Siwaliks are soft and friable and the hills are composed mainly of clay, sand, sandrocks, poorly bedded sandstones and the conglomerates. Siwaliks in their structure are more or less homogeneous along their entire length. Obviously, with this type of geology, the Chandigarh Siwalik Hills (CSH) in NW India have become more prone to soil erosion after the building up of the capital city of Chandigarh. Today on the whole, in the Siwaliks of Punjab and Haryana thick vegetation is scarce and the hills presenting badland topography have lot of bare soil areas. When such areas are subjected to human activities as road building, terraced and choe valley cultivation, over grazing or frequent collection of fuel and firewoods, the landscape becomes vulnerable to high rate of water run off and soil erosion. This is what is happening in the NHE of ISCR over the past several decades. Soil degradation, soil erosion, and heavy run off are noticeable on the W & SW Siwalik hill slopes, in *'choe'* valleys, and on *'choe'* terraces. Contributing to this in a big way, are the fluctuating forest cover, badland topography of the hills, and the diversion of forest land for agriculture, and habitation due to increasing pressure of native population as well as the labour population of the Chandigarh City (Fig. 5).

The rate and extent of soil erosion are governed by the quality and extent of vegetal forest cover, rainfall, erodibility of the terrain, topography, land management, and socio economic conditions of the people. Infiltration gets altered with vegetation cover and the change in sub-surface flow can modulate surface flows that cause much soil erosion (Barrow, 1991). Due to lack of vegetation cover, hard driving rain will cause compaction of the surface of normally permeable soil, reducing the pore space, and thereby lowering the infiltration capacity (Morgan, 1971). Liebscher (1985) had stated that forests are able to store a far greater volume of water in their plant surfaces than grassland. Non adapted forms of cultivation, clearing of slopes and gallery

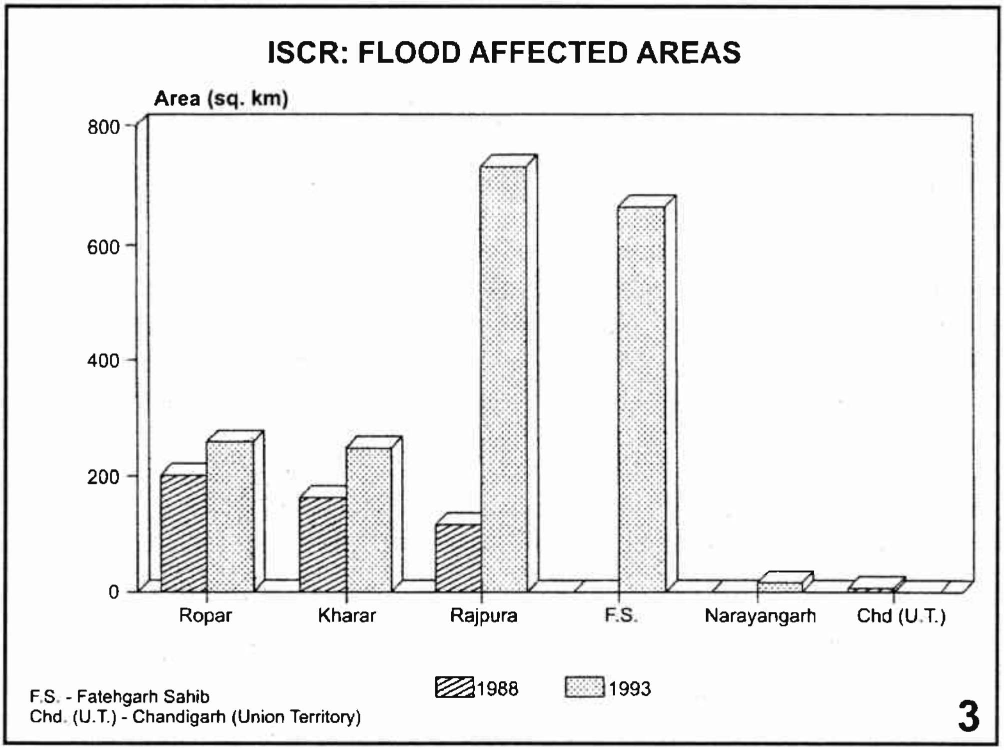
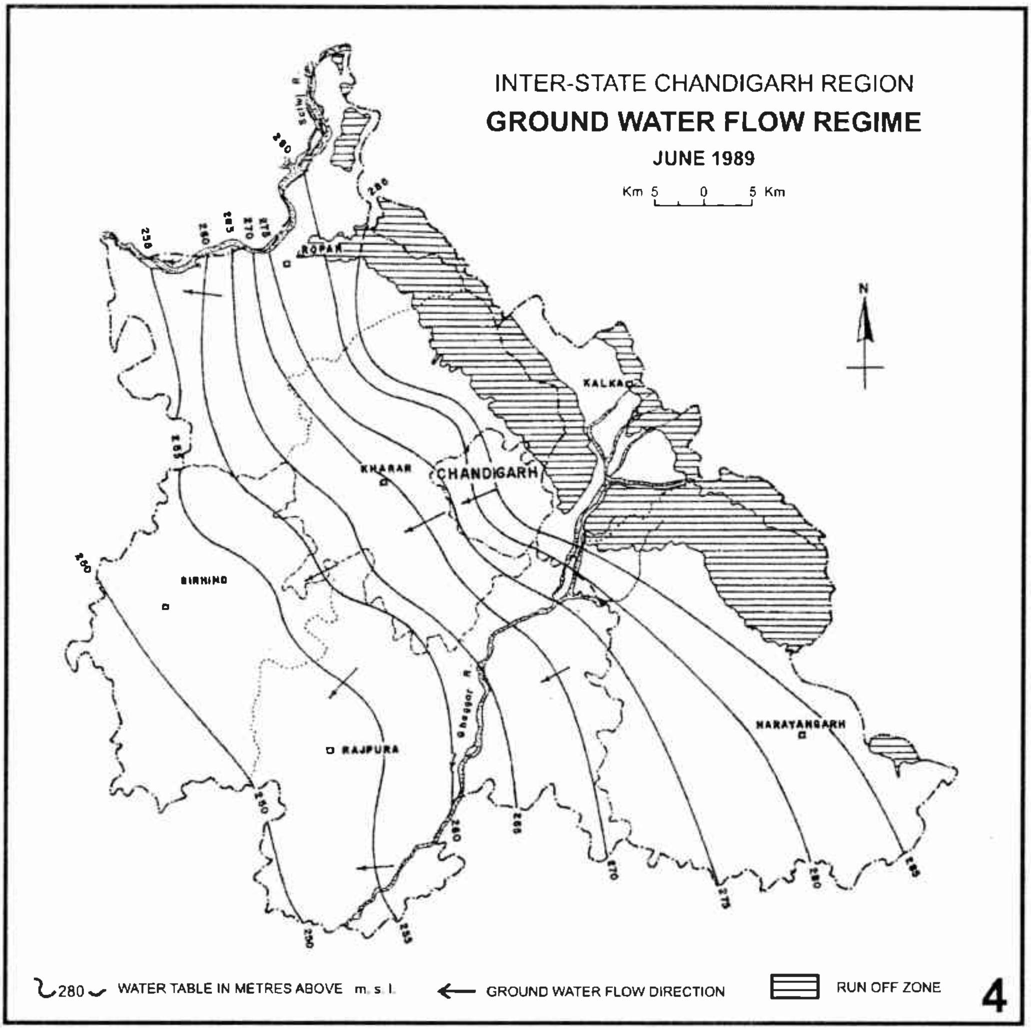


Fig. 3: Flood affected areas of ISCR during rainy season of 1988 and 1993.

forests result in severe erosion, higher flow rates and an increase in the sediment load carried by streams and rivers. The erosion under grass is more than under bare soil until grass cover reaches a critical value beyond which it exhibited protective effects (Deploey 1981).

Often high frequency and heavy monsoonal downpours in the NHE create high run off that carries away large volume of soils to the tune of 6.15 million tons per annum from 167.33 km^2 sampled area of CSH giving an alarming rate of 367.5 t/ha/year (Singh Y. 1994). During monsoons in CSH the intensity of rainfall exceeds the infiltration capacity of the soil thereby resulting in excessive surface run off. Often, 70% of the rainfall is lost in run off. In the areas of highest water erosion in CSH, the dominant vegetation is herbaceous with common density of stunted trees below 10% (Y. Singh, 1994b). Economically important grass of the region *Eulaliopsis binnata (babbar)* is quite frequent in *Acacia catechu* (*katha*) forests on W & SW slopes and is frequently harvested as the *katha* trees. This lays bare the hills prone to soil erosion.

Based on Universal Soil Loss Equation as developed by U.S. Soil Conservation Services, the scope for reducing soil loss lies in reducing the slope gradient and slope length to decrease flow velocity and increase opportunity time and in adopting improved cropping and management



Based on PSTC, GWC - Agr. Dept. Punjab & MITC, Haryana

Fig. 4: Inter State Chandigarh Region depicting ground water flow regime in June 1989.

practices as would protect against rain drop impact (Prihar, Gajri, Benbi & Arora, 2000). Evidently, efficient land use practices in NHE, HUIE and DAE with emphasis on water conservation will help reduce soil loss through reduction in run off. Recently developed technology based on the use of crop residues is highly effective in reducing soil loss (Alberts & Neibling, 1994). This method can conveniently be applied in the NHE where harvesting of timber, fuelwood and firewood, and *Eulaliopsis binnata-Acacia catechu* should be done scientifically. Forest residues (in the form of stumps, root stocks, humus, leaf litter, etc.) need to be left out in the CSH in particular so as to beat the force of rainfall and thus increase infiltration and reduce run off as well as soil erosion. This will ultimately reduce loss of humous and top soil in the NHE, make the forest regeneration easy and ultimately in due course of time these forests will be more productive. Also application of crop residue method in NHE agricultural lands (*'choe'* valley lands, hill-terrace fields, and depositional terraces) will greatly reduce quick run off and soil loss as well as help in water infiltration.

Over the years, creditable work has been done in submountainous region of Punjab (Siwalik foot hills), in particular Hoshiarpur district, in relation to soil erosion which is now about a century old problem. Salient features of the more recent select studies are as follows:

(1) Based on studies of mixed watershed (236 ha) consisting of agricultural, pasture and forest lands in village Fatehpur-Kangar (31° 08 N Lat. & 71° 18 E Long.), Kukal & Sur (1992) pointed out that the whole area was susceptible to erosion with 25% area being highly eroded, sheet erosion confined to 62.3% while rest exposed to rill and gulley erosion and potentially 23% area had high to severe risk of erosion.

(2) Working on soil erosion management on arable land, Kukal, Khera & Hadda (1993) noted that (i) contour cultivation reduced soil loss as compared to slope cultivation, (ii) ridging and furrowing at sowing was effective in controlling soil loss; (iii) on sloping lands contour bunding decreased soil loss and increased yields, (iv) bench terracing proved to be more suitable for land with slopes between 6-33%, and (v) water ways, drop structures and control dams reduce sheet, rill and gulley erosion. They also suggested that different crop patterns (diverse crops, strip cropping, crop cover increase, multiple cropping) agroforestry, mulching, conservation tillage, ridging furrows, etc. also decrease soil erosion. Maize cultivation showed minimum soil loss by run off.

(3) Soil conservation strategy based on morpho-conservation mapping was worked out by Kukal, Sur, Hadda & Bawa (1994) and recommended that (i) land in NE part with high value of drainage density, drainage texture, and steep to very steep slopes need to be brought under afforestation with dense cover of grasses and bushes to minimize the impact of rain drops. The area is also fit for making of water harvesting reservoirs, (ii) S & SW part with strong sloping land to be cultivated after graded bunding and /or bench terracing, and (iii) the area sandwiched between (i) & (ii) types should be developed as permanent pastures with system of rotational grazing.

(4) Rill characteristics in relation to land parameters and ground cover were examined by Kukal, Bawa, Khera & Hadda (1998) and concluded that the rill size seems to be effected either by divergence or convergence of run off in rills depending upon prevailing run off velocity, run off discharge, and geometrical variation in profile cross sectional area and their interacting effect.

It may be pointed out that the experiences gained through studies on the characteristics of the terrain and run off features in Hoshiarpur district together with the measures undertaken for decreasing or stopping soil erosion could easily be utilized in Chandigarh-Morni Siwalik Hills which face similar problems.

R.B. Singh (1998) writing about land use and land cover changes in the Upper Beas Basin in Kulu valley of Himachal

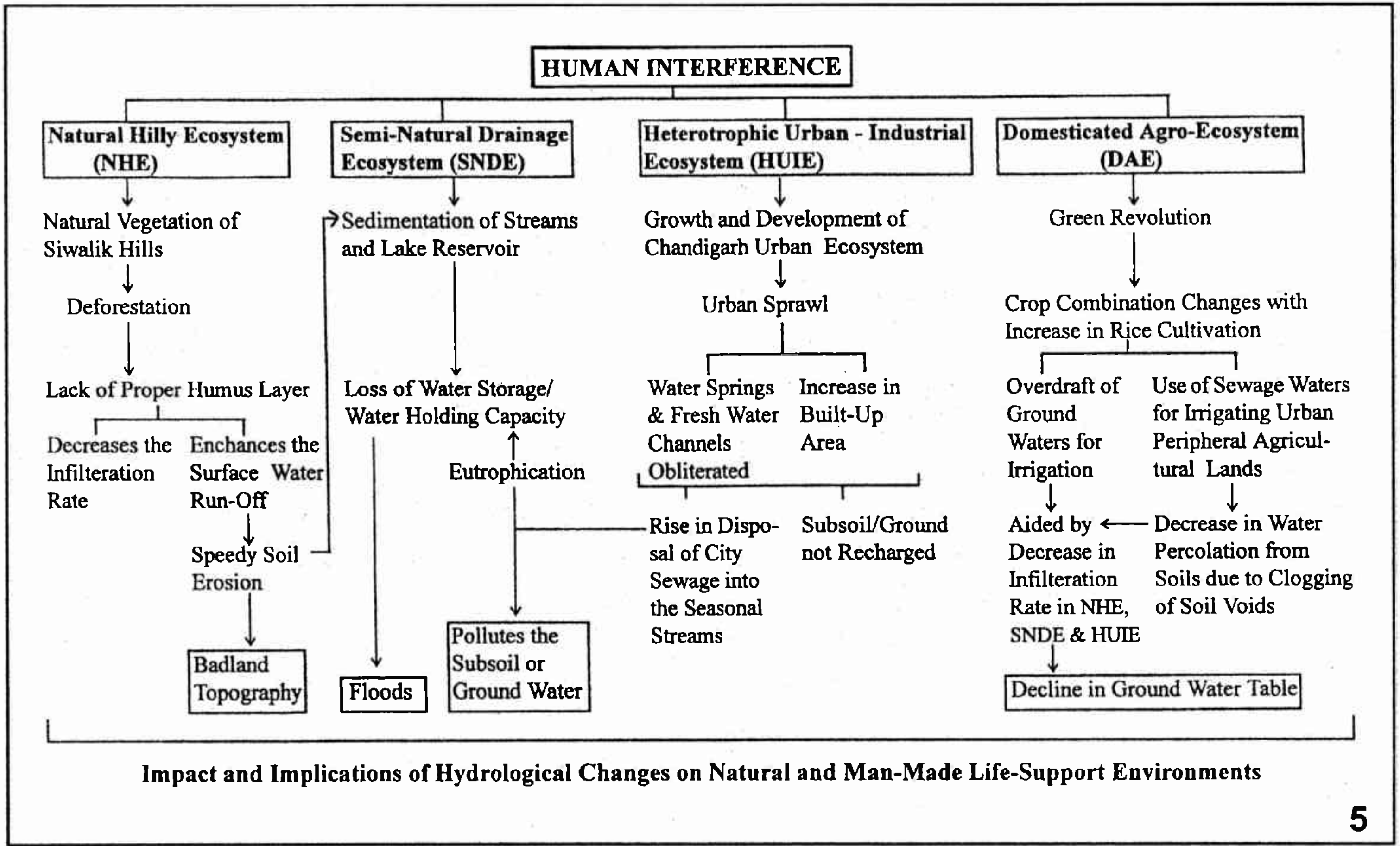


Fig. 5: Impact and implications of hydrological changes on Natural and Man-Made Life-Support Environment – A Flow Diagram.

Pradesh, stressed that (i) land use is of vital importance for the well being of the mountain dwellers, and (ii) hydrological system for the well being of the mountains and plains is very sensitive to the unsustainable and unadapted anthropogenic activities in the form of landuse change in the highlands as well in the low lands. The problems of land use in NHE and SNDE of ISCR are not different from this. Citizens' Report No. III (1991) on the state of India's Environment concerns such as floods, flood plains and environmental myths with north Indian examples is noteworthy. It lays stress on proper land use zonation and planning and major rethinking on flood control embankments which have caused more damage than good.

Experiences of floods in Punjab area of ISCR are the same. Railway lines, roads and canal systems obstructed natural flow of excess waters from hills and thus caused great havoc in certain urban and rural areas. Walsch, Davies & Musa (1994) pointed out that there is a greater susceptibility to floods as a result of increased human occupation of flood prone sites, inadequate urban drainage, and increased run off coefficients. It will be interesting to point out the findings of Beach (1994) to the effect that soil particles eroded from the hill slope change (i) the soil from which it has been removed, (ii) the water that transports it, and (iii) the soil on which it is deposited. These changes effect the physical appearance of the earth's surface and hydrology of the area involving run off, water quality, and channel flow. Hagen (1987) earlier while evaluating the effects of settlement pressures and destruction of forests in Rwanda (East Central Africa) stressed that the loss of forests as a water storage area guaranteeing adequate supply of water, would pose risk even to the basis of existence. Water conservation and water recycling are central to the on-going debates on deforestation and land-surface-atmosphere feedback.

As far as hydrological problems of the urban areas as HUIE of the ISCR are concerned, comments of Douglas (1976) are significant in the fact that management of water in urban areas involves (i) control and regulation of two hydrologic systems as man-made supply system and waste-water disposal system, and (ii) the modified natural drainage network in which built up area is included. Often hydrologic consequences of land use changes are felt not in the locality of change but at a considerable distance down stream. Similar is the situation consequential to the development of Chandigarh and its satellite towns.

Low infiltration and high run off in urban areas as characterised by CUE are explained by Barry (1990) in that transformation of the urban land surface by paving and construction creates a set of hydrologic effects more clear and / or more uniform than those produced by rural land cover change. He thinks that urbanization produced more rapid run off and greater peak flow down stream with occurrence of floods in the down stream basins.

Location of Chandigarh in the piedmont of the Siwaliks and adjacent to the catchments of several streams forces the civic management to face pressures of uphill hydrologic flows and deluges in rainy weather. Gregory (1976) conducted geomorphological study of changes in drainage basins and asserted that the magnitude of changes is indicated by 4-fold increase in the peak flows during urbanization of small experimental catchment illustrating the morphological consequences of change as modification of land use or conversion of land by urbanization.

Finally, excessive use of ground water and its depletion is not exclusive to CUE and DAE of ISCR. Meyer (1996) elaborating the human impact on earth pointed out that the annual human withdrawal of water from hydrologic cycle has increased from about 100 cubic km three centuries ago to only about 1,400 cubic km in 1950 and this has risen to more than 3,600 cubic km at present. According to him the rise to current totals exceeded in a mere three and a half decades which reflects the increase in the world's population, global spread of new forms of use and four fold increase in per capita use of water. This is the state of affairs in urban India, whether Chandigarh or else where.

Remedial and Corrective Measures

Close scrutiny of the hydrological problem of the Chandigarh Union Territory and the ISCR has made clear that there are no major lacunae in planning the corrective measures for putting checks to quick land use and land cover related hydrological changes in the region. Major bottle-necks have been in their timely and effective implementation. At the same time, not much has been lost and the distortions can be rectified in due course of time provided the implementation is of high order efficiency. Following suggestion are made keeping in view my long span of studies concerning the ISCR:

(1) Inflow of migrant population needs to be regulated conforming to the civic facilities available in the Chandigarh Conurbation area.

(2) Chandigarh Siwalik Hills need to be densely forested and biotic activities need to be restricted at the barest minimum level in the forest areas with a ban on total wood extraction for the next two decades.

(3) Land use and land cover changes need to be supervised and regulated not only in the Urban Ecosystem but also in the adjoining rural areas.

(4) Industrial effluents and urban sewerage waters need to be fully treated before discharge in the natural drainage system. Ground waters of the region are becoming unsuitable for human consumption and agricultural use. Eutrophication in streams carrying urban waters has to be stopped for the free flow of urban waste waters.

(5) Use of clean waters from canal and under ground sources for residential and gardening purposes in urban areas, and for agriculture in rural area need to be strictly regulated. There is continuous fall in the levels of ground water and recharging is greatly on the decline. Canal water supply is also on the decrease in the region.

Acknowledgements

The writer wishes to express his gratitude to Prof. G. S. Gossal (Chandigarh), Prof. (Mrs.) S. Mehta (Chandigarh) and Dr. (Mrs.) Dhian Kaur (Chandigarh) for inspiration, fruitful discussions, and guidance. Prof. M.S. Gill (Patiala) and Prof. Harjit Singh (New Delhi) have been a great source of encouragement.

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