

Cause-effect analysis between irrigation and agricultural expansion on sub-surface water resources: a case study of Kanksa Block in Ajay–Damodar Interfluvium of Bardhaman District, West Bengal, India

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Abstract Human effort to fight nature's in the supply of water to agriculture takes the form of irrigation in the first attempt. Adoption of high yielding varieties (HYV) and intensification of agriculture in a country like India without the availability of irrigation is not possible. Indian agriculture is a gamble in the hands of monsoon since groundwater utilization may be considered as one of the important sources of irrigation throughout the year to supply water for proper seed germination in agricultural fields in India in general and every state in particular. Most of the area of Kanksa Block in Ajay–Damodar Interfluvium of Bardhaman District (west of Ganga—Brahmaputra delta) is mainly constituted with older and younger alluvium, laterite and ferruginous concentration on undulating topography with moderate to high level of permeability, low storage capacity and groundwater table is not so much developed. Present work focuses threat created on sub-surface water resources due to large scale agricultural expansion with irrigation development in the last three to four decades. Available data reveals that most of the dug wells in the laterite country become almost dry during summer. It is also noted that in the laterite country particularly along the watershed like Gopalpur and north of Panagarh many of the existing tube wells yield little or insufficient water during summer time. Though ample availability of River and canal water, groundwater is highly used input in agriculture. To mitigate such problems as over dependence on groundwater resources and to meet the future water demand, use of surface water as agricultural

input and utilisation of rain water in abandoned laterite quarries should be implemented because the base of each quarry is made up of impermeable lithomeric clay.

Keywords Agricultural expansion · Irrigational intensity · Groundwater depletion · Urbanization · Rain water harvesting

Introduction

Groundwater or sub-surface water is a vital natural resource for the reliable and economic provision of potable water supply in both urban and rural development. Hence, it plays a fundamental role in human well beings as well as that of some aquatic and terrestrial ecosystems. At present, groundwater contributes 345 of the total annual water supply and is an important fresh water resource (Sar et al. 2015). So assessment for this resource is extremely significant for the sustainable management of groundwater resources. Groundwater irrigation has been expanding at a very rapid rate since the 1970s and emerged as the primary democratic source for poverty reduction tool in India's rural areas (Ahmed et al. 2014) and with the increased number in the tubewells have show that groundwater has become the largest single source of irrigation. The groundwater level should rise to the same level as that of previous year at the end of the hydrological year to maintain its sustainability. India is now the largest user of groundwater for agriculture and allied purposes in the world and 64% of the country's population depends on agriculture for their source of livelihood presently (Shankar et al. 2011; Ahmed et al. 2014). The farmers have the full control over the groundwater irrigation which led to the huge withdrawal of groundwater during the last 40 years

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(Acharyya and Shah 2010). According to the Agricultural Census of India (2005–06), 60.4% of the net irrigated area is irrigated using groundwater (Sekhri 2012). As Indian agriculture is a gamble in the hands of monsoon so that groundwater utilization may be considered as one of the important sources of irrigation throughout the year in India. The issue of water table lowering attained major significance in the state from the 1990s (Bandyopadhyay et al. 2014). In West Bengal which is predominantly an agricultural state, geo-climatic variations and agriculture's dependence on rainfall have resulted in three distinct rice growing seasons: Kharif rice (June/July to November/December); autumn rice (March/April to June/July); and boro or summer rice (November/December to May/June). The natural catastrophes such as floods, droughts, etc. hinder the agricultural development. Water wells have helped small farmers to obtain a second (and even third) crop per year, and made irrigation possible beyond the canal command area of government irrigation projects. As a result of technological advances, groundwater use has spread rapidly in recent decades, increasing reliability of irrigation supplies, encouraging crop diversification and expanding the cropping season. Groundwater pumping has also brought immense benefits for safe drinking water supplies, particularly in rural areas. More than 1.5 billion people in the world rely on groundwater for their primary source of drinking water (Clark et al. 1996).

In India, the groundwater-irrigated area has increased 500% since 1960 and the green revolution was a major force behind such kinds of positive dynamics. The adoption of new seeds and fertilizers provided great benefits and the benefits were the best under irrigation. Large investments had been undertaken in surface water projects to provide irrigation water to larger numbers of farmer as well as electricity supply expanded in rural areas making pumping of groundwater easy and economical. Farmers realized that groundwater was abundant in many areas, especially in the large alluvial basins, and they could develop and apply water 'just in time' from groundwater sources, something which was not possible in the institutionally complex and poorly managed canal systems. The result was a quiet revolution, in which groundwater irrigation developed at a very rapid rate (Brisco and Malik 2006), while tank irrigation declined and surface water irrigation grew much more slowly. However, the biggest problems resulting from groundwater use are over drafting and deterioration of water quality.

Scientists, scholars, academicians of different branches of science are concerned with the groundwater problems in different parts of the world as groundwater is a replenishable but finite resource. The groundwater management in many countries has progressed from nil to maximum due to over-exploitation of groundwater. Singh et al. (2009)

discusses about the irrigation problems faced by the small holders and describes few affordable irrigation techniques for row and plantation crops. This paper also describes a new irrigation technology developed by the authors that could be affordable by the small farmers and suitable for closely spaced crops which covers sizeable area on most of the small plots globally. Çolak et al. (2015) evaluate crop water stress index on eggplant under various irrigation regimes applied with subsurface systems in the Mediterranean region of Turkey and show the effect of irrigation treatments on yield and crop growth. Misra (2013) analysed impact of urbanization and unprecedented population growth on quality as well as quantity of groundwater in the Northern part of India physiographically covering the Ganga Plain whereas as he also show the effect of climate change mainly change in rainfall amount simultaneously with the land use-land cover change effect on water resources and mention economically feasible solution effective in the addressing the problems of subsurface water resources in Ganga Plain. Zhang et al. (2008) studied the Population growth and economic expansions have stimulated increasing demand for water resources, resulting in potential water shortage and water quality degradation in many regions across the world (Palanisami 1994, Saleth 1998). Moreover, different types of crops may require varying irrigation methods and water quantities, causing a series of effects on water utilization. Obviously, unreasonable crop planting patterns can lead to many challenges in properly utilizing water resources, further affecting water allocations for agricultural and industrial sectors. Mohtadullah (1997) explains the use of ground water of marginal and poor quality for irrigation may degrade the soils, especially at the tail end of the canal system. He also mentioned that this practice may also give rise to some apparent and hidden soil problems directly or indirectly associated with tube well irrigation. Behera et al. (2012) analyzed in his show that with increasing pressure from the burgeoning human population, only vertical expansion is possible by integrating appropriate farming components which requiring lesser space and time, and ensuring periodic income to the farmer. Irrigation water supply projects provide water for multiple uses such as domestic, fisheries, and livestock as well as wildlife habitat, and environmental preservation and enhancement besides irrigation. Some researches mentioned that Soil salinity and alkalinity are mainly caused by natural and cultural (secondary salinisation) factors. The climate, natural drainage, geological structure, parent material and distance to the sea are natural factors, whereas unsuitable irrigation methods and water quality, inefficient drainage and poor land management are cultural or secondary factors (Mehanni 1988; Özcan and Çetin 1998). Irrigation water quality is a key environmental issue faced by the agricultural sector (Shahinasi and

Kashuta 2008) and it is against the backdrop that this study was set up to examine the suitability of three streams of different agricultural practices for irrigational purposes in the context of their alkalinity (sodium content) and salinity. The study of Ogunkoya (2000) and Ogunfowokan et al. (2013) revealed the levels of impairment caused by different agricultural activities and practices on the quality of stream waters. Variation in the levels of the parameters reported was a reflection of different agricultural practices utilized in the study area (Ogunfowokan et al. 2009). Though secondary salinisation is the most harmful and extended phenomenon of the unfavourable effects of irrigation on the soil and environment since an attempt was made by Verma et al. (2008) to study the impact of poor quality ground water on soils in terms of secondary salinisation and availability of soil nutrients in northern India.

In West Bengal, farmlands close to surface water such as rivers and canals mostly use lift irrigation. As the distance from the surface source increases, shallow tube wells come into play, which, in turn, are replaced by deep tube wells further away from water (Bandyopadhyay et al. 2014). Present study area is not the exception of this scenario. Within 30 years of time span (1971–2001), agricultural development is mainly due to the fulfilment of growing population demand is based on irrigation development. The proportion of irrigated area in Kanksa Block increased from 6.92% (18.36 km².) in 1971 to 18.17% (48.39 km²) in 2001, amounting 11.25% increase of land in this category. Over 30 years of time span there is a net increase of 30.04 km² of irrigated area in the study area. Spatial Mosaic of Irrigated area reflects that southern portion of Kanksa mainly the right bank of Kunur and Left bank of Damodar River has experienced drastic change in irrigated area. Whereas northern part experienced slight increase in irrigated area in comparison to the southern part of the study area. Physiographic and geological constrains to groundwater recharge has not become the barrier of the groundwater drafts in domestic and agricultural purposes. As a result there is a high risk of this block to become a semi-critical block in groundwater crisis scenario of district. It should be checked by alternative irrigation practices such as rain water harvesting and river lift irrigation or canal system. Present study focus on the groundwater situation in different cropping season with their fluctuation with their spatial mosaic including the agricultural development mainly with the help of irrigational intensification during last three decades.

Study area

Present study area Kanksa C.D. Block has approximately 278.4 km² (Census, 2011) of areal coverage, encompassing Ajay–Damodar Interfluves which consists of central part of

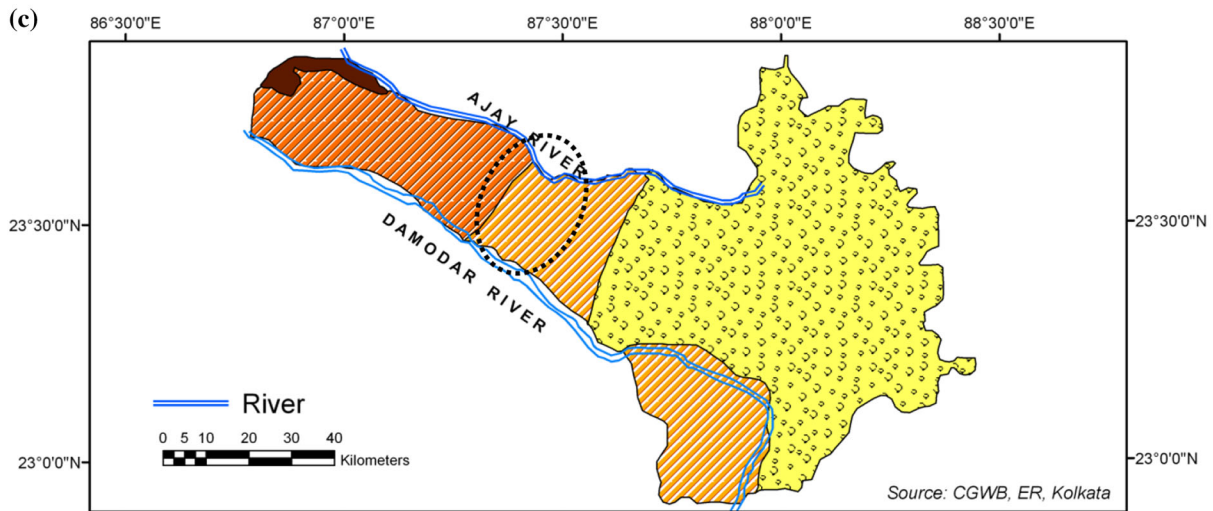
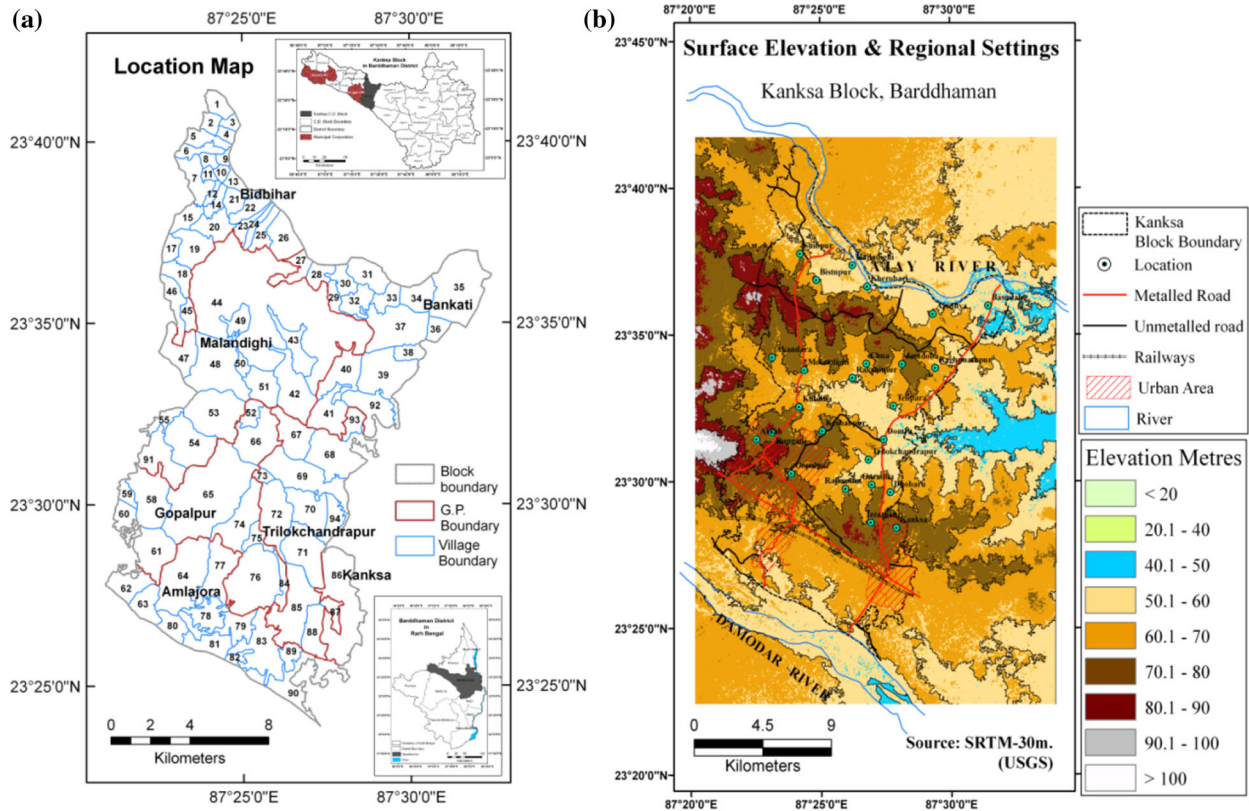
Barddhaman District (Fig. 1a). Administratively Kanksa Block bounded by Birbhum District in the North, Bankura District in the South, Faridpur–Durgapur Block in the west and Aushgram II Block Barddhaman District in the east. This mainly belongs to the central most part of Rarh Bengal. The latitudinal extension ranges from 23°25'N to 23°42'N and longitudinal extension ranges from 87°20'E to 87°32'E. It is the lateritic elevated interfluve portion (mean relief of 50–60 m) of Ajay (north) and Damodar (south) Rivers (Fig. 1b). Lithology of the study area is mainly construct with older alluvium, laterite and ferruginous concentration of upper Tertiary group whereas some part construct with siltstone, clay stone and sandstone of Gondwana period (lower tertiary group) (Fig. 1c). Due to the moderately thick regionally extensive confined and unconfined aquifers down to 300 m, groundwater yield prospects are moderate i.e., 50–150 m³/h (Gupta et al. 2008) (Table 1).

On the land use perspectives, more than one-third (87.2 km², i.e., 31%) land belongs to protected and plantation forest under Burdwan Forest Division. These forested tracts mainly distributed on the elevated topography ranges between 60 and 90 m mainly constitutes with Laterite (Fig. 2b). Built up area (78 km² i.e., 28% of the total area) mostly concentrated in the southern part of the study area, along the national and state highways or built around the Durgapur Industrial complex and block headquarters. In the remaining land along the bank of Damodar, Kunur, and Ajay (from South to North direction) River agricultural activities mainly occur due to availability of alluvial soil (Fig. 2b).

Climatic condition and general geo-hydrology of the study area

The climate of the study area has been identified as sub-humid and sub-tropical monsoon type, receiving mean annual rainfall of 1000–1300 mm. According to agro-ecological regionalization study area belongs to hot-dry sub-humid region (Sarkar et al. 2005). General trends of annual rainfall (IMD 2013) from 1970 to 2013 is very much fluctuating (Fig. 3a).

The general temperature is in the range of 12 °C in winter to 39 °C in summer. The average annual rainfall varies from 1100 to 1350 mm and major rainfall occurs during the south-east monsoon, mid June to mid October. The area is surrounded by the Kunur Nadi, a tributary of Ajay River in the north-east and Damodar River in the south-east. The area shows a gently undulating topography and the elevation (altitude) ranges from 50 to 70 m above mean sea level (Fig. 1a). The area is mostly covered by a blanket of alluvium and laterite. The alluvial cover of unconsolidated sediments ranges in age from middle



| Era/Group | Lithology | Index | Hydrology | Groundwater Potential |
|----------------|---|-------|---|--|
| Quaternary | Younger alluvium, Clay Silt, Sand, gravel, Peebles, Calcareous concentration etc. | | Fairly thick, regionally extensive confined and unconfined aquifers down to 300m. | Large yield prospects above 150 cub.m./hr. |
| Upper Tertiary | Older alluvium and Laterite, Silt, Sand, Ferruginous concentration, lithomeric clay, gravel, pebbles etc. | | Moderately thick, regionally extensive aquifers down to 150m. | Moderate yield prospects 50-150 cub. m. /hr. |
| Lower Tertiary | Siltstone, Claystone, Sandstones (Gondwana Sedimentaries) | | Groundwater restricted to weathered residuum and secondary porosity | Limited yield prospects <50 cub. m. /hr. |
| Archaean | Gneiss, Schist and Intrusives | | | Very Limited yield prospects 5 cub.m./hr. |

Fig. 1 **a** Location of the study area in Bardhaman District, **b** its regional settings with surface elevation and **c** geo-hydrological scenario of the Ajay Damodar Interfluve (*red* marked area indicates area under focus)

Table 1 Areal coverage and their percentages of occurrence of different land uses in the study area

| Landuse class | Area in km ² | Percentages of area |
|-------------------|-------------------------|---------------------|
| Dense forest | 48.6 | 17 |
| Plantation forest | 38.6 | 14 |
| Agricultural land | 98 | 35 |
| Built up land | 78 | 28 |
| Water bodies | 9.14 | 3 |
| Wastelands | 10.6 | 4 |

cretaceous to recent overlying a semi-consolidated basement of the lower and upper Gondwanas, the thickness of the unconsolidated sediments ranges from 31.5 m in the north-western part to about 177 m in the south-east (Das and Biswas 1969). The unconsolidated sediments include granular zones of variable thickness consisting of very coarse to fine sand, sandy clay, lateritic gravels and quartz pebbles. The groundwater occurs in these granular zones generally under unconfined conditions in shallow aquifers within 37 m below ground level. Groundwater in semi-confined to confined conditions in deeper aquifers (31–118 m b.g.l.) were also recorded mainly in the eastern part (Das and Biswas 1969). Here, impervious beds such as clay, shale and argillaceous limestone overlie the water saturated granular zones. The impervious layers separating different granular zones in the eastern part pinch out towards west, and thus the different zones become

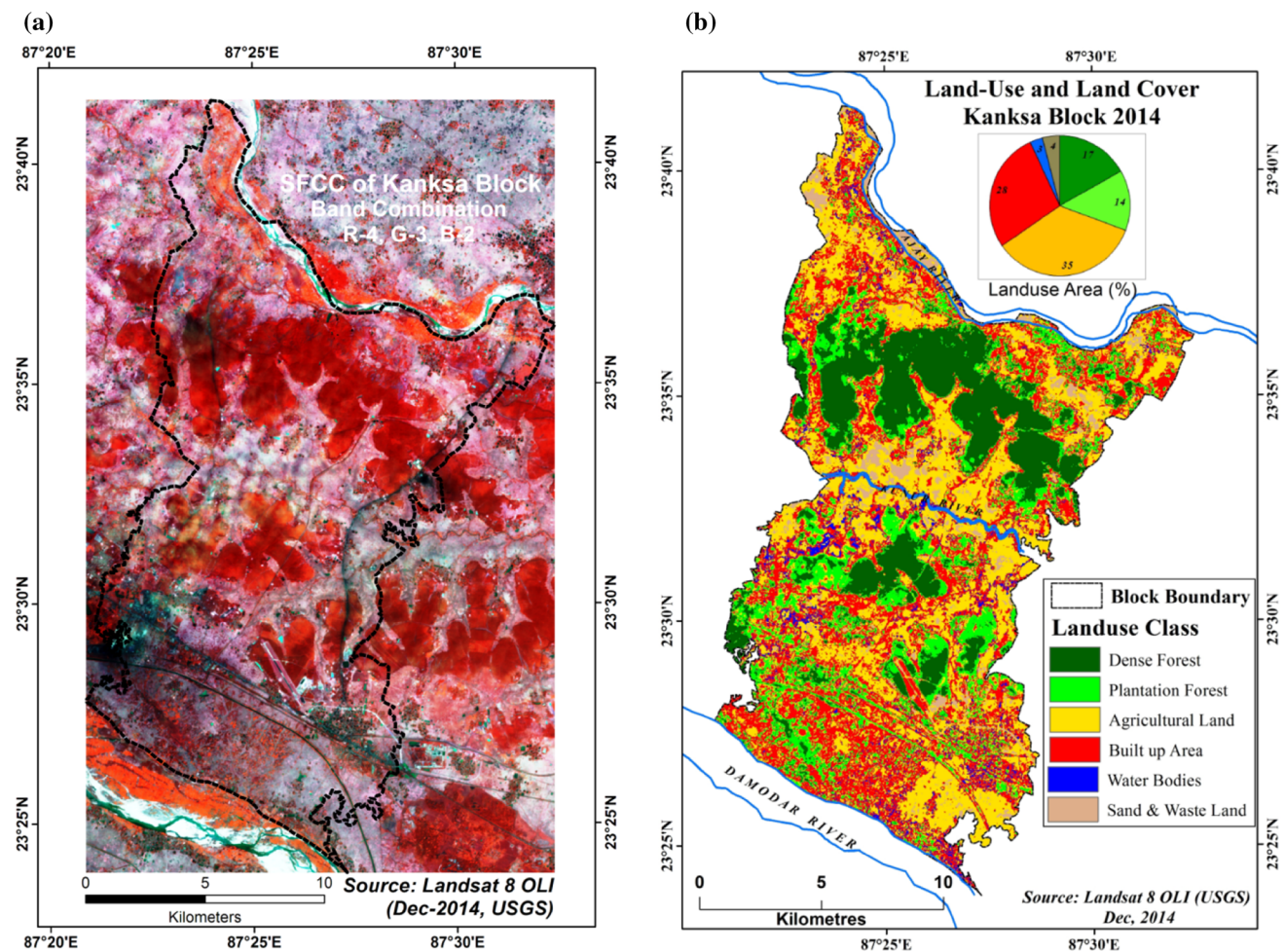


Fig. 2 **a** SFCC of Study area shows *dark red* patches of forest cover as well as lateritic tract and **b** land use and land cover of the study area along with flows of drainage channels

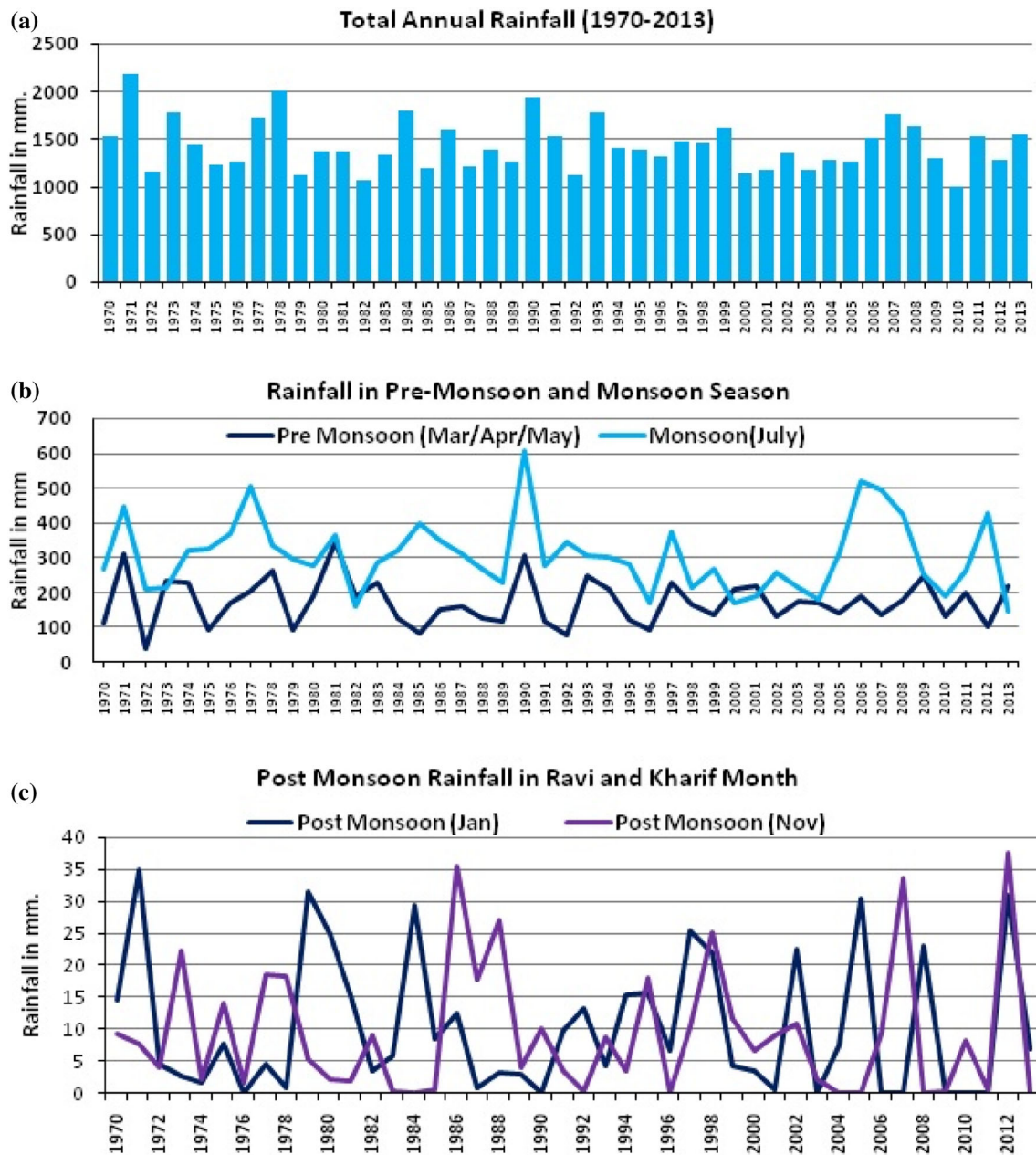


Fig. 3 Rainfall pattern of the Bardhaman District (1970–2013), **a** annual rainfall trends, **b** pre-monsoon and monsoon season and **c** post-monsoon seasons

hydraulically interconnected with the near surface granular zones (Das and Biswas 1969). The groundwater is being exploited in the study area mainly through shallow tube wells for drinking and domestic purposes.

Demographic and urbanization history of the study area

The spatial variations in the distribution, density composition, migration and growth of population have a direct impact on the utilization of resources and the levels of development of a region. As a whole, in the study area

population growth is very rapid after 1951 but quite steady and slow after 1981 (Fig. 4b). Decadal growth rate is maximum in between 1951 and 1961. In last two decades (1991–2001) this growth is almost same (Table 2). Till 1991 there were no urban centres. But from 2001 to the present, seven urbanized tract in terms of Census Town (CTs) have enrolled in Kanksa. As a result urban share of population significantly increased from nil to 20.4% in 2001 and 41.8% in 2011. As a result of urbanization seven census towns have emerged from initially agro-based rural units. These are Kanksa, Debipur, Prayagpur, Arrah, Gopalpur, Bamunara and Amlajora (Fig. 4a).

Fig. 4 **a** Location of urban areas (CT) and **b** Absolute and decadal growth of population in Kanksa Block

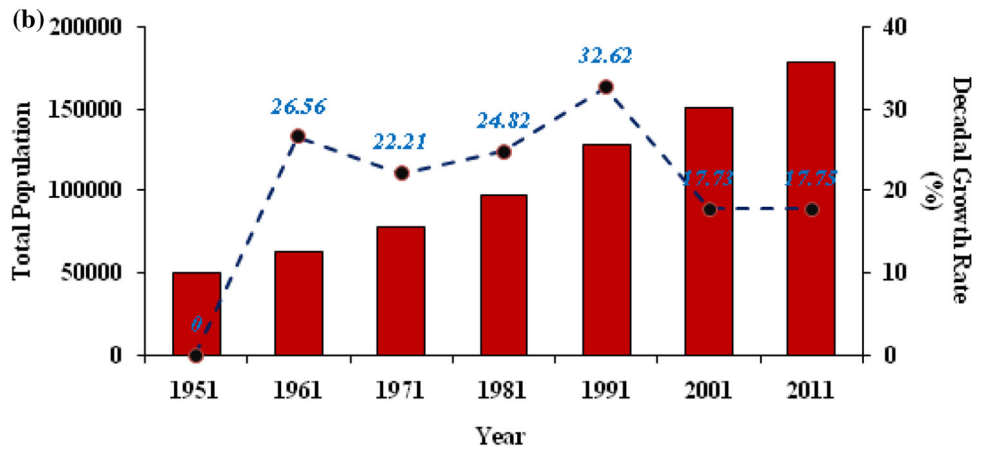
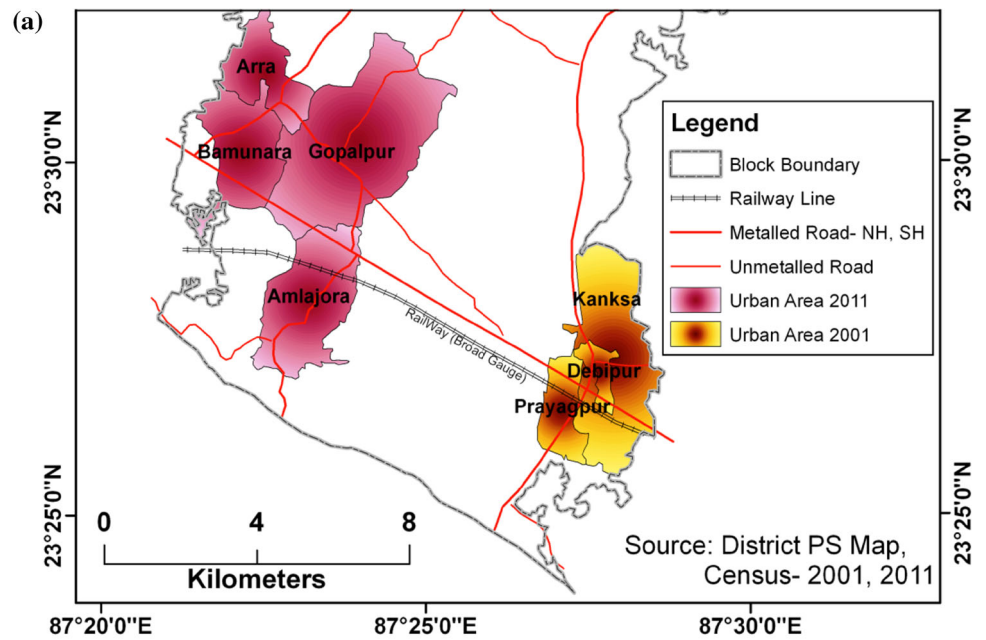


Table 2 Absolute, decadal growth rural–urban share of population along with number of urban centres in Kanksa Block (District Census Handbook 1971, 2001, 2011)

| Year | Total population | Absolute growth | Decadal growth rate (%) | Population density | Rural population | | Urban population | | Number of census towns |
|------|------------------|-----------------|-------------------------|--------------------|------------------|------|------------------|------|------------------------|
| | | | | | Total | % | Total | % | |
| 1951 | 50,191 | – | – | 180 | 50,191 | 100 | NIL | NIL | – |
| 1961 | 63,522 | 13,331 | 26.56 | 228 | 63,522 | 100 | NIL | NIL | – |
| 1971 | 77,628 | 14,106 | 22.21 | 279 | 77,628 | 100 | NIL | NIL | – |
| 1981 | 96,893 | 19,265 | 24.82 | 348 | 96,893 | 100 | NIL | NIL | – |
| 1991 | 128,497 | 31,604 | 32.62 | 462 | 128,497 | 100 | NIL | NIL | – |
| 2001 | 151,276 | 22,779 | 17.73 | 543 | 120,480 | 79.6 | 30,796 | 20.4 | 3 |
| 2011 | 178,125 | 26,849 | 17.75 | 640 | 103,594 | 58.2 | 74,531 | 41.8 | 7 |

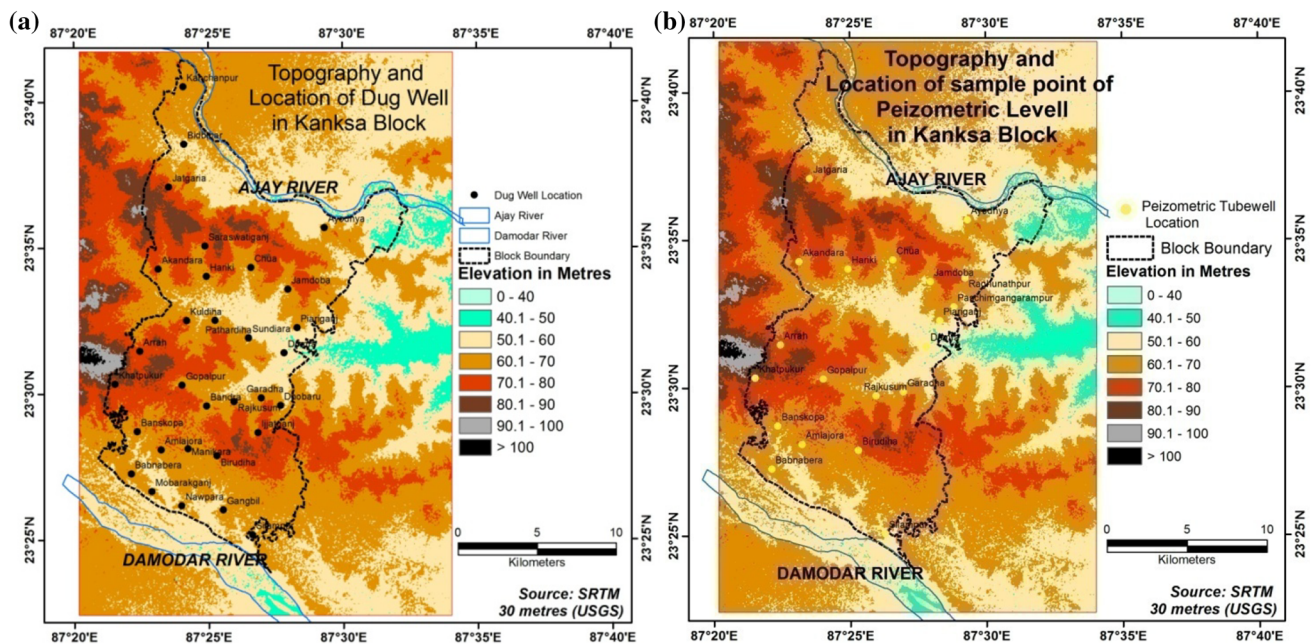


Fig. 5 Location of dug well and tube well for measurement of groundwater level both confined (a) and unconfined aquifer in the study area (b)

Database and methods

The present study depends mainly on secondary data and maps obtained from different sources which are given below:

1. Static water level data has been collected from State Water Investigation Directorate, West Bengal.
2. Dug well and peizometric water table data have been collected from the unpublished report of Geological Survey of India.
3. Block map, topographic details and geological information has been collected from Census Series of Map, SOI topographical map as well SRTM 30 m (USGS) and District Resource Map of Bardhaman District published by Geological Survey of India, respectively.
4. Net sown area and area under irrigation at different village level has been collected from District Census Handbook (village directory) (1971, 2001).

A block map of Kanksa Block has been geo-referenced in Arc GIS 9.3. A polygon layer has been built to vectorise all the mouzas of the block. The centroid of required mouzas has been selected for plotting the borehole points. Thus, a point vector has been created on the base map with 32 points to locate the positions of the Dug-well and 23 sample points of Location of Tubewells. Spatial Mosaic has been done based of the available data using IDW tools in Arc GIS 9.3. Spatial distribution of Agricultural and irrigation land has been portrayed using choropleth method in MapInfo Professional 7.0. All others data has been tabulated and interpreted by using MS-Excel 2007.

Results and analysis

Regional groundwater set up of Ajay–Damodar Interfluvium

The regional groundwater condition and resources within Ajay–Damodar interfluvium of Bardhaman district are directly controlled by geological set up of the area. About one-third of the district in the western part is covered by hard sedimentary rocks of Gondwanas and Post Gondwanas within a small portion in its north by Achaean. Within these hard rocks, groundwater occurs mainly under unconfined conditions along the joints, fractures, cracks and fissures which gives secondary porosity to the rocks. This unconfined condition of groundwater continues up to Durgapur in the east. From Durgapur east-ward, groundwater occurs both under unconfined and of confined conditions within the granular zones of unconsolidated to semi-consolidated Quaternary and Tertiary deposits which overlie the basement of Rajmahal Traps and Gondwanas.

Groundwater condition of the study area

The study area constitutes a part of Ajay–Damodar interfluvium between Durgapur in the west and Panagarh in the east and is bounded by Ajay River in the north and Damodar in the south. Groundwater occurs in the area within a thick saturated granular zone both under water table and of confined condition. To assess the groundwater situation in confined (Fig. 5b) as well as unconfined

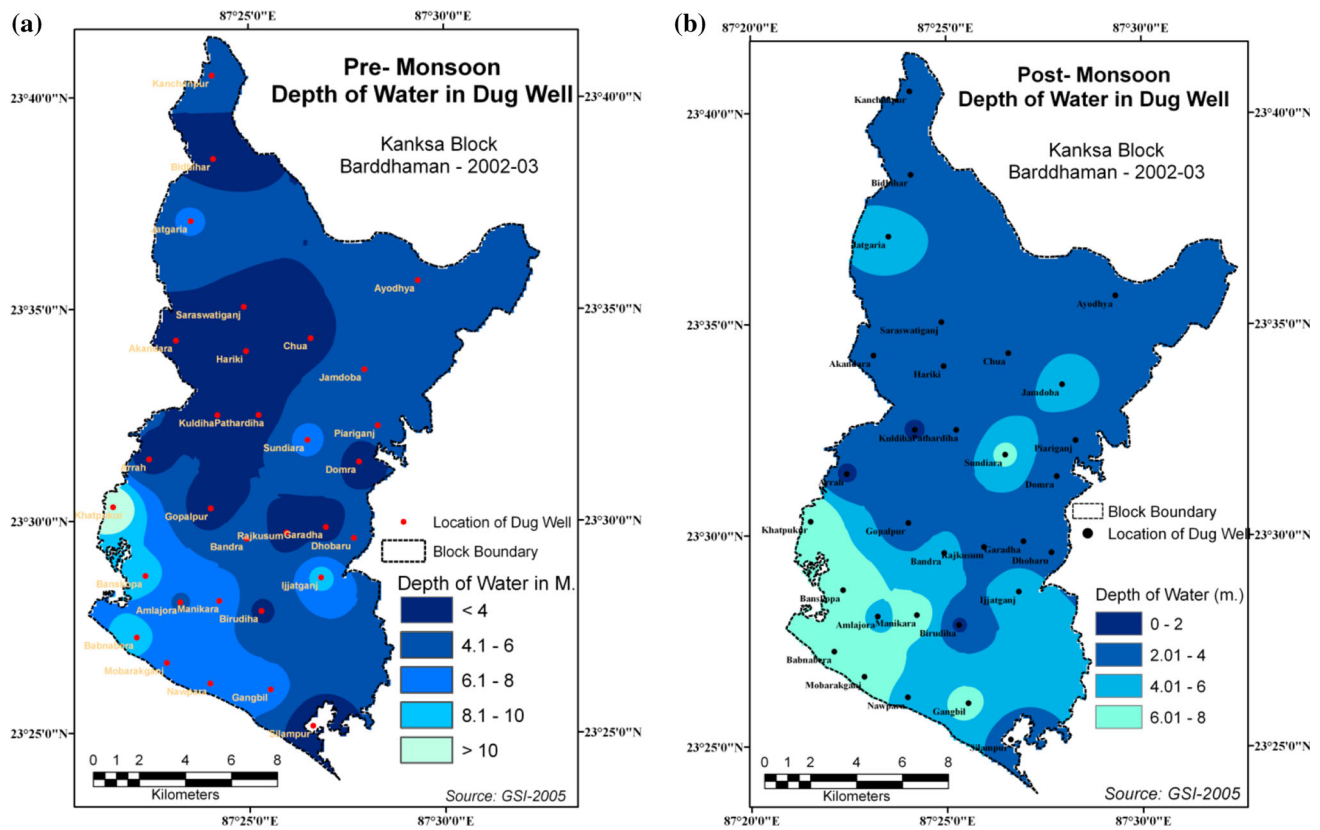


Fig. 6 Spatial distribution of pre-monsoon (a) and post-monsoon (b) depth of water of dug well

aquifers (Fig. 5a) groundwater table data of various dug-wells (in case of unconfined aquifers) and tube-wells (for confined aquifers) distributed all over the region have been used. Spatial mosaics of such situation are reflected as follows:

Groundwater under unconfined condition

In the near surface aquifer comprising clayey silt to sandy silt and laterite, groundwater occurs under water table conditions and is usually tapped by dug wells which at places dry up during summer. Depth to water table of unconfined aquifer as measured in dug wells varies between 1.93 m (Silampur) and 12.85 m (Khatpukur) below ground level during pre-monsoon period (Fig. 6a) and from 1.62 m (Birudiha) to 14.8 m below ground level (Ajodhya) during post-monsoon (Fig. 6b). The seasonal fluctuation of water table ranges from 0.95 m (Piyriگانj) to 3.76 m (Khatpukur) below ground level. The fluctuation is mainly caused by evapo-transpiration, discharge of groundwater by out flow, groundwater draught and hidden faults. Water table fluctuation map (Fig. 8a) prepared based on relative level of water level with reference to mean sea level, reveals that regional fluctuation is more in

and Kanksa area. On perusal of the map it is revealed that slope of both pre- and post-monsoon water tables is towards south and east (Fig. 6a, b).

Groundwater under confined condition

Groundwater occurs under of confined condition in the deeper aquifers. A perusal of the available bore hole litho log of the study area reveals that the granular sediments, comprising unconsolidated to semi-consolidated fine to coarse sands and pebbles occurring at different depths constitute the deeper aquifer system in the area. The thickness of the unconsolidated sediments increases from west to east. It is about 8 m near Durgapur and 130 m near Kanksa in the east. The bore hole litho log up to 152 m b.g.l. shows that the deeper aquifer system is represented by multiple layers of sand/pebble layers of varying thickness ranging from 1 to 23 m. The thickness of sand-pebble layers varies between 1 and 35 m.

The maximum thickness of such individual aquifer unit is 35 m as noted at Nadihaat the depth range of 65–100 m b.g.l. At Khatpukur a single aquifer attaining maximum thickness of 27 m within the depth range of 91.5–118.5 m b.g.l., while at Kuldiha, it is 18 m at the depth range of

79–97 m b.g.l. Thus, the thickness of aquifer increases from north to south between Kuldiha and Nadiha, where these unconsolidated thick granular zones are underlain by sandstone. Local inventory reveals that most of the tube wells in the area usually tap groundwater from the depth ranges of 15–25 m b.g.l.

The piezometric surface of semi-confined to confined aquifers as measured in tube wells varies between 2.85 m (Kuldiha) and 16.5 m (Jatgaria) below ground level during pre-monsoon period (Fig. 7a) and from 3.45 m (Kuldiha) to 17.93 m (Bankati) during post-monsoon (Fig. 7b).

The seasonal fluctuation of piezometric surface (Fig. 8b) ranges from -0.1 m (Piariganj) to 5.95 (Amlajora). Negative fluctuation at some places in the study area especially along the southern border of the area around the villages Narayanpur, Babnabera, Gangbil, and Silampur from west to east may be attributed to over exploitation of groundwater during winter for cultivation of boro crop, Ravi crop and vegetables. Piezometric surface contour map prepared on the basis of the data with reference to mean sea level, reveals that the slope of piezometric surface is towards east and southeast (Fig. 7a, b). This conforms to the regional ground slope of the area.

Agricultural profile of the study area

Socio-economic landscape in the study area concerns economic activity mainly agriculture and also non-agricultural functions i.e., collection of timber and non-timber forest products (NTFPs) mainly among the tribal peoples. Both these activities have immense importance in the socio-economic profile of the study area. Agriculture seems to be the mainstay of economy of rural livelihood though it is true that soil fertility and productivity are not conducive for profitable agriculture. At the same time, climatic regime has restricted agriculture (wet agriculture) mainly once in a year. In present study, area agricultural land constitutes more than half of the study area and may be broadly divided into two categories, namely, single crop and double crop areas (Bhattacharya and Dhar 2005). The major part of agricultural land comes under single crop cultivation, in which rain fed paddy is grown on Lalgarh surface. Double crop cultivation is practised only in Chuchura and Sijua surface, where, in addition to rainfed aman cultivation, boro crop is also grown using ground water and canal water irrigation. In this alluvial tract, vegetables particularly potatoes are grown. Chuchura and Hooghly surface including channel and point bars, Rabi crops such as oil

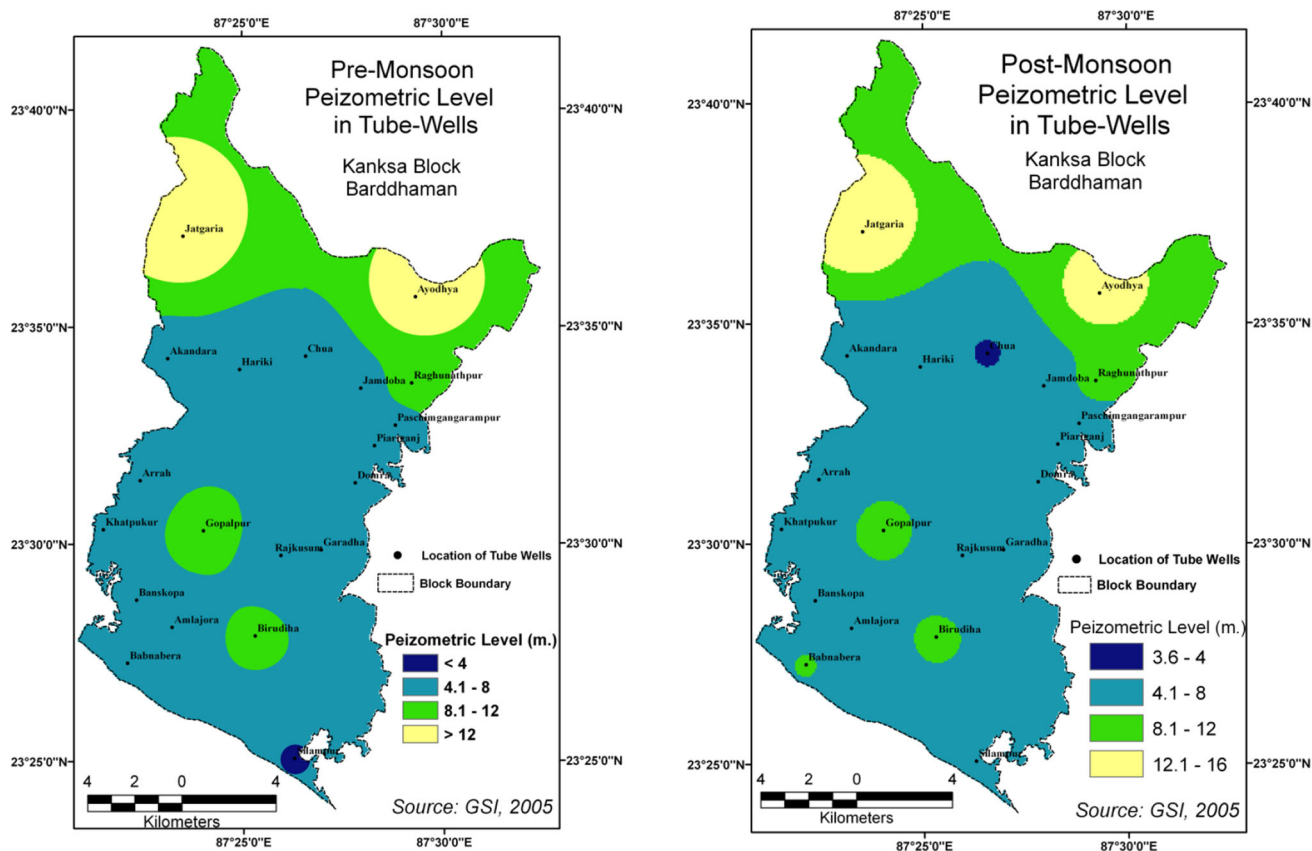


Fig. 7 Piezometric water level of tubewell in pre-monsoon (a) and post-monsoon season (b)

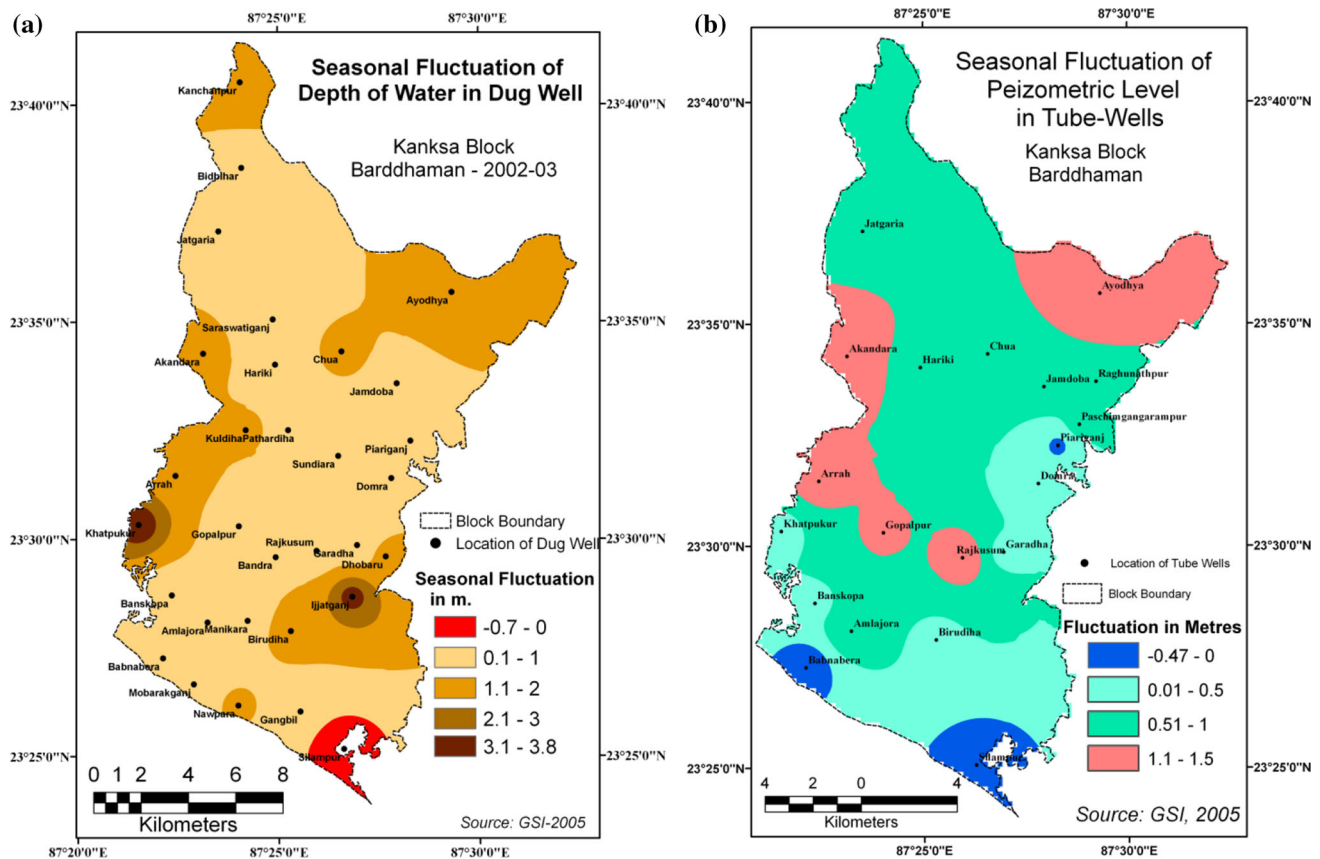


Fig. 8 Seasonal fluctuation of depth of water in dug well (a) and piezometric level of tube-wells (b) in Kanksa Block

seeds, wheat and pulses are also grown at places. In the latosol areas of Lalgarrh surface boro paddy is grown locally where canal water for irrigation is available. Canal water and shallow boring facilities are available along the alluvial tract in the southern and northern part of the area where it also yields boro crop, Rabi crop and variety of vegetables.

Spatio-temporal change of agricultural land

Changing physico-cultural settings over the last three decades has been causing significant spatio-temporal variation in net sown area in the study area. The proportion of net sown area in this block increased from 47.7% (132.86 km²) in 1971 to 51.2% (136.34 km²) in 2001, amounting 3.5% increase of land in this category. Over 30 years of time span there is a net increase of 3.48 km² of net sown area in the study area. For geographical analysis of change in net sown area (1971–2001), the study area may be divided into three broad regions (Table 3; Fig. 9a, b).

From the analysis salient features are as follows:

1. Within 30 years of time span (1971–2000) there is a wide range of change in NSA in Kanksa Block. The

magnitude of change ranges between 0.01 to >95% increase and 0.01–30% decrease of NSA. Such wide range of change implies that the pace of development is not uniform rather it is highly variable in the study area.

2. During this 30 years there is a net increase in NSA 3.48 km² which overcome the decrease on NSA by urban encroachment in six rural mouzas i.e., JL No. 59, 60 under Faridpur–Durgapur block and JL No. 86, 87, 88 as Census Town category in Kanksa Block. Out of 86 mouzas (excluding 5 urban units) 54 mouzas (63%) have experienced below 30% increased in NSA where as 20 mouzas have very slight increase i.e., under 5%. Only seven mouzas (9%) have more than 30% increases in NSA. JL No. 3, 4 and 46 have more than 80% increase in the NSA.
3. Negative change is not uniform in all parts of the study area. Out of 86 mouzas 20 mouzas have experiencing upto 30% decrease in NSA. Among them only eight mouzas have more than 5% decreases in NSA. These are JL No. 49, 54, 64, 70, 78, 83, 89, and 91. Rest of the Mouzas have very minor decrease (i.e., <5%) in NSA.

Table 3 Spatio-temporal variation in net sown area in Kanksa C.D. block (1971–2001)

| Areas | Name of mouzas (J.L.) | Total number of mouzas | Percentages |
|---|--|------------------------|-------------|
| Areas experiencing increase in NSA | | | |
| Less than 30% | 2, 5, 6, 7, 12, 13, 21, 22, 24, 25, 26, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 39, 40, 41, 42, 44, 45, 47, 48, 50, 51, 52, 53, 58, 61, 62, 63, 65, 66, 67, 68, 69, 71, 73, 74, 75, 76, 79, 81, 85, 90, 92, 93, 94 | 54 | 63 |
| 30–60% | 1, 27, 38 | 3 | 4 |
| Greater than 60% | 3, 4, 46, 84 | 4 | 5 |
| Area experiencing decrease in NSA | | | |
| Less than 30% | 8, 10, 11, 15, 18, 19, 20, 23, 49, 54, 64, 70, 72, 77, 78, 80, 82, 83, 89, 91 | 20 | 22 |
| Area experiencing no change in NSA | | | |
| No change | 14, 17, 25, 43, 55 | 5 | 6 |
| Total number of mouzas | | 86 | 100 |

Source: District Census Handbooks (1971, 2001)

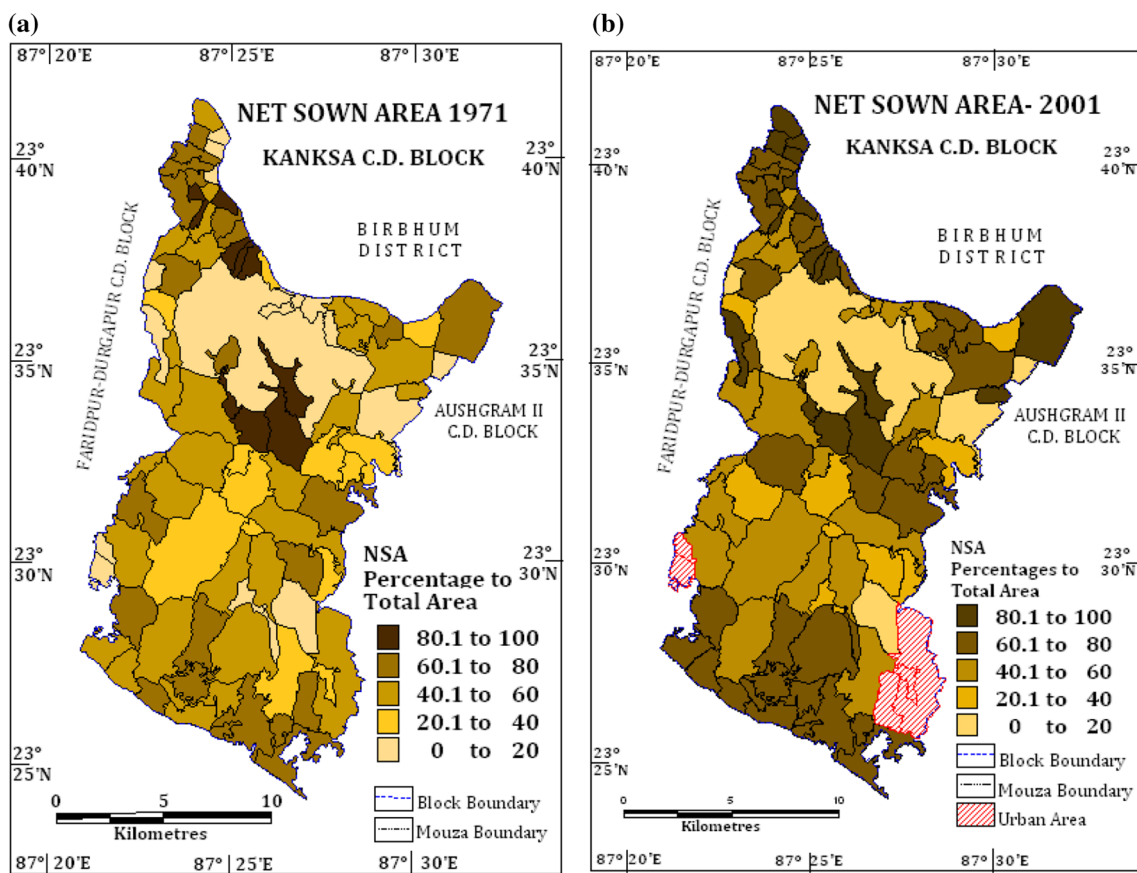


Fig. 9 Spatial mosaic of agricultural development between 1971 (a) 2001(b) in Kanksa Block

Areas experiencing increase in net sown area

From 1971 to 2001, 54 mouzas out of 86 experienced less than 30% increase in net sown area. Very minute increase

(<5%) of net sown area has been associated with 22 mouzas mainly concentrated along the Ajay–Kunur inter-fluves area. These all mouzas faced increased irrigation from Ajay and Kunur River mainly. Favourable alluvial

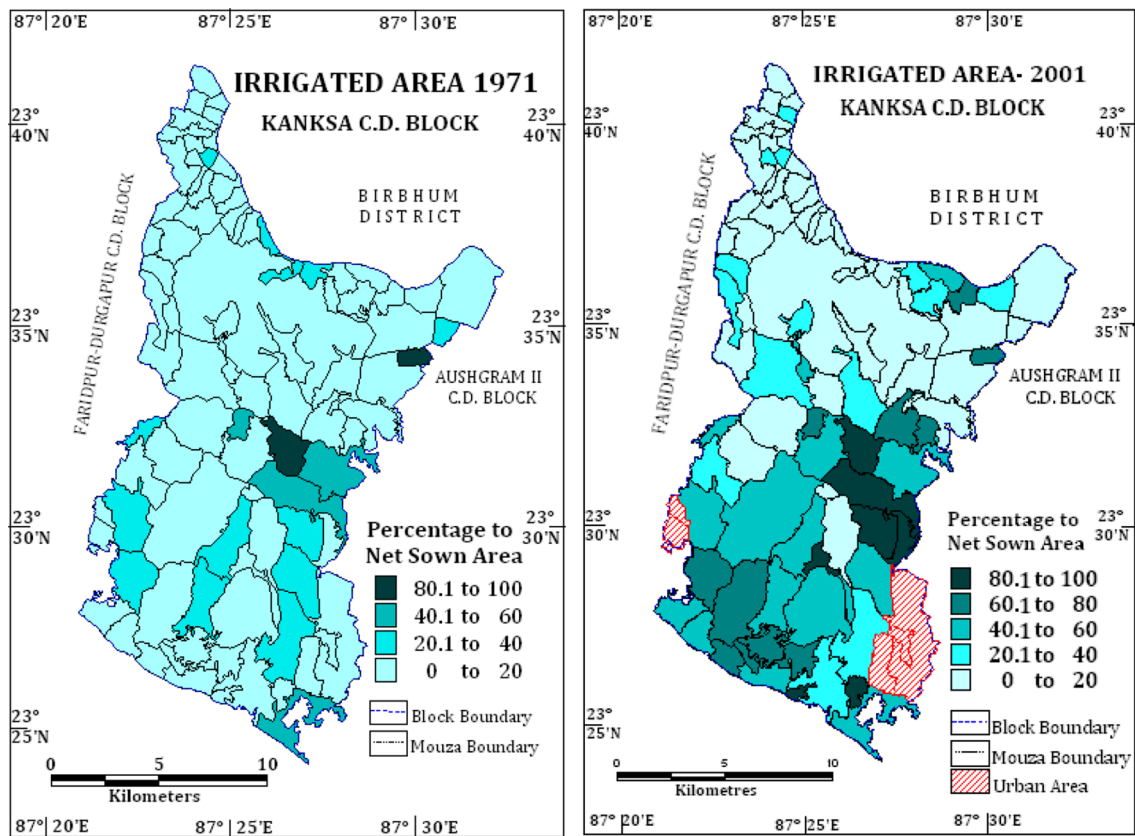


Fig. 10 Irrigation development during last three decades (1971–2001) concentrated mainly in the southern portion of the block

soil and potential of high level irrigation influences the increase in agricultural area in these mouzas. Only three mouzas i.e., JL Nos. 1, 27, 38 have an increase in NSA about 30–60%. Rest of the four mouzas have abrupt increase in NSA (>60%) due to the direct irrigation impact from Ajay river (JL. Nos. 3, 4 and 9). As for example in Talbahari (JL. No. 4), irrigated area increased 36.89% and NSA also increased with same pace as 95.14% (Fig. 9a, b). So overall trend is the increase of net sown area all over the block though there are some exceptions.

Areas experiencing decrease in net sown area

As against the general trend, 20 mouzas (22% of total number of mouzas) in the study area experienced negative change in net sown area. Area affected by decreased NSA is more in the lower part adjoining to Damodar watershed than in the upper part adjoining to Ajay watershed in the study area. Major cause of decrease of agricultural land is the decrease in irrigation facility. Rupganj (JL. No. 54), Jatgaria (JL. No. 19), Rajkusum (JL. No. 72), have show decrease in irrigated area influences the agricultural land (Fig. 9b). As a result NSA decreases 10.49, 0.1 and 4.38%, respectively. In rest of the suffering mouzas have either population increase with urban spread in terms of

construction of road and railway or increased area of wasteland due to low fertility of land.

Spatio-temporal change of irrigated area

Irrigation is one of the prime pre-requisite for agricultural development. Though Indian agriculture is a gamble in the hands of monsoon, since groundwater utilization may be considered as one of the important sources of irrigation throughout the year in India in general and every state in particular. Present study area is not the exception of this scenario. Within 30 years of time span (1971–2001), agricultural development is mainly due to the fulfilment of growing population demand is based on irrigation development. The proportion of irrigated area in Kanksa Block increased from 6.92% (18.36 km²) in 1971–18.17% (48.39 km²) in 2001, amounting 11.25% increase of land in this category. Over 30 years of time span there is a net increase of 30.04 km² of irrigated area in the study area. Spatial Mosaic of Irrigated area reflects that southern portion of Kanksa mainly the right bank of Kunur and Left bank of Damodar River has experienced drastic change in irrigated area. Whereas northern part remains unchanged or slight increase in irrigated area (Figs. 10a, b, 11; Tables 4, 5).

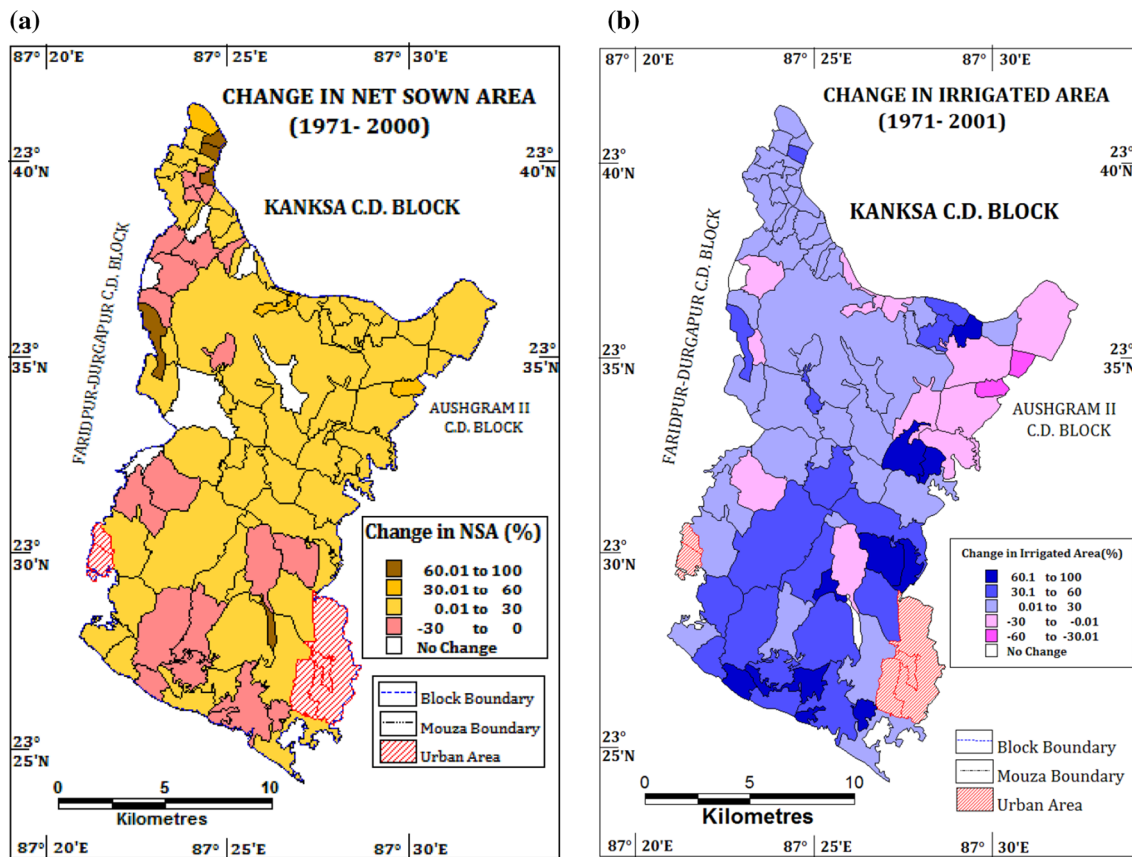


Fig. 11 Spatial mosaic of agricultural (a) and irrigational (b) development in 1971–2001

Table 4 Mouza level spatio-temporal change of NSA in Kanksa Block

| Areas | Name of mouzas (J.L.) | Total number of mouzas | Percentages |
|---|--|------------------------|-------------|
| Areas experiencing increase in irrigated area | | | |
| <30% | 1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 18, 20, 21, 22, 23, 24, 25, 29, 30, 34, 42, 43, 44, 47, 48, 49, 51, 52, 53, 55, 58, 62, 67, 68, 73, 77, 85, 90, 91 | 43 | 50 |
| 30–60% | 4, 31, 32, 46, 50, 61, 63, 64, 65, 66, 69, 71, 74, 76, 78, 81, 83 | 17 | 20 |
| >60% | 33, 41, 70, 75, 79, 80, 82, 89, 93, 94 | 10 | 12 |
| Area experiencing decrease in irrigated area | | | |
| <30% | 19, 26, 27, 28, 35, 37, 39, 40, 45, 54, 72, 92 | 12 | 14 |
| 30–60% | 36, 38 | 2 | 2.3 |
| Area experiencing no change in irrigated area | | | |
| 0% | 17, 84 | 2 | 2.3 |
| Total | | 86 | 100 |

Critical analysis-groundwater withdrawal and fluctuation of groundwater table

Field investigation regarding ground water exploitation for domestic and agricultural use reveals that in the Lalgah formation area exploitable ground water is available beyond 50 m b.g.l. While in the alluvial tract groundwater

for domestic and agricultural use is available at shallower depth, between 10 and 30 m b.g.l. (Bhattacharya and Dhar 2005). Irrigation through deep tube wells is significantly increased during the short time span of 2003–2007. Number of deep tube wells and area under this irrigation system massively increased from 14 (irrigated area 1.02 km²) to 135 (6.05 km²) in these 4 years which further indicates the

increase in groundwater drafts in agricultural as well non-agricultural purposes. Field inventory of dug wells reveals that most of the dug wells in the laterite country become almost dry during summer. It is also recorded that in the laterite country particularly along the watershed such as Gopalpur and north of Panagarh many of the existing tube wells yield little or insufficient water during summer time; as a result in Gopalpur and north of Panagarh, groundwater

is drawn by PHE from deeper level i.e., 90–120 m b.g.l. (Bhattacharya and Dhar 2005).

Analysis of data reveals that water table is fluctuating in more irregular way in pre-monsoon periods than post-monsoon periods (Table 6). Two stations from two different locations have been chosen from different regional geo-hydrological sites. Data from 1996 to 2014 show that in agriculturally developed rural populated region and semi-urban area of Basudah (a agriculturally developed populated rural tract) and Kanksa (highly populated urban tract), respectively, the fluctuation rates are very irregular mainly in pre-monsoon seasons (Fig. 12a, b).

It is clear that a strong correlation exists between the population increases, agricultural with irrigational change with groundwater level fluctuation in the study area (Fig. 11). In the northern part of the study area (i.e., northern part of Kunur River) fluctuation in unconfined aquifer is noticeable due to increased level of irrigation and agriculture. Whereas in the southern part of the study area which is mainly the urban to semi-urban highly populated space, level of confined aquifer fluctuated at a considerable rate due to increase of domestic use of water. To meet the demand of growing population in the census towns (e.g., Kanksa, Debipur, Pryagpur, Bamura, Gopalpur, Arra, Amlajora) domestic water draft significantly increased

Table 5 Changing agricultural profile

| Change in net sown area (NSA) and irrigated area (1971–2001) | NSA Total number of mouzas (%) | Irrigated area Total number of mouzas (%) |
|--|--------------------------------|---|
| Positive change | | |
| 0.01 to 30% | 54 | 43 |
| 30.01 to 60% | 3 | 17 |
| >60% | 4 | 10 |
| Negative change | | |
| 0 to –30% | 20 | 12 |
| –30 to –60% | 0 | 2 |
| No change | | |
| No change | 5 | 2 |
| Total | 86 | 86 |

Table 6 Pre-monsoon, monsoon and post-monsoon water table fluctuation in two different locations (Source: State Water Investigation Department 2014)

| Year and seasons | Station: KANKSA (water level in m.b.g.l.) | | | | Station: BASUDAH (water level in m.b.g.l.) | | | |
|------------------|---|---------------------------|---------------|---------------------------|--|---------------------------|---------------|---------------------------|
| | Post-monsoon Ravi (Jan) | Pre-monsoon (Mar/Apr/May) | Monsoon (Aug) | Post-monsoon Kharif (Nov) | Post-monsoon Ravi (Jan) | Pre-monsoon (Mar/Apr/May) | Monsoon (Aug) | Post-monsoon Kharif (Nov) |
| 1996 | 3.40 | 8.33 | 1.24 | 4.05 | 1.9 | 2.77 | 1.24 | 4.05 |
| 1997 | 5.78 | 15.77 | 1.51 | 3.22 | 2.31 | 2.97 | 1.51 | 3.22 |
| 1998 | 4.70 | 6.73 | 2.37 | 4.05 | 1.64 | 3.31 | 2.37 | 4.05 |
| 1999 | 6.94 | 12.11 | 1.17 | 2.65 | 2.12 | 2.73 | 1.17 | 2.65 |
| 2000 | 4.09 | 7.56 | 2.50 | 3.16 | 1.99 | 2.91 | 2.5 | 3.16 |
| 2001 | 6.76 | 6.77 | 2.39 | 4.14 | 2.64 | 0.97 | 2.39 | 4.14 |
| 2002 | 7.51 | 7.56 | 1.77 | 3.27 | 3.21 | 1.14 | 1.77 | 3.27 |
| 2003 | 5.55 | 6.13 | 5.96 | 3.27 | 2.41 | 1.73 | 5.96 | 3.27 |
| 2004 | 5.01 | 9.49 | 2.36 | 2.57 | 2.23 | 3.07 | 2.36 | 2.57 |
| 2005 | 5.02 | 6.56 | 4.14 | 3.97 | 2.32 | 1.69 | 4.14 | 3.97 |
| 2006 | 5.41 | 9.01 | 2.78 | 3.40 | 2.45 | 3.55 | 2.78 | 3.4 |
| 2007 | 2.95 | 8.68 | 1.20 | 1.68 | 2.44 | 2.96 | 1.2 | 1.68 |
| 2008 | 4.19 | 6.61 | 4.85 | 3.31 | 2.44 | 2.91 | 4.85 | 3.31 |
| 2009 | 4.39 | 7.64 | 3.56 | 4.41 | 1.92 | 4.06 | 3.56 | 4.41 |
| 2010 | 6.61 | 8.93 | 6.36 | 3.70 | 2.75 | 3.97 | 6.36 | 3.7 |
| 2011 | 8.47 | 11.10 | 2.35 | 1.82 | 3.27 | 4 | 2.35 | 1.82 |
| 2012 | 4.16 | 8.31 | 4.42 | 2.92 | 2.76 | 3.62 | 4.42 | 2.92 |
| 2013 | 4.99 | 3.01 | 1.70 | 2.05 | 3.17 | 4.05 | 1.7 | 2.05 |
| 2014 | 2.51 | 6.91 | 4.26 | 2.83 | 2.01 | 3.65 | 4.26 | 2.83 |

Fig. 12 Temporal change in water table in two different location of Kanksa Block shows comparatively variable fluctuation in monsoon, post-monsoon season and pre-monsoon seasons, **a** fluctuation in Kanksa and **b** fluctuation in Basudah

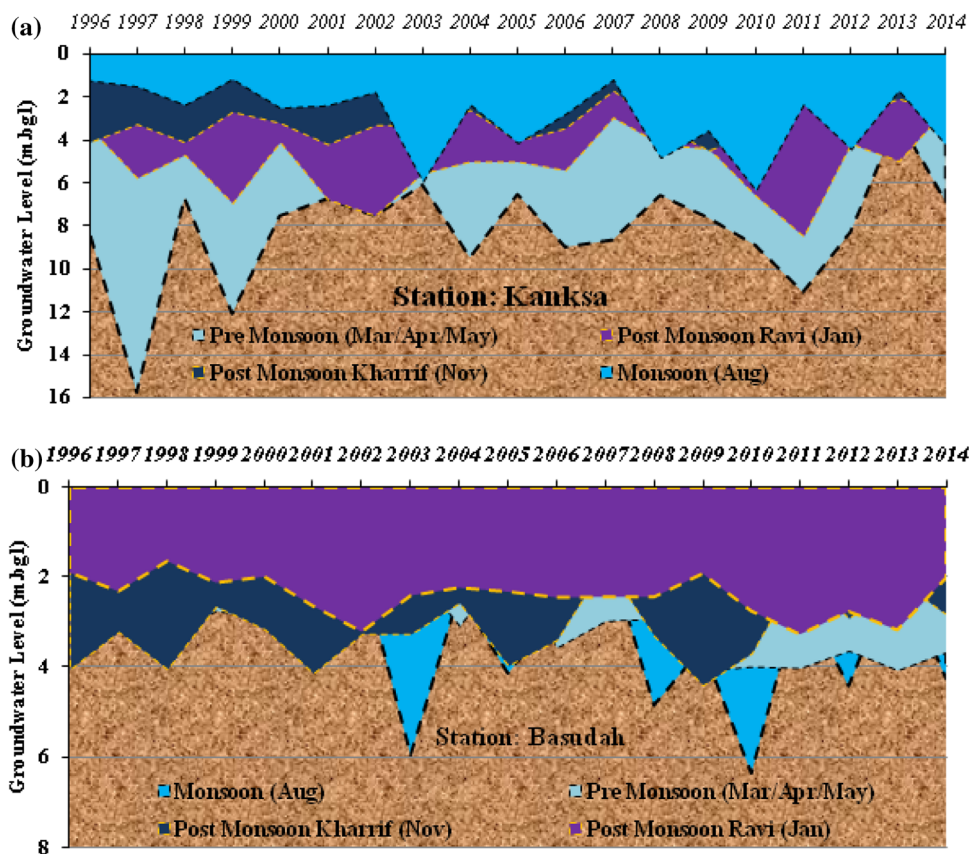


Fig. 13 Land quarry Dhobaru–Ranisayer in pre and post-monsoon season has different uses

during last two decades (1991–2011). As a result groundwater level fluctuated at a high rate during pre as well as post-monsoon period. Study of groundwater level trends show that earlier in most of the alluvium covered areas, depth to water level used to be in the tune of 2–5 m b.g.l. during pre-monsoon season and 0–2 m b.g.l. during post-monsoon season (Gupta et al. 2014). With advent of

energized pumping system as well as groundwater intensive agricultural irrigation such as “Boro” cultivation, average water level has gone down to 5–10 m b.g.l. during pre-monsoon season and 2–5 m b.g.l. during post-monsoon season.

Study also shows that fall in post-monsoon water level is increasing at a much higher rate than that of pre-monsoon

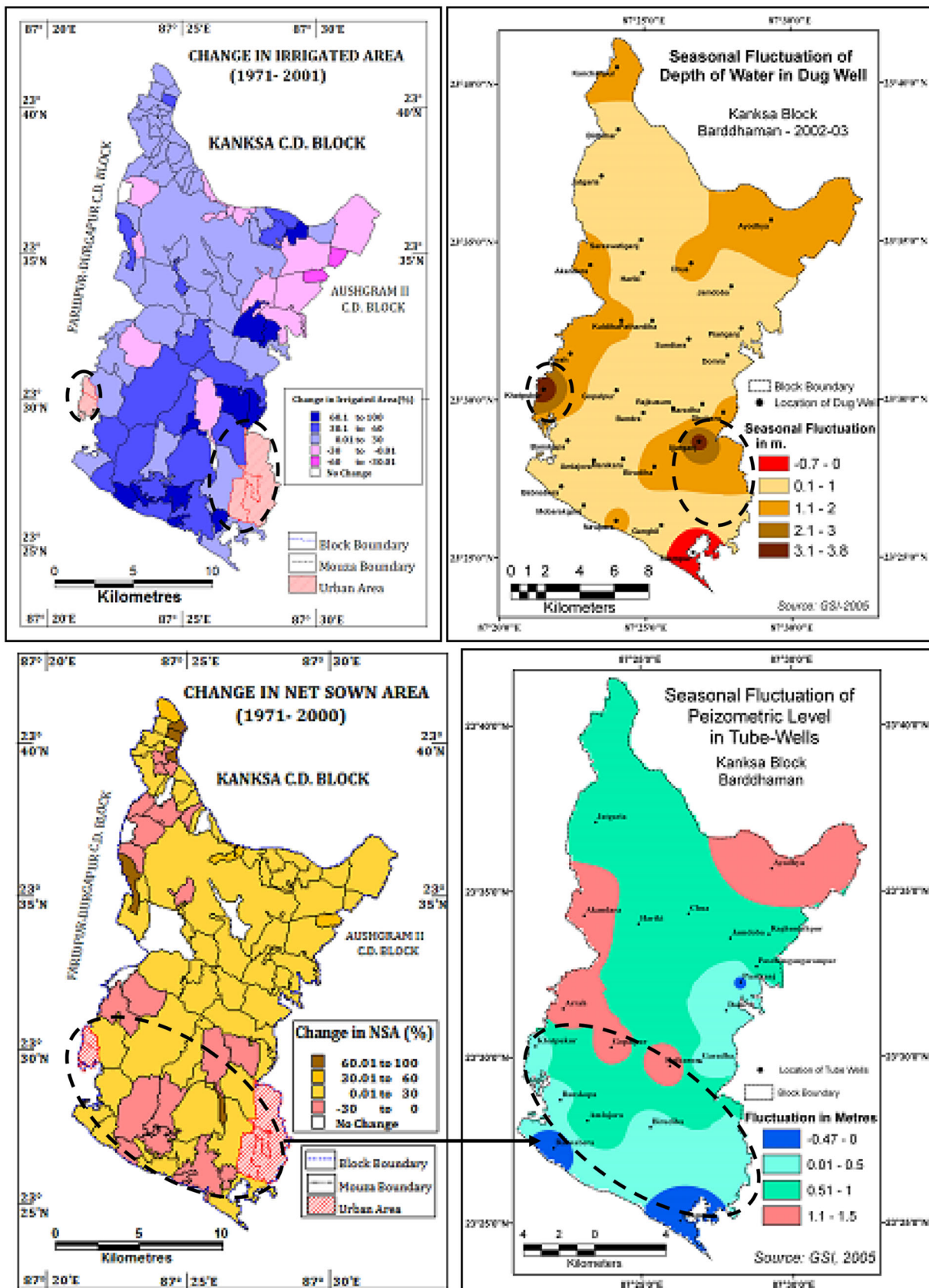


Fig. 14 Spatial association of agricultural and irrigational change with seasonal fluctuation of groundwater level

depth to water level (Gupta et al. 2014). This may be due to two reasons (a) lesser rainfall due to climate change, so that the aquifer is not getting fully recharged; and (b) groundwater draft is exceeding recharge. This situation may be approached with two pronged strategy, i.e., tackling the problem of lesser rainfall with artificial recharge or rain water harvesting to augment recharge; on the other hand, implementation of suitable regulations for sustainable ground water development to control draft.

The area around Gopalpur and Kanksa contain innumerable number of laterite quarries with areas up to 200 m × 100 m and depth up to 5 m which can be utilized for preserving rain water because the base of each quarry is made up of impermeable lithomeric clay. In Dhoabaru region, it is found that abandoned murrum quarried land uses for rain water storage in post-monsoon season (Fig. 13). Scarcity of water may be reduced by limited use of groundwater for drinking purposes only and supply of untreated water should be ensured from Damodar or from rain water harvesting for general purpose use. The area between Amlajora and Silampur is highly dissected forming broad valleys with narrow neck and is covered by sticky less permeable silty clay of Sijua formation. These broad valleys are suitable for rain water harvesting by providing small dams across the narrow portion of the valleys (Fig. 14).

Conclusion

West Bengal has a very little scope to increase agricultural production through expansion of land, as the cultivated land has remained constant and even decreased in many cases due to high population pressure and urbanization. So increase in the yield of production to meet the e growing need is only alternative and which is only possible by the help of irrigational development. Kanksa region under Ajay Damodar interfluvies geologically dominated by lateritic tract which have high to medium porosity but very less water holding capacity which creates hindrance to ground water recharge. During the past few decades population increase in rural as well as urban area and transformation of rural tract to urban (Census town like Kanksa, Debipur, Gopalpur, Arrra) to semi-urban tract added with the agricultural development with the irrigational input change. Except the region under Chuchura and Sijua formation Around the Ajay, Damodar and Kunur River, groundwater level is not so much developed. But the heavy pressure of groundwater draft for agricultural as well as non-agricultural activities mainly causes the decrease in seasonal groundwater level year by year. In the urban area such as Kanksa pre-monsoon groundwater level low than

monsoon and post-monsoon season which matches with normal situation of ground water level scenario. But in the rural agriculturally developed rural tract of Basudah the scenario is slightly reversed. Here, in some years the pre-monsoon water level is high than monsoon water level which is deviated from normal scenario. Though this region is not fall under critical or semi-critical stage of groundwater situation in considering the other regions of district but a significant critical relationship between groundwater irrigation, agricultural development and water level fluctuation further put a question of sustainability of groundwater situation in near future.

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