ASSESSMENT OF HYDROLOGICAL FUNCTIONS AND WATER BUDGET OF KEOLADEO NATIONAL PARK WATERSHED

THESIS

SUBMITTED TO THE

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DEHRA DUN

UTTARAKHAND

For

THE AWARD OF THE DEGREE OF
DOCTOR OF PHILOSOPHY IN FORESTRY
(Forest Ecology and Environment)

By

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Dehra Dun
2007

DECLARATION

I hereby declare that the thesis entitled "**Assessment of hydrological functions and water budget of Keoladeo National Park watershed**" submitted for the award of Doctor of Philosophy in Forestry (Forest Ecology & Environment) to Forest Research Institute University, Dehradun is a record of original research work done by me under the supervision Mr. B.C. Choudhury, Professor, Wildlife Institute of India, Dehradun and it has not formed the basis for the award of any other degree or diploma. I also declare that the thesis embodies the result of my own work and observations and in that respect the investigation appears to advance knowledge in the subject.

Ritu Singh.

Date: 30 August 2007
Place: Dehradun

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Countersigned:

(Mr.B.C.Choudhury)
Supervisor

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CERTIFICATE

This is to certify that the thesis entitled **"Assessment of hydrological functions and water budget of Keoladeo National Park"** submitted for the award of Doctor of Philosophy in Forestry (Forest Ecology & Environment) to Forest Research Institute University, Dehradun is a record of original research work done by Ms. **Ritu Singh** at Wildlife Institute of India, Dehradun under my guidance and supervision. I further certify that this research work has not previously formed the basis for the award of any other degree or diploma and it fulfils all the requirements laid down in the Ordinance governing award of Ph.D. degree of Forest Research Institute University.

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The Study Rationale

Keoladeo National Park (KNP) is situated in the plains of Bharatpur (27°7'6"N – 27°12'2"N and 77°29'5"E – 77°33'9" E), Rajasthan, India. It is considered to be the last remaining grassland- wetland complex in the Yamuna floodplains in this region. The wetland Protected Area (PA), located in the semi-arid tract of India is largely dependent on the erratic and short duration of the precipitation time. To enhance the wet characteristics of the protected area, additional water supply provisioning has historically been made from other large water harvesting structures within its watershed. However, due to the development of intense agriculture in the watershed and increased or incessant harvesting of surface water flow in the river systems and catchment combined together, the protected area is facing an acute water problem gradually decreasing the wet regime of its wetlands, this is also further diminishing its functional values.

Over the past few years the crisis of and conflict over availability of surface flowing water and its distribution in the KNP watershed has gained mammoth proportions. The national park originally received water from the catchments of two rivers- the Gambhir and the Banganga. However, the Banganga has been dry for a long period of time and waters of the Gambhir have been dammed at Panchana recently and Baretha & Jagar previously (see map). As a result the water provisioning to KNP has been reduced drastically. In such a scenario, for better management of the national park it becomes imperative to understand the basic hydrological dynamics within the park and also in the region as all wetlands are dependent on the landscape or the watershed for realising its characteristics. In case of KNP, as it is located in semi-arid region and fed by ephemeral rivers, the affects of water crisis are acute as well as immediate in the Park. Further, the wetlands of KNP perform several important hydrological functions like groundwater recharge that have value not only for sustaining the ecology of the region but also for the surrounding villagers in the area in providing water for irrigation. These functions and values of the national park need to be highlighted. The present study is an assessment of the current situation of hydrological regime of KNP and the watershed.

Objectives

The main goals of the study are:

- to ascertain water budget of the Keoladeo National Park,
- to identify hydrological functions of the Keoladeo National Park wetland based on Hydrogeomorphic approach,
- to assess the functional value of the wetland and its role in maintaining water table and contributing to quality and quality of groundwater in areas adjacent to the Keoladeo National Park
- to know the impact of the hydrological regime on the biodiversity of the Keoladeo National Park

The hydrogeomorphic approach essentially is based on three fundamental factors that influence how wetlands function: position in the landscape (geomorphic setting), water source (hydrology), and the flow and fluctuation of the water once in the wetland (hydrodynamics). (*Here it is important to note that we are not attempting to classify KNP wetland according to the HGM classification system developed by Mark.*

M. Brinson (1993; Wetlands Research Program Technical Report WRP-DE-4 of US Army Corps of Engineers) being followed in the USA; only using the HGM approach to study the hydrological dynamics of the wetland and its watershed.)

INTRODUCTION

Paleobotanical and Historical Perspective on Keoladeo National Park Wetlands:

Paleobotanical studies trace a 26,000 year history when this area was a large open water lake that subsequently went through four dry phases finally becoming a marsh land. (Sharma & Chaterjee, 2007). The fort and the city of Bharatpur were founded by Suraj Mal in 1732 A.D at an already built Fatehgarh fort in early 18th century. The fort was surrounded by low-lying marshes. Two dams were commissioned to prevent flooding and to provide succour in times of famine (Singh, 1981). One of these two dams have formed the present day Moti Jheel that is used to accommodate rain water runoff from northern Bharatpur and also flood water of the Ruparail river. The second dam commissioned by Suraj Mal is the Ajan Bandh that used to contain the runoff as well as flood from the Banganga. Earliest written records note Bharatpur as a fort city surrounded by marshes which not only protected it from enemies but were home to feral cattle and received unusually large number of waterbirds in winters. This area used to get inundated by waters of Banganga every year in the monsoon season and as the terrain is flat, not directly draining into the Yamuna, a system of wetlands and grasslands has evolved. Present day Keoladeo National Park is a remnant of the same.

STUDY AREA

Geomorphological setting of Bharatpur

KNP lies at the western edge of the gangetic plain in floodplains of Banganga river in Bharatpur district of Rajasthan, India. Bharatpur consists of vast alluvial plain with several depressions. The Bharatpur district forms a part of eastern Rajasthan plains lying east of the Aravalli hill ranges. Most of the area of the district is occupied by alluvial plains which form part of the Banganga and the Gambhir river basin. KNP encompasses a slight depression within the plains- the height of ground level varying from 174 m to 178m above mean sea level (AMSL). General slope of the area is easterly towards river Yamuna. There is a slight gradual fall in ground level from north towards the City of Bharatpur. In the district there is a central alluvial ridge separating Gambhir River Basin from Banganga River Basin (CGWB, 1997).

Drainage and Watershed

All the major rivers in the district orignate from outside the district and are ephemeral. Banganga originates in Jaipur district in the Aravalli hills. It has an easterly flow and disappears in the sandy track near Ghana before meeting any big river. The Gambhir originates in Karauli district in the Vindhyan ranges, enters Bharatpur in southern part and passes to Uttar Pradesh to join river Yamuna. River Ruparial originates from the Thanagazi hills in Alwar district, enters Bharatpur district near Gopalgarh and is dammed by Sikri bandh. Thus, it is of no consequence to drainage and hydrology of Keoladeo National Park today.

HYDROLOGICAL FUNCTIONS

The landscape is limited to the areas upstream of KNP in the Banganga and the Gambhir river basins. Keoladeo National Park is a surface water depression wetland. As it exists in a depression, it is hydrologically and ecologically a ‘sink’. Hydrologically, there are no surface water outflows. Ecologically, the outflows are essentially biomass extraction, an important wetland function and value. Such areas receive surface water inflows only, there are no groundwater inflows. Water outflows are through infiltration and evapotranspiration. Infiltration is the process that leads to groundwater recharge that maintains a high water table in and around Keoladeo National Park.

Utilization of groundwater in the surrounding areas also has profound effect on the hydrology of a wetland. Often a cone of depression is formed under the influence of high capacity wells. Hydrologic functions include the capacity of wetlands to reduce and desynchronize peak flood discharge, influence baseflow, modify groundwater-surface water interactions, and stabilize shorelines (Lewis, 1995).

Wetlands, depending on their position within the watershed or the landscape perform various functions. Wetland functions are subject to the hydrological flux through the wetland system. Hydrology is probably the single most important determinant for the establishment and maintenance of specific types of wetland and wetland processes (Mitsch & Gosselink, 1986).

As KNP is a semiarid, monsoonal wetland, it essentially performs two important functions i.e., flood mitigation and groundwater recharge. In case of local floods, the Park absorbs excess water that otherwise would flow in the surroundings and helps in mitigation of flood damages in Bharatpur region. That the wetland stored flood waters is proved by records mentioning that waters of the Banganga remained stored in 'ghunna', that efforts were made to keep wild cattle inside this private preserve by erecting a fence as early as prior to 1887. (National Archives Record # F.D /Intl. B/ July 1887/ Nos 402-409).

To study the role of Keoladeo National Park marshes in maintaining water table of the area by aquifer recharge, the water table in and around the wetland were noted over three years, May 2002 to April 2005. Significant variation in rainfall and water inflow from the watershed was observed during these three years. The recharge is seen only after monsoon of 2003 as then the wetland received water from Ajan bund. This water was retained, albeit in small pools till March 2004. The general trend observed through this graph is that (a) water table gradually falls as the distance from the wetland increases and (b) while recharging, the water table rapidly rises during monsoon months and continue to do so until late October or November, reaches a plateau during the post-monsoon months and rapidly falls during drawdown months of January-March. This is followed by gradual fall during pre-monsoon months of April-June. The results show that ground water recharge, in case of Keoladeo National Park is a function of retention time of water in the wetland and is not dependent on rainfall, making this critically important to be shared with the villagers as water in Keoladeo National Park is not only good for this wetland but for their socioeconomic utilization.

Water Budget

The water budget has been calculated based on: -

a) ecological and management needs - this includes assessment of water holding capacity of the wetland, calculated from a countour map and evapotranspiration.

b) management needs- these are essentially same as above

c) stakeholder needs (visitors/ tourism/ vilagers etc.)- assessment of groundwater withdrawal by surrounding villages due to which there is faster movement and loss of water from the wetland. Excessive pumping in the surroundings leads to quicker and early drawdown and drying of the wetland.

Water budget is basically a routing procedure that sums the water inputs into a wetland area, the outflows, and the storage, based on this equations have been drawn (WRP Technical Note HY-EV-2. 1; January 1993; US Environment Protection Agency & MDOT Drainage manual).

This is expressed by the following equation:

$$P + SWI + GWI = ET + SWO + GWO + dS/dt$$

Where,

P = Precipitatipn

SWI = Surface water inflows

GWI = Ground water inflows

ET = Evapotranspiration

SWO = surface water outflows

GWO = Ground water outflows

dS/dt = Storage

Infiltration- accounting for groundwater inflows was calculated using double ring infiltrometers during April-May 2002, for calculating evaporation from open water surface pan evaporation rates were recorded using a standard I.S.I pan evaporimeter specified by IS-5973-1970 which is also know as *modified class A pan.* For actual evapotranspiration (AET) phytometers seeded with wetland soils were established. Water utilized by the vegetation was measured and averaged for daily utilization (2003-2004) and water storage capacity of wetland was calculated using a 0.5 m contour map based on dumpy level survey of the area (source: Office of Director, Keoladeo National Park) were examined. It was observed that infiltration/ groundwater recharge and evapotranspiration form major components of water outflow from the wetland and supplementation are the major sources of inflows, though rainfall also contributes to the water budget it is not as significant.

As Keoladeo National Park is a semi-arid depression monsoonal wetland, the inflows are in the form of precipitation (P) and surface water inflow (SWI). There are no surface outflows from this wetland (therefore, SWO= 0). Groundwater inputs to a site depends on the hydrogeology of a wetland. In case of Keoladeo National Park it is nil as the wetland is situated in a depression and the water table in much lower in the region, the groundwater does not flow into the wetland. As it is a depressional wetland in a semi-arid region and the geology of the region is such that the sub-terrain is alluvial, the unconfined aquifer is much lower than the ground surface, this wetland has no groundwater inflow, but groundwater outflows only (GWO). Other significant outflows are in the form of evaporation from open water and evapotranspiration from the vegetated parts of wetland. The water budget equation adopted for Keoladeo National Park's situation, therefore, is:

$$P + SWI = ET + Ew + Es + GWO + S$$

Where,

P = Precipitation

SWI = Surface water inflows

ET = Evapotranspiration

Ew = Evaporation in winter

Es = Evaporation in summer

GWO = Groundwater outflows

S = Storage

This may further be expanded to the following

Precipitation + Supplementation = ET + Ew + Es + IC + IR + S

Where,

Supplementation = Surface water inflow (SWI)

IC (Infiltration capacity) + IR (Infiltration rate) = Groundwater outflows (GWO)

Components of water requirements are:

Component of water budget	**Volume in Million Cubic Meters (MCM)**
Storage (S)	7.132
Recharge from ecotone (fringe around the 176m contour)	0.5
Infiltration capacity(IC)	3.029
Infiltration rate (IR)	3.814
Evapotranspiration (ET)	2.984
Evaporation during winters (Ew)	0.066
Evaporation during summer (Es)	0.612
TOTAL in MCM	18.138

Of this about 5 MCM is provided by rainfall, therefore, supplementation from Ajan bund required is about 13 MCM.

Water Management

Hydrologic connectivity to the rivers and their watershed is the primary reason for development of ecology of the wetlands. In case of Keoladeo National Park the wetland, annually depends on the flow of fish fry, vegetation and other organic matter from the river for development of characteristic ecology, and related heronry, hosting of migratory waterfowl etc. A large body of evidences has shown that the natural flow regime of virtually all rivers is inherently variable, and that this variability is critical to ecosystem function and native biodiversity. Rivers with highly altered and regulated flows lose their ability to support natural processes and native species. Thus, to protect pristine or nearly pristine systems, it is necessary to preserve the natural hydrologic cycle by safeguarding against upstream river development and damaging land uses that modify runoff and sediment supply in the watershed (LeRoy Poff et. al., 1997).

High biodiversity in KNP developed due to its connectivity with the river. In absence of flow in the river, the perennial pools supporting large variety of fish diversity will be lost, as also the movement of fish to Ajan Bund to Keoladeo National Park. Further, organic matter, invertebrates that contribute to the richness and characteristics of the park would also be lost. It is evident that the ecological integrity of the park relies on its hydrological connectivity with the Gambhir river. However, as is always the case in water disputes in a water stress regions human needs are usually placed above the needs of animals.

The total runoff from Gambhir river basin is 573.64 MCM while water requirement of Keoladeo National Park is 18.12 MCM. Therefore, Keoladeo National Park's total requirement is 3.12% of the total runoff from the basin which is only a fraction. Of this, some is met with the rainfall in the natural regime. Remaining requirement in a normal monsoon year is 2.28% of the total runoff of the Gambhir river basin.

CHAPTER 1

WETLAND HYDROLOGY IN THE CONTEXT OF KEOLADEO NATIONAL PARK AND THE PRESENT STUDY

Hydrology of the region determines the functions and values of a wetland complex. Hydrology controls abiotic and biotic characteristics of wetlands. Abiotic characteristics such as soil colour, soil texture, and water quality depend on the distribution and movement of water, as do abundance diversity, and productivity of plants, vertebrates, invertebrates and microbes (Lewis,1995). Hydrologic conditions are extremely important for maintenance of wetland's structure and function, although simple cause and effect relationships are difficult to establish. Hydrologic conditions affect many abiotic factors, including soil anaerobiosis, nutrient availability, and salinity in costal wetlands (Mitsch & Gosselink, 1993). These, in turn, determine the flora and fauna that develop in a wetland. Finally, completing the cycle, biotic components are active in altering the wetland hydrology.

1.1. Wetland Hydrology- A Review of Literature

Hydrology is probably the single most important determinant of the establishment and maintenance of specific types of wetlands and wetland processes. (Mitsch & Gosselink, 1993). Hydrology primarily affects chemical and physical aspects of the wetland, which, in turn, affect the biotic component of the wetland ecosystem. Mitsch and Gosselink (1993) have propounded several principles stating the importance of hydrology in wetlands. These principles are: a) hydrology leads to a unique vegetation composition but can limit or enhance species richness; b) primary productivity and other ecosystem functions in wetlands are often enhanced by flowing conditions and a pulsing hydroperiod and are often depressed by stagnant conditions; c) accumulation of organic material in wetlands is controlled by hydrology through its influence on primary productivity, decomposition and export of particulate organic matter; d) nutrient cycling and nutrient availability are both significantly influenced by hydrologic conditions. Keddy (2000) equates water level fluctuations in wetlands to forest fires. They eliminate one growth form of vegetation (e.g., woody plants) in favour of another (e.g., herbaceous species) and allow regeneration of species from buried seeds.

When hydrologic conditions in wetlands change even slightly, the biota may respond with massive changes in species composition and richness and in ecosystem productivity. Hydrology affects species composition and richness, primary productivity, organic accumulation and nutrient cycling in wetlands. Generally, productivity is highest in wetlands that have highest flow through of water and nutrients or in wetlands with pulsing hydroperiods (Mitsch & Gosselink, 1993). When the hydrologic pattern remains unchanged from year to year, a wetland's structural and functional integrity may persist for many years. In a study in southern Everglades, Florida, USA, an ordination analysis, based on plant species abundance, revealed that plant species abundance in study area was associated with hydrologic patterns. Marsh plant community structure showed evidence of cyclic inter-annual variation corresponding to hydrologic change over the decade evaluated. Lower water depths, the occurrence of marl substrates, and high periphyton cover were correlated. These factors contributed to reduced macrophyte cover in portions of study area from which water had been diverted (Busch et. al.,1998). A study undertaken to determine the relationship between vegetation cover type and length of saturation, water-level fluctuations over time were analysed in freshwater swale wetlands on lower Hatteras Island, North Carolina, USA. It was found that areas dominated by herbaceous vegetation had significantly longer flooding regimes than areas dominated by shrubs (85-95% vs. 12-69% of the growing season respectively). Only 22-25 cm elevation differences were found to separate emergent marsh from the various shrub cover types, suggesting that lowering mean water-level via drainage has likely been responsible for shrub swamps replacing emergent marsh in these wetlands (Rheinhardt and Faser, 2001). Bledsoe and Shear (2000) describe the vegetation of two alluvial swamp forest stands along Durham Creek in Beaufort County, North Carolina, USA, in relation to elevation, hydrologic and edaphic gradients. The two stands had very similar annual surface flooding regimes, but subtle differences in growing season flooding frequency, soil characteristics, and disturbance history have apparently resulted in dissimilar plant community composition and structure. An elevation difference of as little as 10 cm resulted in 20% difference in the frequency of surface flooding during the growing season. Species distributions were significantly correlated with depth to mottling, flooding frequency, elevation and several soil chemical properties.

Internal drainage in arid and semi-arid regions often gives rise to wetland complexes. In many areas in western North America, flood irrigation for hay production has created many wetlands in the Laramie Basin, Wyoming. Snow-melt from surrounding mountains is distributed throughout semiarid intermountain basin, creating complexes of wetlands across the landscape that otherwise would not exist. More efficient irrigation would affect not only the number and area of wetlands, but also the relative abundance of different wetland communities. However, given the dramatic reductions in water applied to the fields (>50%), such changes would affect total area and proportions of wetland types far more than annual variations in snowpack. Different irrigation practices have contrasting effects on a range of wetland types. These effects will change seasonally to impact different organisms with varying life histories, flooding requirements and salinity tolerance. Considering such complex factors in irrigation management is key to maintaining the entire range of wetland communities, whose integrity is closely tied to both positive and negative effects of irrigation (Peck and Lovvorn, 2001). Plant communities of tidal freshwater marshes fluctuate in composition seasonally and among years under the influence of changes in hydrology. The effects of hydrology on vegetation of tidal freshwater marshes along the Patuxent River in Maryland, USA, in field and greenhouse experiments showed that lowering marsh sods (marsh soil and vegetation) by 10 cm (i.e., water conditions) reduced plant species richness by 26% compared to the sods placed level with marsh surface, while raising sods by 10 cm (drier conditions) increased richness by 42%. Total stem length of a majority of the most common species, as well as, for all species combined was more than twice as great in raised sods as in lowered sods. These findings suggest that hydrology is a dominant environmental variable controlling inter-annual variation in plant species composition of tidal freshwater marshes (Baldwin et. al.,2001). In Keoladeo National Park, it was recorded that for all vegetation types, the biomass changed seasonally in response to changing water levels and temperature. After the 1986 monsoon (poor monsoon), above-ground biomass for all vegetation types was much lower than it had been after 1985 monsoon. Mean below ground biomass was very low in all vegetation types. *Paspalum distichum* had higher above ground biomass at nearly all water depths in all seasons than in the pre 1982 vegetation types. During the years with average monsoon, the overall primary production of these wetland was estimated to have increased 2.5 to 3.5 fold since they have overgrown with *Paspalum distichum* (van der Valk et. al.,1993). Another study at Keoladeo National Park demonstrated that aquatic plants of Indian monsoonal wetlands have different inherent abilities to survive and grow after clipping, their tolerance depends on the water depth at which the plants are growing and the amount of clipping the plants receive (Middleton, 1990)

Just as many other ecosystems exert feedback (cybernetic) control on their physical environments, wetland ecosystems are not simply passive to their hydrologic conditions. The biotic components of wetlands, mainly vegetation, can control their water conditions through a variety of mechanisms, including peat building, sediment trapping, nutrient retention, water shading, and transpiration (Mitsch & Gosselink, 1993).

The biotic component of a wetland also can affect hydrology by increasing or decreasing water level or flow (Lewis,1995). In a study of Cypress wetlands in Florida, USA, and effect of clear-cut harvesting on hydrology were studied by Riekerk and Korhnak (2000). The poorly drained pine flatwoods of the Lower Coastal Plain of the Southern United States contain many pond cypress (*Taxodium ascendens*) wetlands, which cover about one-third of the area. Management of the resource includes pine silviculture and cypress harvesting for lumber, plywood, paper and mulch. The results showed that openwater evaporation after wetland harvesting exceeded evapotranspiration of the control, explaining in part a decrease in outflow after wetland harvesting. Increased run-off from the pine upland, generated by reduced evapotranspiration and expanded saturated areas after clear-cut harvesting, apparently was buffered to some extent by increased evapotranspiration from the embedded clear-cut cypress wetland. The average openwater area was about 50% larger than the wetland area as defined by the vegetation. The application of this information in water management is for better control of first-year run-off from the pine-cypress landscape as a whole (Riekerk and Korhnak, 2000).

Vijayan (1991) budgeted the water balance of the Keoladeo National Park following mass balance relations of inputs and outputs. Surface inflows during 12 out of 24 years (1966 to 1990) were 14X10^6 m^3 or above. The highest inputs from rainfall (4.38 X 10^6 m^3) were recorded in 1985. The highest water storage recorded in 1984 was 10.36 X 10^6 m^3. Evapotranspiration losses in May 1984 were 2.99 X 10^6 m^3 and infiltration losses were estimated by balancing the water budget equation. Average loss by subsurface outflows was approximately 20% of total outflow.

The hydrologic boundary of a particular wetland is different from the hydrologic boundary of the watershed that contains it. The wetland is that locus of points in which the water balance produces enough saturation to maintain substrate and biota that are characteristic of wetlands. In contrast, the watershed that contains the wetland typically includes upland areas that share a common drainage pathway with the wetland. The wetland boundary might change over time as a complex function of factors that control the balance of terms in the water budget for the entire watershed (Lewis Jr., 1995).

The hydroperiod or hydrologic states of a given wetland, can be summerised as being a result of the following factors:

i. Balance between inflows and outflows

ii. Surface contours of the landscape

iii. Subsurface soil, geology and groundwater situation.

The first condition defines the water budget of a wetland, whereas, second and third condition defines the capacity of the wetland to store water (Mitsch & Gosselink, 1993). A wetland's hydroperiod integrates all aspects of its water budget (rainfall, evapotranspiration, runoff from adjacent areas, flooding, net seepage of ground water). A major technical challenge is to determine an average or characteristic hydroperiod for sites for which there are no hydrologic data, or for which hydrologic data cover only a short interval (Lewis Jr., 1995). Surface water depression wetlands loses water only through infiltration into the ground and through evapotranspiration (Mistch & Gosselink, 1993). Groundwater recharge is defined as the rate of replenishment of the water table. This rate of replenishment is the essential parameter one needs to know for sustainable development of the groundwater resource (de Silva, 1999). Groundwater is one of the most important components of wetland hydrology, both for qualitative and quantitative purposes, but probably, it is also one of the most difficult components to quantify (LaBaugh et. al. 1986). Interaction between a wetland and its surrounding aquifer was studied in Rochefort agricultural marsh (150 km^2) on French Atlantic coast. The natural discharge volume represents only 20% of the artificial freshwater injected each year into the wetland to maintain the water level close to soil surface. Understanding and quantifying the groundwater component in wetland hydrology is crucial for wetland management and conservation (Weng et. al., 2003). In Cypress wetlands in Florida, USA, Sun et. al. (2000) recorded "groundwater levels significantly elevated (i.e., by about 32-41 cm on average), and outflow doubled in the five month dry period immediately following tree harvesting. Groundwater table in upland was also raised by about 29 cm on average due to wetland and upland tree harvesting. This study suggested that evaluating effects of forest harvesting on flatwoods hydrology, a ground water and evapotranspiration dominated 'storage based' system must consider short term (e.g., seasonal) climatic variability".

In many wetlands evapotranspiration is the most important output flux accounting for upto 100% of annual water losses. Evapotranspiration rates were recorded to be as high as 0.672 cm per day in wetland of Cottonwood Lake area of North Dakota, USA (Parkhurst et. al., 1998). The effects of different disturbance histories, specifically patterns of ditching and drainage on wetland evapotranspiration rates for two sites within Indiana Dunes National Lakeshore, Indiana, USA, were studied and results showed that when standing water is present at each site there is very similar flux partitioning (3.5 mm d^{-1}). When the disturbed site has no standing water, evapotranspiration rates are maintained at the same level (3.5 to 3.77 mm d^{-1}). Difficulties in accurately calculating evapotranspiration in wetlands can lead to inaccurate water balances. Simple meteorological methods or off-site evapotranspiration data are often used to estimate evapotranspiration, but these approaches do not include potentially important site specific factors such as plant community, root zone water levels, and soil properties. A study was carried out to compare a commonly used meteorological estimate of potential evapotranspiration (PET) with direct measurements of evapotranspiration (lysimeter and water table fluctuations) and small scale root zone geochemistry in a natural and constructed wetland system. Unlike what has been commonly noted, the results of the study demonstrated that the commonly used Penman combination method of estimating PET underestimated evapotranspiration that was measured directly in natural wetland over most of the growing season. The result is likely due to surface heterogeneity and related roughness effects not included in a simple PET estimate (Lott and Hunt, 2001). Although penmen equation method is the most widely used method for estimation of potential evapo-tranpiration, there are wide variations therein as compared actual evapotranspiration. Earlier studies of evaporation rates from the Ham Wall reed bed in Somerset, using a Bowen-ratio station, (Gilman et al., 1998) indicated that from April to July, evaporation rates were some 5% less than the potential rate (Penman, 1948). This increased to 20% greater than potential in August but fell to around 7% greater in September. These measurements were undertaken when the reeds were first planted and short and might not reflect evaporation rates from fully grown (> 3 m) reeds (Acreman et. al., 2003). Smid (1975) in his paper has collated information from various researchers to present evapotranspiration rates of different wetland plants, *Typha angustifolia* and *Lemna gibba* have 10-12 mm, *Phragmites communis* 17.9 mm and 27.8 mm at two sites, and *Cyprus papyrus* 6.0mm per day.

Transpiration is the process by which the water leaves a living plant, through its leaves, to enter the atmosphere as water vapour. Large amount of water, much more that what is really consumed by the plant, is thus, given away by the plant to the atmosphere. The ratio if the moisture thus transpired by a plant to the atmosphere, to the actual moisture consumed in its nourishment, may be as high as 800 or more. The moisture consumption in actual nourishment for building plant tissue, during its metabolic process, is thus, negligibly small, and hence, generally ignored. Heavy quantities of water from the surface of the earth are, thus, lost by trees, plants and other vegetation through transpiration, and hence, transpiration constitutes an important part of the hydrologic cycle. In addition to transpiration, water is also lost during the growth of plant by evaporation from soil body and or water body surrounding the plant. Since in the process of vegetation growth it is generally not feasible to separate the transpiration as its connected evaporation from plant's surrounding, a combined measure is obtained and is called evapotranspiration. When sufficient moisture is freely available to completely meet the needs of vegetation fully covering an area, the resulting evapotranspiration is called potential evapotranspiration (PET). The real evapotranspiration, occurring in specific situation in field is called actual evapotranspiration (AET).

There are several methods available to predict evapotranspiration. They vary in difficulty of application and accuracy. Either physical methods or climatological based methods can be used to compute evapotranspiration. The Penman-Monteith equation utilises energy balance equation to compute ET. Climatologically based methods rely on temperature reports and requires straightforward computations. The Tornwaite-Mather method is a very commonly used method. The commonly used ET equations have essentially been developed for agriculture areas. Although Penman equation method is the most widely used method for estimation of potential evapotranspiration, there are wide variations therein as compared actual evapotranspiration. The penman method assumes that the evaporating surface is short grass of uniform height, completely shading the ground, actively growing, and adequately supplied with water to compute reference Potential Evapotranspiration (PET $_{ref}$) (Gasca-Tucker et. al., 2007). It is because of these assumptions that the values generated through computation vary immensely with respect to the actual values and may not be universally applicable to all wetland types in different climatic zones. Where PET estimates alone are used as input evaporation data, during conditions of surface saturation, actual evaporation from the grass canopy may be underestimated by more than 50% while under dry conditions the method will overestimate evaporation (Gasca-Tucker et. al., 2007).

As PET is calculated based on empirical methods ctritically dependent on climatologically factors, rather than on characteristics of plants or soil it tends to vary widely with AET which is largly affected by soil conditions and vegetation factors.

During dry climatic periods, the rate of water inflow to the wetland may greatly diminish. In this instance, the amount of water lost through evapotranspiration may exceed the rate of all water inflow to the wetland. The water losses through evapotranspiration can result in extreme declines in the water table and a desaturation of the wetland, as is observed in Keoladeo National Park and detailed in the previous chapter.

Hydrology and hydroperiod of a wetland determine its characteristics as well as extent of functional process that fall under the following broad categories:

- Hydrologic
- Biogeochemical
- Life Support

Hydrologic functions include flood control, aquifer recharge, shore line stablisation, maintenance of base flows in rivers etc. Biogeochemical functions a related to nutrient transformation, sediment stablisation and improvement of water quality. Life support functions include provision of habitat for wild life, production of biomass etc. Hydrologic conditions are so important in defining wetlands that they are often used by scientists to classify these ecosystems. Classification and mapping of wetlands based on biotic features often matches the hydrologic conditions of the different wetlands very well.

In their paper titled 'Role of wetlands in the hydrological cycle' Bullock and Acreman (2003) have drawn a database from 169 publications to present an ordered database of published papers on hydrological functions of wetlands, provide a collation of scientific evidence among hydrological measures and wetland type, and to stimulate debate and further research. The focus of the paper is limited to water quantity functions, including impacts on water resource availability, groundwater replenishment and flood control. The main conclusions of the analysis are as following:

1. Wetlands are significant in altering the water cycle. 169 scientific studies published during 1930-2002 (as traced by the paper) provide 439 statements on hydrological significance of wetlands. Of 439 statements, only 83 (i.e., 19%) statements have concluded that wetlands' influence on water cycle had been neutral or insignificant. The vast majority of researchers have concluded that the wetlands either increase or decrease a particular component of the water cycle.

2. There are some significant generalisations that emerge from the published hydrological evidence. These are different from the long standing generalisations that wetlands always reduce floods, promote groundwater recharge and regulate river flows. Most (but not all) studies (i.e., 23 of 28) have shown that floodplain wetlands reduce or delay floods, with examples from all regions of the world. The same influence on floods was also seen, but less conclusively (i.e., 30 of 66) of wetlands in headwaters of river systems (e.g., bogs and river margins).

3. evaporation of water from wetlands is more water than other land types, such as forests, savannah grassland or arable land. Two thirds of the studies (48 of 74) concluded that wetlands increase average annual evaporation or reduce average annual river flow . About 10% of the studies (7) have concluded the opposite; for example some woodlands in Zambia had greater evaporation than the adjacent wetlands. The remaining 25% are neutral.

4. Two-thirds of studies (i.e., 47 of 71) have concluded that wetlands reduce the flow of water downstream rivers during dry periods. Evidence is mainly from North America and Europe, but includes floodplains in Sierra Leone and wetlands in Southern Africa. This is backed by overwhelming evidence (22 of 23 studies) that shows evaporation from wetlands to be higher than from non-wetland portions of the catchment during dry periods. There is no discernible difference for different wetland sub-types. In 20% of the cases, wetlands increase river flows during the dry season.

5. Many wetlands exist because they overlie impermeable soils or rocks with little interaction with groundwater. The database contains 69 statements

referring to groundwater recharge; 32 statements include merely that recharge takes place and 18 statements conclude that there is no recharge. There are similar number of studies that report wetlands either to recharge more (i.e., 6) or less than (i.e., 9) other land types. ***Some wetlands, such as floodplains on sandy soils in India and West Africa, recharge groundwater when flooded.***

6. Conclusions have been drawn on flow variability. The over riding picture appears to be a reduction in flood peaks by floodplains. In some cases, such as many headwater wetlands, increasing flood flow combines decreasing dry season flows to widen the overall range.

In Africa, numerous floodplain wetlands provide a host of hydrologic, ecologic, economic and social benefits. They play a fundamental role in supporting significant human populations. In common with all wetlands, the hydrology of Africa's floodplains is central to their functioning and in turn plays a key role in determining the benefits that they provide. Impacts of hydrology upon human activities and land use in the Hadejia-Nguru Wetlands of northeastern Nigeria were studied. The timing of different cultivation practices in wetlands was shown to be in tune with the annual flood cycle. Rice is cultivated in inundated areas that were then planted with other crops after the flood recede. The intensity of fishing and cattle grazing also varied with the pattern of rising and falling water levels. The distribution of major land-uses was observed to be strongly influenced by spatial variations in hydrologic characteristics. Modifications to the hydrologic characteristics of some parts of the wetlands resulting from drought and upstream irrigation schemes have required local communities to adapt, with varying degrees of success, their modes of floodplain resource use. Farmers along Burum Gana have embraced small scale irrigation, while those along the Keffin Hausa River, which has all but dried up, have had no option but to concentrate on rain-fed agriculture. The strong inter-connections between hydrology, land use and human activities dictate that any further hydrological modifications should not be undertaken without a full appreciation of their potential impact (Thompson and Polet, 2000). The impacts of changing land use on hydrology and dominant plant species from 1850 – 1990 were investigated in palustrine wetland in southern Wisconsin, USA by Owen (1999). The hydrologic budget of the wetland was dominated by precipitation and evapotranspiration, although overland flow into the wetland from the sub-watershed had increased twenty fold since 1850. Water level stabilization in the adjacent river, creek channelization and groundwater extraction have decreased inputs of groundwater and spring fed surface water, and increased retention of precipitation. *Typha* spp. and *Phalaris arundinacea* L. have increased in the wetland, while *Carex* spp. have decreased. *Typha* spp. dominated in several hydrologic settings, indicating that water depth was not the only factor controlling its distribution. The distribution of dominant plant species in the wetland were most closely correlated with site elevation and average water levels, with some weaker correlations with vertical groundwater inflows and specific conductance.

Results of long-term field studies of wetlands in four different hydrogeologic and climatic settings in the United States indicate that each has considerably different sources of water, which affects their response to climate variability and land use practices. Mirror Lake fen provides an example of a wetland that is essentially created and maintained by seepage from a nearby surface-water body. The wetland depends almost entirely on the lake for its source of water. The very permeable aquifer that connects the two results in a very short residence time for the lake water to be in contact with minerals enroute to the fen. Therefore, management of Mirror lake fen would require management of Mirror Lake in terms of both lake-level maintenance to maintain the water supply as well as for water chemistry to maintain the present ecosystem of the fen. In contrast, the principal source of water to Little Singobee Fen is affected by a complex hydrogeologic setting, because of which, its management would require management of the groundwater recharge area east of the Singobee river and of the intervening deep flow system that underlies the local flow system associated with the Singgobee river. Third, the case of prairie-pothole wetlands in North Dakota, present and extreme opposite of the fens, these wetlands depend almost entirely on precipitation for their water supply. Therefore, the only way to manage their water volume is to prevent them from draining. Finally, the lake and wetland complex in the Crescent Lake NWR in Nebraska presents yet another variation, although the stage of these water bodies show a relationship to precipitation, the moderating effect of the extensive groundwater system associated with them results in more gradual changes overtime compared to the prairie-pothole wetlands in North Dakota. In the case of these lakes and wetlands, their water source is a combination of seepage from upgradient lakes and groundwater recharge between the lakes in this huge ground-water reservoir. Therefore, managing the water source of lakes in the sandhills depends on managing groundwater development- the major threat to water source of lakes and wetlands is pumping and exporting large volumes of groundwater from their immediate vicinity (Winter et. al.,2001).

Wicken Fen in East Anglia, UK, is a unique habitat and a wetland of international importance (Cooper et. al.,1998). The fen is ‘drying’ and there may be a number of reasons for it. As a result of three centuries of drainage and arable agriculture, peat shrinkage in the surrounding fields means that the fen is upto 2m higher than the adjacent farmland, much of which is at of below mean sea level. Second, a comparison of two series of water table measurements made between 1928-1930 and again between 1974 and 1976 indicate that, even allowing for differences in rainfall, summer minimum water levels in the 1970s were approximately 300mm lower than they had been earlier in the century. For conserving the fen one possible method is irrigating by surface flooding; the filling of internal ditches until they spill, thereby spreading water over the fen surface. The timing of such flooding would be very important. Another possible approach is maintenance of high summer water levels in denser ditch network. Historically, there have been more ditches in the fen than that at present. Detailed understanding of hydrological functioning is required if water management for conservation is to be successful (McCartney & Hera, 2004). A 63 ha fen in the southern Rocky Mountains, USA, named Big meadows in Rocky Mountain National Park, was ditched for agricultural purposes in early part of the century. Although use of the ditch ceased after the establishment of Rocky Mountain National Park in 1915, it continues to intercept sheet flow in the central and southern portions of the fen causing groundwater level to decrease and aerobic soil conditions to develop in mid- to late summer of most years. In 1990, the ditch was blocked in an attempt to restore hydrologic regime in the fen. In post-restoration year with extremely low rainfall in July and August, water levels throughout the fen decreased to levels similar to those in pre-restoration period. This study suggests that this and other fens in the southern Rocky Mountains are extremely sensitive to summer precipitation and the hydrologic changes created by even small ditches and water diversion (Cooper et. al.,1998).

1.2. Rationale for The Present Study

Hydrology, affects all other processes of a wetland, and is in turn affected by certain attributes of the wetland. Wetland hydrology and vegetation are closely linked, and most wetland functions rely on their interaction. However, understanding how hydrology controls wetland ecosystems is often hampered by the complex nature of this interaction and sparse data (Lewis, 1995). For this reason it becomes imperative to understand hydrology of wetland areas, particularly those of national and international importance like the Keoladeo National Park. Unless we understand the hydrology and related constrains directly or indirectly affecting the wetlands, conserving these important high biodiversity areas would be extremely difficult. Increasing intensive management of water resources through water infrastructure development for agriculture has resulted in extensive interventions in drainage of the region. Dams have been built in the head waters to provide for irrigation demand resulting in severe water crisis in the downstream areas. The natural depressions have dried up and the rivers have ceased to flow for any appreciable length of time. The river Gambhir that earlier flowed for eight months in a year (National Archives record no. F.D./ Intl. B/ Oct. 1893/ nos. 260-261), now barely flows only during heavy rainfall. Historically, the wetlands of Bharatpur have helped in flood control and in maintaining the groundwater table.

Keoladeo wetlands performed a number of important functions that could be categorized under the abovementioned themes and is equally important to all the thre.; The present study limits itself to its hydrologic functions and its direct influence on the physical habitat. For this the following aspects were studied:

- Changes and fluctuations in water availability in natural regime through precipitation
- Supplementation through canals systems
- Other changes in Keoladeo National Park that may have altered its water holding capacity

The study examines drainage of the region, which is, Keoladeo National Park's watershed, spreading over two river basins- that of the Banganga and the Gambhir. This, therefore, includes all the factors contributing to the hydrology of the area, both surface and subsurface. Though the surface water quantum has been documented in the past, the subsurface water regime in totality with surface waters in context of dependency on watershed / catchments had not been documented so far. Over the years the water stress has been increasing for various reasons and River Banganga has been contributing less and less in quantity. Ajan Bund is the single most significant source of water to the Keoladeo National Park, and it, in turn, is fed by the Pichuna canal from river Gambhir and Uchain canal from river Banganga. Over the years, the supply from Uchain has become rare and from Pichuna lesser, raising an alarm for quick action for securing sufficient water for Keoladeo National Park. "Sufficient" in this case is difficult to define. As the water requirement or the water budget of the Park has to be of such quantum that would address the needs of various stakeholders (primary one being Keoladeo National Park itself, other stakeholders include villagers/ agriculture, fisheries, irrigation, tourism etc.).

Presently the water available in the Ajan Bund is being distributed among the Keoladeo National Park and the villages surrounding the Protected Area; in the present study the following are analysed:

- Whether the water distribution is rational?
- What is the shortfall and why?
- If the shortfall is there how it can be met with.
- How it affects the ecology of the wetland.

With increasing demand for water for irrigation, extensive interventions in both river basins have occurred over past few decades. Both the river systems have a number of medium and minor infrastructure in headwater areas. As the drainage of the region is such that these rivers arise in hills and quickly descend to plains, the watershed area downstream headwaters have little to contribute to river flows. During later part of 19th century and early 20th century river Gambhir used to flow for eight months in a year. The river Banganga, though used to flow for shorter duration but had high water flow (National Archives record no. F.D./ Intl. B/ Oct. 1893/ nos. 260-261). Today the Gambhir flows only for a few days in a year if the rainfall is high. Its waters are impounded in Panchana, Jagar and Baretha dams and Banganga remains dry, its waters dammed behind the Jamwa Ramgarh Bandh, Senthal, Arvari and Kalako bunds. In such a scenario it is important to document the role of hydrology in conservation and management of Keoladeo National Park.

1.3 Paleobotanical and Historical Perspective of Keoladeo National Park Wetlands with Special Reference to Hydrology

To study the history of development of Keoladeo National Park as a wetland ecosystem the historical records available at the National Archives, New Delhi were studied in detail, specifically those pertaining to water management of the region. Also old maps were sought from the National Archives and description of erstwhile Bharatpur State in the Imperial Gazetteer of India was studied.

Paleobotanical studies trace a 26,000 year history when this area was a large open water lake that subsequently went through four dry phases finally becoming a marsh land. (Sharma & Chaterjee, 2007). The present day Keoladeo National Park is a wetland well known as an important wintering ground for migratory waterfowl. The city of Bharatpur is situated in the low lying pocket in the saucer shaped topography more or less at the confluence of the waters of the Banganga, the Gambhir and the Ruparail rivers. The fort and city of Bharatpur were founded by Suraj Mal in 1732 A.D at a place 32 Km south-west of Deeg called Soghar after defeating Thakur Khem Karan Singh Sogharia, who had already built Fatehgarh fort in the early 18th century surrounded by low-lying marshes, access to which in monsoon was not easy. Two dams were commissioned to prevent flooding and to provide succor in times of famine (Singh, 1981). One of these two dams have formed the present day Moti Jheel that is used to accommodate rain water runoff from northern Bharatpur and also flood water of the Ruparail river. The second dam commissioned by Suraj Mal is the Ajan Bandh that used to contain the runoff as well as flood from the Banganga. Earliest written records note Bharatpur as a fort city surrounded by marshes which not only protected it from enemies but were home to wild cattle and received unusually large number of water birds in winters (The Imperial Gazetteer of India, 1909).

The main attraction of the region has been the huge number of migratory water birds staging and wintering in the wetlands of Bharatpur where the present day Keoladeo National Park is located. It has been called a man-made/ man-managed wetland by several researchers, and finds repeated mention in literature. However, the present study of historical records proves it to be a natural wetland situated in a natural depression. These records have been referred to and mentioned throughout this document. The history can be traced to the erstwhile Bharatpur state when it was duck-shooting reserve owned by the Maharaja of Bharatpur. That the natural wetland was modified significantly on the lines of duck shoot reserves of Britain around the turn of the nineteenth century is a fact (Anon., 1960). The Imperial Gazetteer of India, 1909 (henceforth, The Gazetteer) states that "besides the usual small game, wild hog (*Sus scrofa*), nilgai (*Boselaphus tragocamelus)* and occasionally wolves (*Canis lapus*) are found in the forest preserves (Ghana), and tigers and leopards in the Bayana and Wer hills. The so called wild cattle, which used to be notorious for their ravages on the crops, have almost all been impounded, a good many of them have been tamed, trained, and sold. **Wild duck are extraordinarily plentiful in the cold season".** The Gazetteer further refers to grazing in 'Ghana'; "there are no real forest but about 98 sq. kms are occupied by fuel and fodder reserves (locally called Ghana and rundh), and the following trees: 'desi babul' (*Acacia nilotica),* 'fards' (*Tamarix orientalis*), 'handi' (*Prosopis cineraria*), 'karel' (*Capparis aphylla*), 'nim' (*Azadirachta indica*) etc. Grasses and wood are supplied for State animals and after the first crop of grass has been cut, the village cattle are allowed to graze on payment of a small fee." These notes clearly refer to a larger area, of which, the present day Keoladeo National Park is a part (see Fig. 2.4). Development of today's Keoladeo National Park as a duck shooting reserve probably happened towards the turn of the century when in 1895 the then ruler Maharaja Ram Singh was ousted, and the management of the state was taken over by the British (Anon., 1960).

Bharatpur region is a flat plain sloping towards east. In the north, west and south it is bound by hill of various branches of northern Aravalli ranges. These ranges are discontinuous and rain/flood waters drain into the plains of Bharatpur. In the north, waters from Alwar region are drained by the Ruparail River, in west from Jaipur by the Banganga River and from south / southwest by the Gambhir River. The present day Keoladeo National Park is remnant of these wetlands and grasslands. A map of Bharatpur district dated 1855 (Fig. 2.4) clearly marks the location of these wetlands and grasslands. It also shows river Banganga, Gambhir and the areas inundated by Banganga. Old British records mention that "there are some valuable reserved woodlands, one of which occupies an area of some 104 sq. kms, and is properly worked for fuel". (National Archives Record no. F.D./Intel. B/ Dec 1890 No. 1-5/ Pg. 4-5). That the wetland stored flood waters is proved by records mentioning that waters of the Banganga remained stored in '*ghunna*', that efforts were made to keep wild cattle inside this private preserve by erecting a fence as early as prior to 1887 (National Archives Record no. F.D /Intl. B/ July 1887/ Nos. 402-409).

Evaluating historical records, historical maps and ecology of the wetland systems it seems that area now occupied by the Keoladeo National Park was a part of a forested wetland dominated by 'kadam' (*Mitragyna parviflora)*. However, there were also deeper depressions having open water lakes as well as grasslands. These areas were privately owned by the Maharaja of Bharatpur and system of resource sharing existed wherein the fodder was first extracted for cattle of the royal farms and then local people were allowed to graze their cattle in the 'rundhs'(The Imperial Gazetteer of India, 1909). A 'rundh' is a grazing land for cattle in the local colloquial language.

The present day Park traditionally was the protected grazing ground – a complex system of marshes and grasslands for the wild as well as domesticated cattle. It was fenced off as early as the year 1880 A.D to contain the cattle from ruining crops not only in Bharatpur but also in neighbouring Mathura and Agra regions (National Archive record no. F.D./Intl. B/ July 1887 & Sept. 1889). It is essentially a wetland that used to get inundated annually from the Banganga waters as the river has low banks and overflowed easily. Hydrology of the region has had the most important role in development of this system of wetlands and grasslands. The almost flat terrain allowed the water to spread over a larger region supporting grasslands in the floodplains and depression developed into lakes and wetlands, other forest areas regularly inundating developed into forested marshes. As Bharatpur was regularly inundated by waters from Banganga and occasionally also from Ruparail and Gambhir, the marshes of Bharatpur performed important function of storing flood waters, and releasing it slowly towards east, and of recharging groundwater, which not only provided the people of this region with potable drinking water but also water for irrigation (National Archives Record no. F.D /Intl. B/ Oct. 1893/ Nos. 260-261).

The present day situation is such that Keoladeo National Park wetlands are probably the only remnant of a natural ecosystem. The other satellite wetlands that previously were natural wetlands in Bharatpur have been drained and land use has been changed to that of agriculture. However, there still is a system of satellite wetlands, which now consists of the small and medium dams built across the rivers. Some of the examples are Sikri, Kalako, Band Baretha, Juggar Tal, etc.

As a part of the study, hydrology of the region in the past was studied. This threw light on hydrologic functions that the marshes of Bharatpur performed of which today's Keoladeo National Park wetlands are a part. As Keoladeo National Park is a semiarid, monsoonal wetland, it essentially performs two important functions i.e., flood mitigation and groundwater recharge. In case of local floods, the Park absorbs excess water from the surroundings and helps in mitigating of flood damages in Bharatpur region (personal communication, S. Sharma, Director KNP). In the past, about a century back, the Banganga used to flood annually, and as has been previously mentioned, overflowed its low banks and inundated floodplain marshes and forests of which Keoladeo National Park is a part. These floods were desirable as they would also recharge groundwater, utilized for irrigation during rabi season. Traditionally, Bharatpur had a system of well irrigation. "The region was well known for its well engineered and numerous wells. These masonry wells were constructed over ground to about 9 metres and left for a year, and then they were undermined and sunk in the sandy terrain. Construction continued for several years and deep wells were sunk" (Galton, 1872). Some of these still exist Keoladeo National Park e.g., two wells near Keoladeo temple in the center of the Park. One of these, known as "*Dawri walla kuan*" was, as the legend goes, constructed by the ruler of Bharatpur for provisioning drinking water during severe drought years. It is strategically placed towards the center of the depression so as to tap maximum benefits from the wetland. It is used regularly by Park management to extract groundwater to fill areas of wetland near Keoladeo temple in Block 'E' and to fill Mansarover during summers every year and for much longer duration during drought year, as well as, when supplementation of water from Ajan Dam is absent.

Further, it is noted from the archived records that during later part of the 19th century floods from Banganga were becoming a menace and resulting in huge revenue loss for the British in their territories in Fatehpur Sikri and Agra. To control this menacing river extensive surveys and studies were undertaken. Several measures were suggested one of which was to let the river change its course because then it would take a longer circuitous route through the great marsh of Bharatpur that would absorb the floods, to Khari nadi, although a much smaller drainage channel not capable of retaining Banganga waters. This new drainage route that the Banganga was taking was through Uchain to "the great Ajan Depression" which was then a system of marshes contiguous with "agahpur forests". (National Archives of India record number F.D/ Intl. B/ Oct. 1893/ nos. 260-261). This establishes the fact that the flood mitigation role of these marshes was very well understood.

Today with extensive interventions in the drainage this functional role of the wetland has reduced to containing local floods from immediate catchment of Ajan Dam in case of excessive rainfall. River Banganga, that use to be the source of annual floods had since been dammed at Ramgarh and several other palaces and had stopped flowing in plain regions outside Aravalli hills. Construction of the Ramgarh reservoir was suggested as early as 1850s by the then Jaipur Darbar, which was opposed by the then Maharaja of Bharatpur as it would affect annual flooding cycle of Banganga – so important for surface and subsurface hydrology of Bharatpur (National Archives of India record no. F.D./Intl. A/ Apr 1897/nos 208-215). As is mentioned earlier, Bharatpur was known for its wells. Agriculture was completely dependent on well irrigation. Around the turn of nineteenth century erstwhile Bharatpur State had 23% land under cultivation, irrigated by 22,000 wells of which 14,000 were masonry wells, each well irrigated three acres of land (The Imperial Gazetteer of India, 1909). This was obviously the reason for opposition to construction of any reservoir upstream, particularly in headwater region that contributes maximum discharge to the river. Headwater streams are first order and second order streams; therefore, in aggregate these streams compose over 2/3rd of total stream length in river network (Leopold et al. 1964, cited from Freeman et al. 2007).

1.4 Objectives of the present study

- To ascertain water budget of the Keoladeo National Park.
- To identify hydrologic functions of the Keoladeo National Park wetland based on Hydrogeomorphic approach.
- To assess the functional value of the wetland and its role in maintaining water table and contributing to quality and quality of groundwater in areas adjacent to the Keoladeo National Park
- The impact of the hydrological regime on the biodiversity of the Keoladeo National Park

CHAPTER 2

THE STUDY AREA

The study was conducted during 2002-2005 in the district of Bharatpur in the Rajasthan State wherein the Keoladeo National Park is located As the study concerns wetland hydrology a larger landscape which is the source and the Keoladeo National Park which is the sink, form the main component of the study area. Keoladeo National Park forms the intensive study site of the present work.

2.1. The Geographic Scope of the Study Area

The present study aims to assess hydrological budget, water availability and distribution in the Keoladeo National Park watershed. It also aims to work out water requirements for Keoladeo National Park wetland and to assess hydrological functions of this wetland. Therefore, its geographical scope of this study is three tiered. Thus, the present study first looks into the larger landscape of which Keoladeo National Park is a part. This is limited geographically by the watershed of Keoladeo National Park. The hydrological budget is assessed in the drainage area i.e., the watershed of the Keoladeo National Park for water availability in the watershed and its distribution. Secondly, the geographical scope for assessing hydrological functions is Keoladeo National Park Protected Area limits and immediate surrounding to 2 kms[1]. Lastly, for calculating water budget for the Keoladeo National Park the present study limits itself

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[1] A 2km area around the Keoladeo National Park was chosen to include agriculture land where groundwater withdrawl takes place on a larger scale. A larger area was avoided as the Keoladeo National Park is situated very close to urban area.

to Keoladeo National Park PA wetland blocks to about 8 sq. km.[2], it is envisaged that calculation of a realistic water budget would help in effective management of the Protected Area.

2.2. Keoladeo National Park

Keoladeo National Park (Fig. 2.1) lies in the floodplains of river Banganga and Gambhir that are the two tributaries of river Yamuna in Bharatpur district of Rajasthan, India. It is situated at 27°7'6"N – 27°12'2"N and 77°29'5"E – 77°33'9" E, lies on the extreme western edge of the Gangetic Basin, Yamuna sub-basin. It is the only natural wetland left in the Yamuna floodplains. Keoladeo National Park was designated as a Wetland of International Importance under the Ramsar Convention in the year 1981 and a World Heritage Site by UNESCO in the year 1985. The terrain is almost flat with elevations varying from 173 m to 178 m above mean sea level with a gentle slope towards the central depression. This depression is a typical 'surface water depression wetland'. The park spread over 29 sq. kms. is a mosaic of dry grasslands, wetlands and woodlands is locally known as 'ghana', meaning dense. The wetland area comprises (Fig. 2.2) of about 800 ha and it is compartmentalized by a series of dykes and gets seasonally inundated.

2.3. Geomorphological Setting of Bharatpur

Keoladeo National Park lies on the western edge of the Gangetic plain in yjr floodplains of Banganga River in Bharatpur District of Rajasthan, India. Topographically Bharatpur consists of vast alluvial plain with several depressions.

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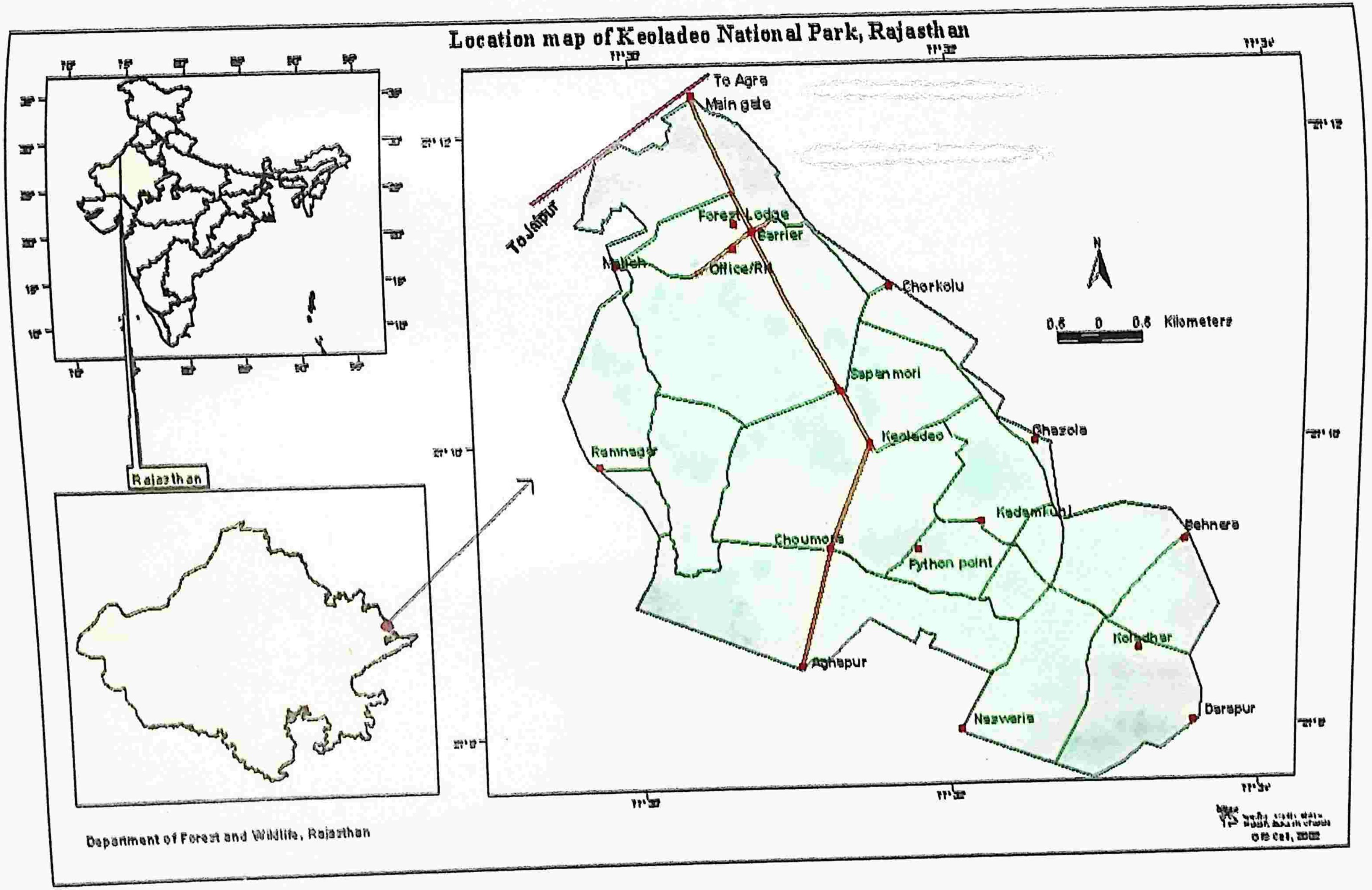
[2] Preliminary literature review and personal communication with Director, Keoladeo National Park had revealed that the wetland was, at that, time about 8 sq. kms. The water budget was required to calculate only for the wetland blocks, therefore the area under wetland blocks known to be approximately 8 kms was considered.

The Bharatpur district forms a part of eastern Rajasthan plains lying east of Aravalli hill ranges. On the basis of topography, the district can be classified into three units namely, (a) isolated hillocks in northern part, (b) large alluvial and wind blown plains covering central and southern parts and (c) low-lying flat topped hills in south-western part of the district (CGWB, 1997).

Most of the area of the district is occupied by alluvial plains which form a part of the Banganga and Gambhir river basin (Fig. 2.3). The isolated hillocks in the north belong to Delhi Super group formation. In the south (south and south-west of Bayana) the flat topped hills belong to Archean (Ranthambor group) and Vindhyan (Bhander group). The height of ground level generally varies from 180 m to 220 m above mean sea level (AMSL). Isolated blocks are comparatively higher like Pahari (369 m) and Panhari (323 m). Keoladeo National Park is a slight depression with in the plains- the height of ground level varying from 174 m to 178 m AMSL. General slope of the area is easterly towards river Yamuna. There is a slight gradual fall in ground level from north towards the Ccity of Bharatpur. In the district there is a central alluvial ridge separating the Gambhir River Basin from the Banganga basin (CGWB, 1997).

Fig. 2.1



Location map of Keoladeo National Park, Rajasthan

Department of Forest and Wildlife, Rajasthan

Fig. 2.2 Base Map of Keoladeo National Park Showing Different Zones

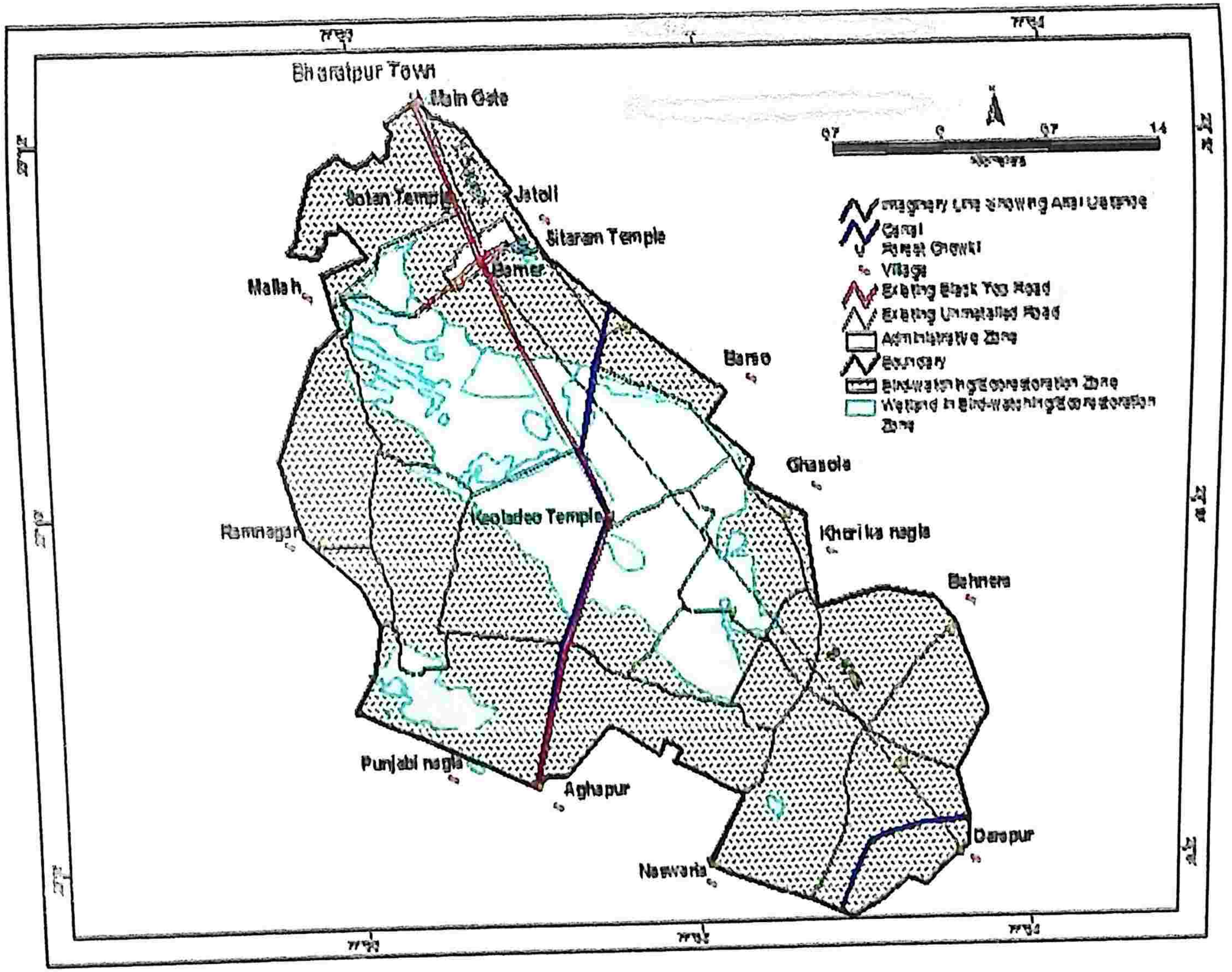
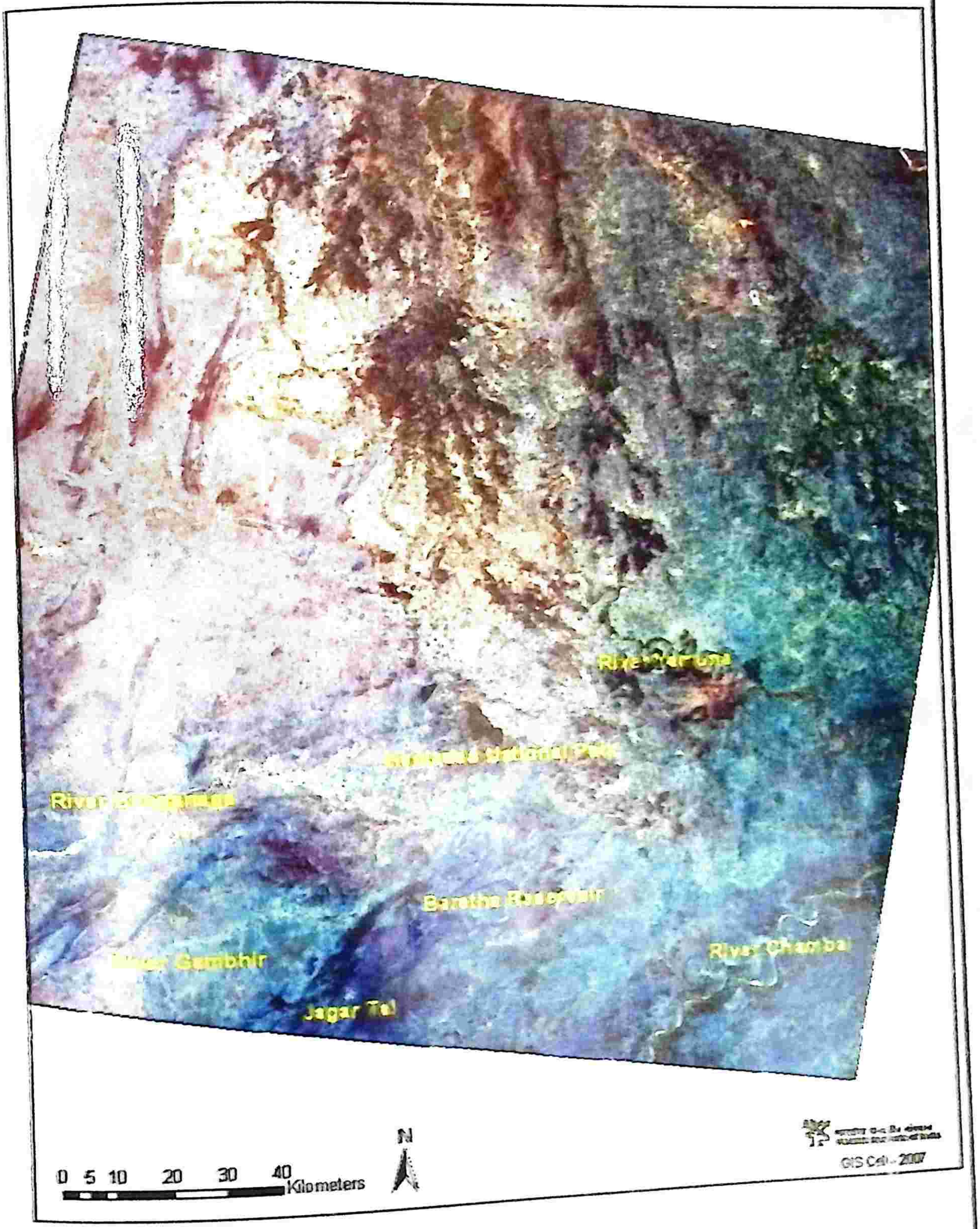
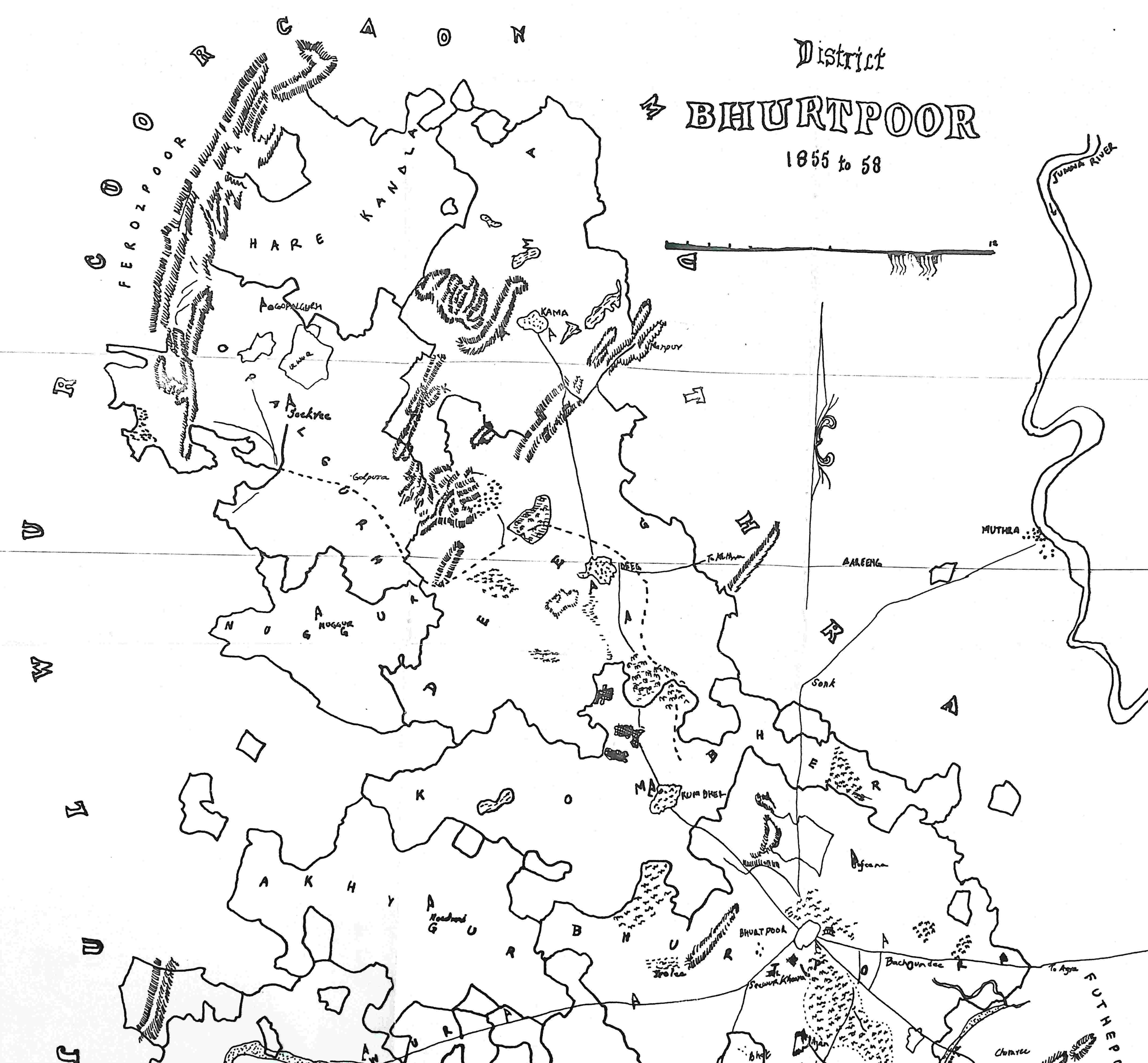


Fig. 2.3 Geomorphologic Setting of Keoladeo National Park

(False Colour Composite)




District
BHURTPOOR
1855 to 58
GOORGAON
FEROZPOOR
HARE KANDLA
GOPALGURH
Joekree
Golpura
KAMA
NUGGUR
DEEG
To Muthra
BAREENG
MUTHRA
JUMNA RIVER
Sonk
KUMBHER
BHURTPOOR
Bachgundee
To Agra
FUTHEPO
12

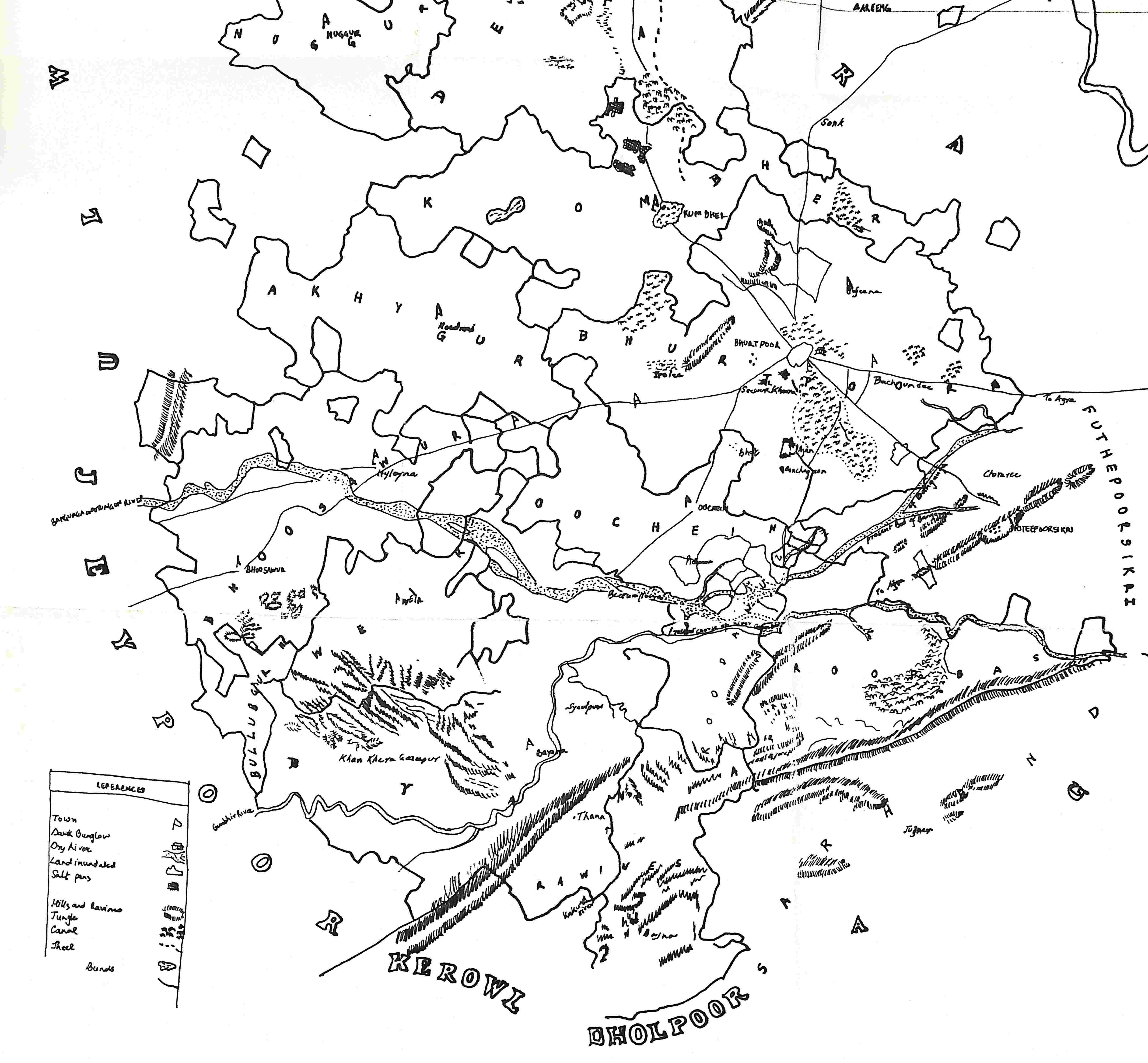
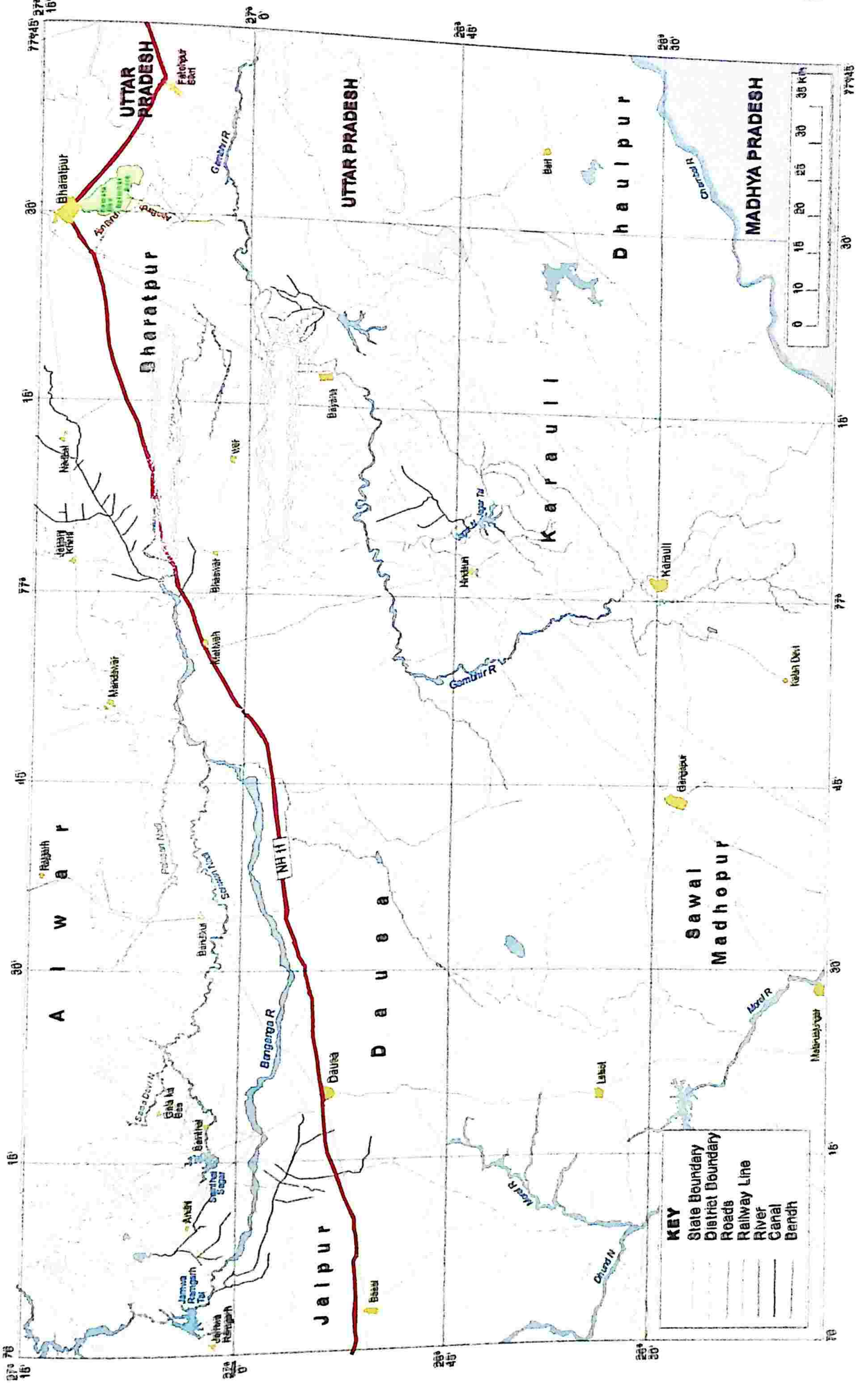

KEROWL
DHOLPOOR
FUTHEPOOR SIKRI
BHURTPOOR
Sonk
Nugaur
Bachgundee
To Agra
To Agra
Chorasee
Oochein
Bhet
Ajan
Sewur Khera
Present bed of Banganga
Banganga or Utungun River
Gumbhir River
Bhoosawur
Hylopna
Bayana
Syedpoor
Khan Khera Gazeepur
Bullubgurh
Thana
Kakund
Jugner
REFERENCES
Town
Dark Bunglow
Dry River
Land inundated
Salt pans
Hills and Ravines
Jungle
Canal
Jheel
Bunds

Fig. 2.5 Drainage map based on Survey of India toposheets (1:50,000)



The drainage of the area is chiefly determined by the Aravalli ranges. Morphologically the Aravalli ranges consist of a number of discontinuous and elongated ridges separated by longitudinal valleys with a general N.E-S.W. trend, parallel to the regional fold trend of Delhi rocks. Drainage of the eastern section is mainly to the northeast through the Sabi River and its tributary the Sota River. But the Banganga and Baraki Nala also carry off the drainage to the east. The drainage, however, has no direct outlet but finds its way out by spillways to the Yamuna River through outflow of water collected in depressions or small *jhils* (Sen, 1983). Keoladeo National Park is one of these depressions. The Banganga and Gambhir River systems together have a catchment area of 14,360 sq. kms., 8.47% of the total catchments of all the rivers systems in the state (Fig. 2.5).

River Banganga: The Banganga is a non perennial river which originates from Jaipur district about 64 km. up stream of Jamwa Ramgarh Bundh. After flowing 241.5 km. In Jaipur, Dosa, Alwar, and Bharatpur districts it terminates at Nekpur head works from where the entire water of river is diverted into Uchain canal and Nekpur feeder. It enters Bhartpur district near village Kamalpur and flow about 64 km. in Bharatpur district before terminating at the Nekpur.

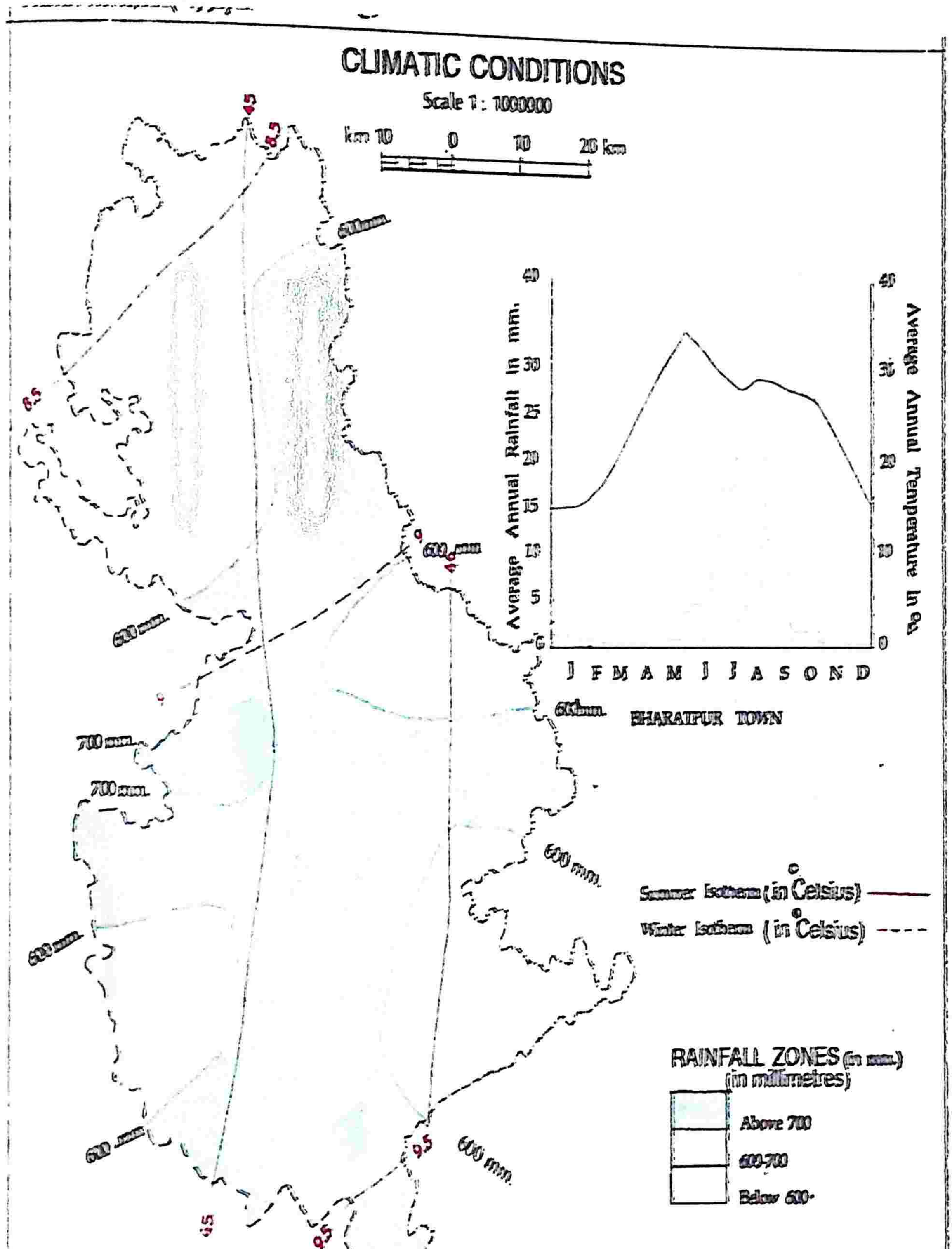
There are nine off take channels of the river namely Ramesh Awami Canal, Pathena Canal, halena Canal, Lalpur Canal, Lalita Mudai, canal, Dharsoni canal, Atari channel, Nekpur feeder and finally Uchain canal. This canal feed a large no of tanks which are constructed in series of inundation irrigation by spreading a sheet in the commanded area. The river brings a heavy discharge of silt from catchment which gets deposited along the entire course of river. The riverbed is thus rising year after year causing meandering effect. As such the flood waters overflows the banks whenever there is a heavy precipitation in the catchment area. As happened in the years 1967, 1972, 1973, 1975, 1977, 1978, 1995, and 1996, (Anon., 1997) left side marginal bund from Bhasina village to Nekpur head has been constructed to save the Bharatpur City from Flood waters. In the right side of the river Chokwara protection bund, Jhala tala protection bund, Ramaspur protection bunds have been constructed.

River Gambhir: Gambhir River is a non perennial river which originates in Karauli hills in Karauli district (previously Sawai Madhopur district) after flowing for 80 km in Karauli it enters in Bharatpur district near village Kalsaria of tehsil Bayana. After flowing through plains of Bayana and Rupbas tehsil it enters in the state of Uttar Pradesh. near village Mertha. The total catchment area of this river in Rajasthan is 3887 sq. km. at Khanwa. The state Govt. has also constructed Panchana project on this river with a storage capacity of 59.5 million cubic metres (MCM). In Bharatpur district there are seven off-take channels from the river namely Pichuna canal, Afflex bundh channel, Dahina canal, Ghata canal, Bokoli canal, Ondel Jat and Sakarpur canal. These canals, feed a large no of tanks which are constructed in series for inundation irrigation by spreading a sheet in the commanded area. Although sluices have been provided in these tanks there is no canal system. All the tanks are depleted latest by the end of Sept. every year and moisture retained by the soil is sufficient to raise and to moisture rabi crop. During the years of high flood the discharge available is very high. At Seola head the water of Gambhir River is diverted to Ajan bund and Sewar bund through Pichuna canal (93.5 cubic metres per second) and the rest of water is utilised in other bunds. The surplus flood waters are drained out in U.P. through Gambhir River. (Anon., 1997, information source- Irrigation Circle, Bharatpur)

2.5. Climatology

In the state of Rajasthan, the climate varies from sub-humid to arid but the region is largely arid to semi-arid. To the west of the Aravalli range the climate is characterised by low rainfall with erratic distribution, extremes of diurnal and annual temperatures, low humidity and high wind velocity. The climate is semi arid to sub humid in the east of the Aravalli range, characterised by more or less the same extremes in temperatures but relatively low wind velocity and high humidity with better rainfall. The entire state is characterised by hyperthermic conditions. The average annual rainfall varies from 100 mm in north-west to 1630 mm at Mount Abu. Bharatpur experiences extremes of temperature i.e., hot dry summers and freezing cold winters, with temperatures ranging from 0 to 2°C in winter to above 48°C in summers. The mean annual precipitation for past 30 years is 593 mm, 85% of which occurs during the monsoon months of July-September. (Fig 2.6) During the study period a weather station was established to record maximum and minimum temperatures and rainfall.

Fig. 2.6 Map of Climatic conditions of Bharatpur

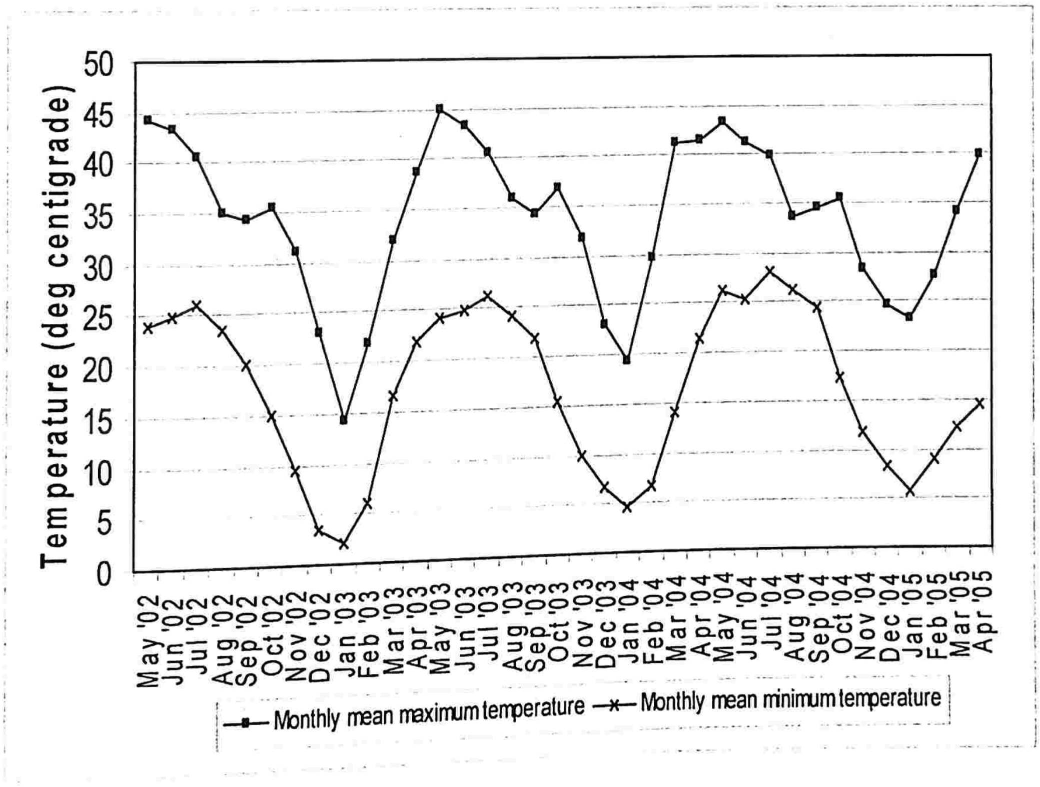


Sources : Collectorate, Bharatpur,
Resource Atlas of Rajasthan, 1995.

2.5.1. Temperature

May is the hottest month of the year with maximum temperature often exceeding 45° C. However, normal maximum temperature is 42.1° C for the month of May. Minimum temperature goes below 5° C quite often during winter. The normal minimum temperature is lowest i.e., 6° C, in month of January. The temperature starts increasing in the month of February till maximum is reached in May or June. Temperature starts falling gradually due to the onset of the south-west monsoon by the end of June. A slight increase in maximum temperatures is observed after the withdrawal of monsoon in September. The minimum temperature however continues to drop. The daily maximum temperature also starts falling in November). The temperatures recorded during the study period May 2002 to April 2005 is given in Fig. 2.7.

Fig. 2.7 Average monthly temperature during study period (2002-2005)



2.5.2. Rainfall

The rainfall in the region is highly seasonal, more than 80% of the rainfalls during south-west monsoon season between July and September. August is the wettest month. Average annual rainfall of the study area for past 100 years is recorded as 647.85 mm and that of past 30 years is 593.62 mm. The area receives highly variable rainfall. Record of past hundred years shows high variability in rainfall. Annual rainfall shows wide variability. Frequency of years with different category of rainfall was calculated from the data available from the Agriculture Department, Rajasthan Government. This is given in table 2.1.

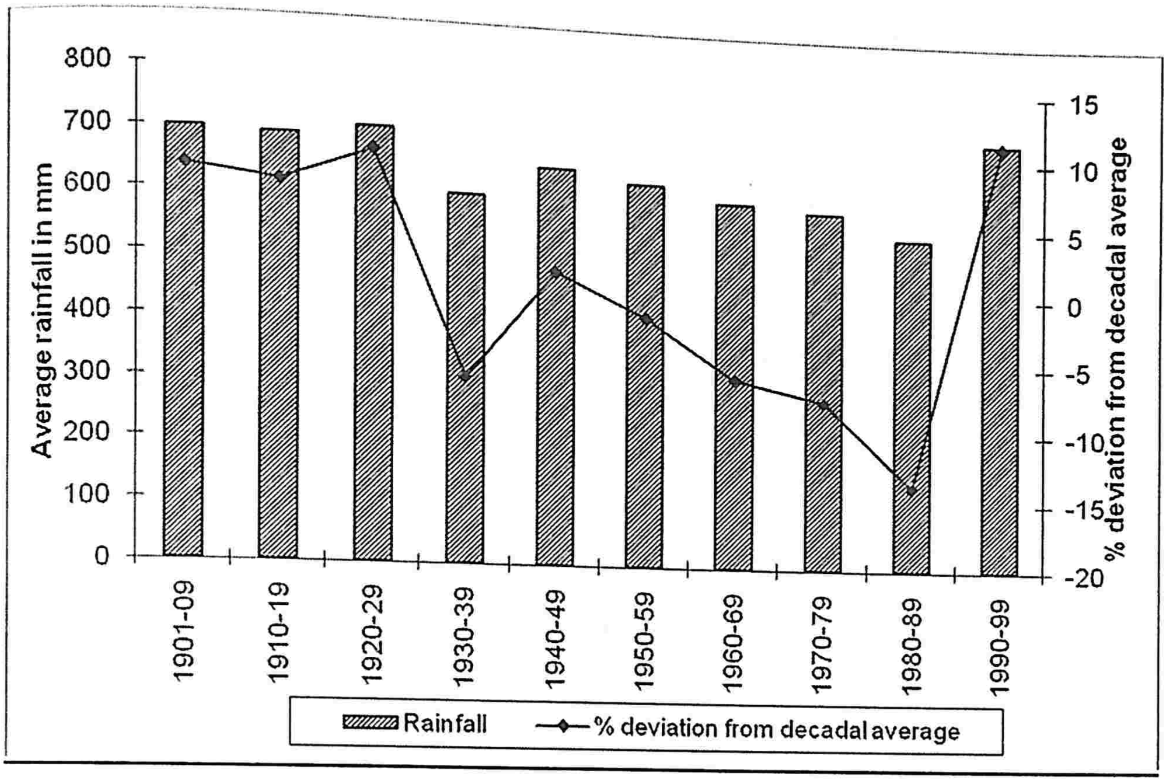
Table 2.1 Frequency of deviation of rainfall (1901-1999)

Category of Rainfall	**Frequency (number of years)**
Excess	29
Normal	39
Deficient	28
Scanty	3

Note: The categories are based on guideline of the Indian Metreological Department. The rainfall is classified as excess if it is +20% of normal rainfall or more; normal if it is +19% to -19% normal rainfalls; Deficient if it is -20% to -59% of normal rainfall and scanty if it is -60% or more

Decadal averages were calculated to find any significant deviation between decades. Fig. 2.8 shows decadal averages for a period ranging 1901-1999 and its deviation from average.

Fig. 2.8 Decadal average – Rainfall (1901 to 1999)



The decadal averages do not show wide variations suggesting that each decade had both excess rainfall and deficient rainfall years. During 1901- 1999 the variations i.e., per cent deviation from normal range had been recorded to be having from 99.43% to -80.12% indicating the considerable extent of variability. Fig. 2.9 shows annual rainfall from 1901 to 1999 and the per cent deviation of annual rainfall from normal rainfall.

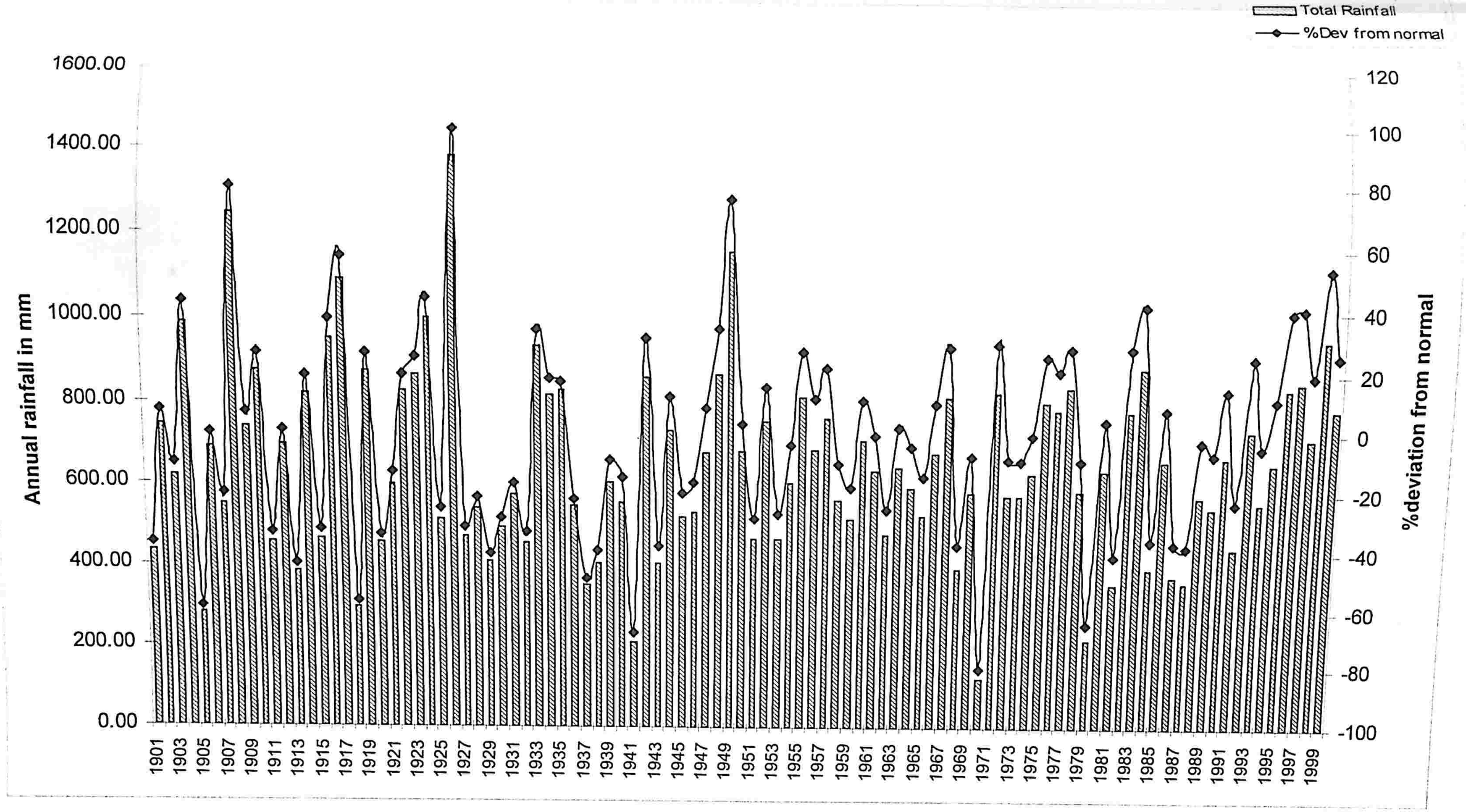
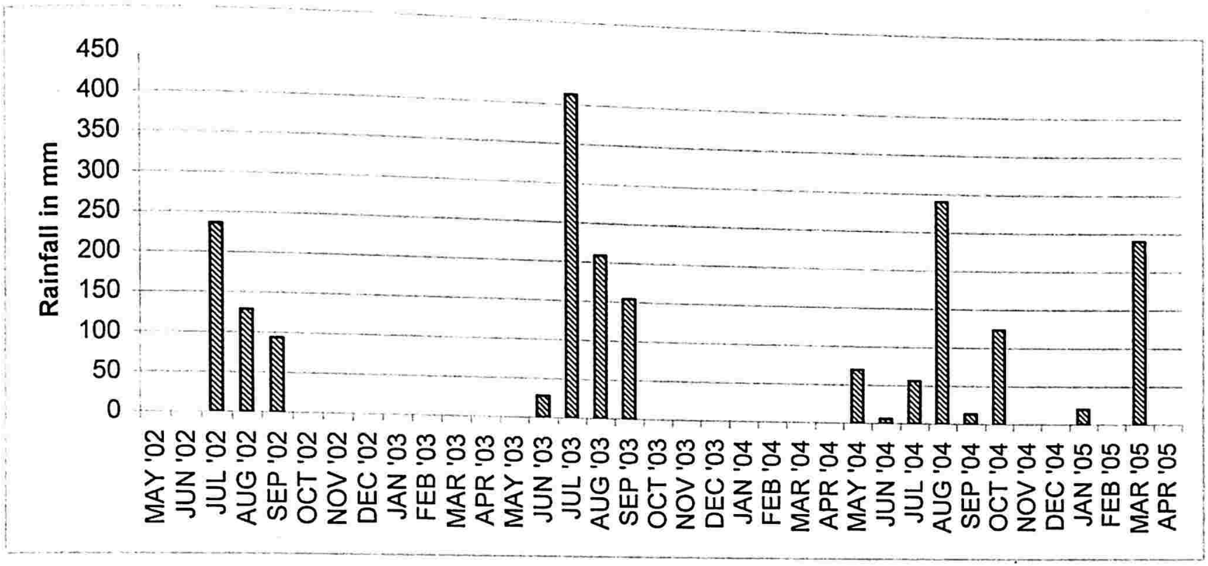


Fig.2.9 Rainfall in Bharatpur 1901 - 1999

Fig. 2.10 Monthly rainfall during study period



It was recorded that during the study period (2002-2005) the area received normal to excess rainfall. However, the normal monsoon of 2002 was -1% of the normal and had followed severe drought (-88% of normal rainfall) of 2001. Table 2.2 gives the categories of rainfall from 2001 to 2005 (Fig. 2.10).

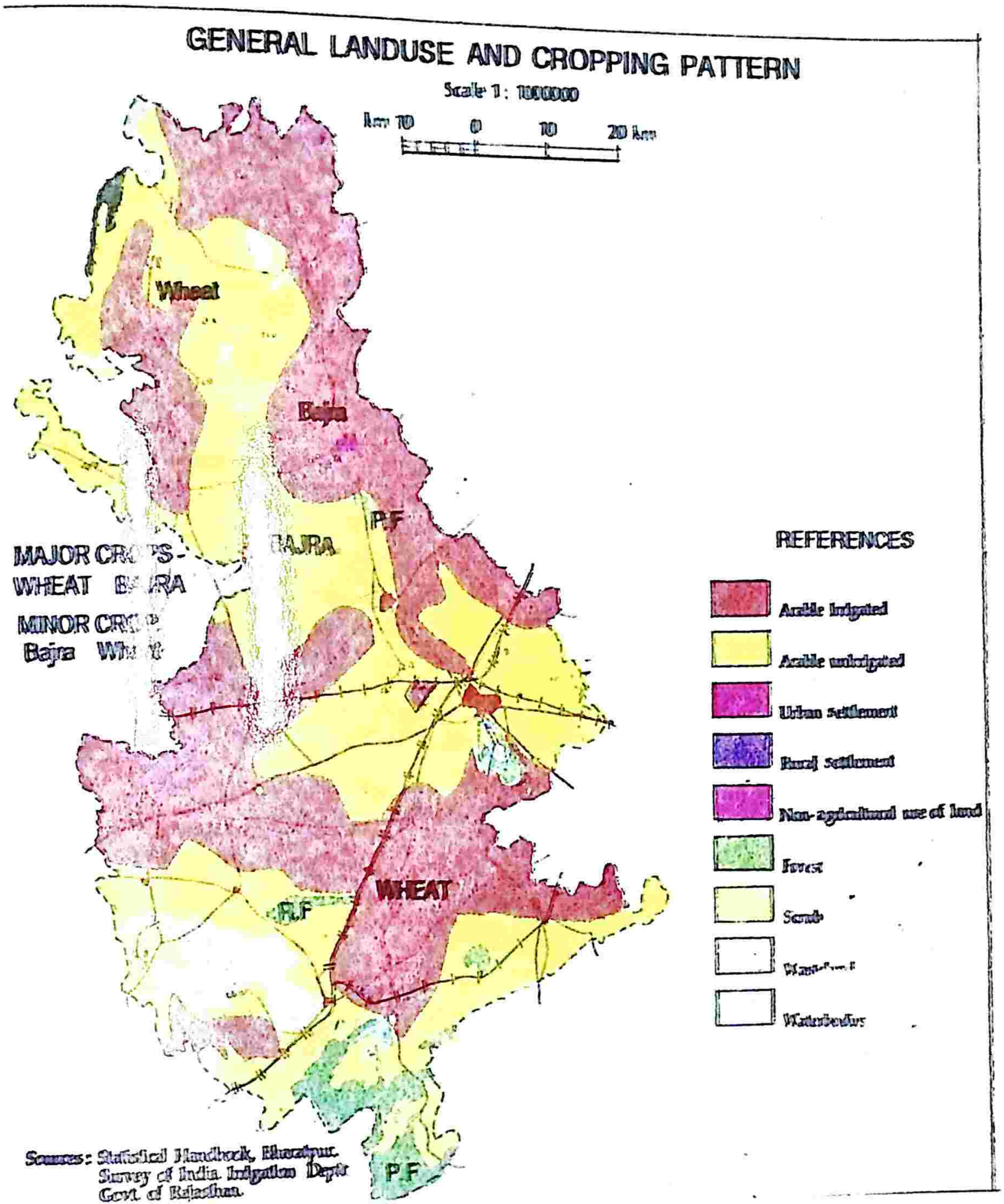
Table 2.2 Deviation of rainfall from normal (2001- 2005)

Year	% Deviation From Normal	Category
2001	-88	**Scanty**
2002	-1	**Normal**
2003	21	**Excess**
2004	-13	**Normal**
2005	15	**Normal**

2.6. Land Use

The region is predominantly cultivated for subsistence agriculture, but cash crops like mustard are also sown. Major crops in the kharif season around Keoladeo National Park are *jowar, barchi* & pulses and during rabi season are wheat and mustard. Although some rice and sugarcane are also grown in the district, they are not grown in the immediate vicinity of the park. Records from Bharatpur shows that in 1967-72 area under sugarcane cultivation was more. Rice was grown in lesser area in the district as compared to other crops such as wheat, green gram, millets (*bajra*) and mustard. There was an increase in the cultivated area under *bajra* in the year 1982-89 and an oil seed crop, mustard has been increasing since 1986. Around Keoladeo National Park wheat and mustard are main Rabi crops (Fig. 2.11) (Table 2.3).

Fig. 2.11 Land use pattern in Bharatpur, Rajasthan



Sources: Statistical Handbook, Bharatpur.
Survey of India. Irrigation Deptt
Govt. of Rajasthan.

Blockwise land utilisation in Bharatpur district is detailed in the table 2.3.

Table 2.3 Land utilisation data for Bharatpur district, Rajasthan

(all figures in hectares)

Block	Area of the Block	Not suitable for cultivation						Cultivable area								
		Forest	Hills	Pasture lands	Barren lands	Tank Ponds	Total	Waste	Irrigated by wells	Irrigated by canal	Irrigated by tanks ponds	Other sources	Total irrigated	Unirrigated	Total area under cultivation
Bayana	81206	15162	10855	6584	1635	1608	35844	7665	19510	2693	15	258	2246	15221	37697
Deeg	49270	948	2223	3568	60	132	6931	798	15840	-	-	-	15840	25701	41541
Kaman	51567	-	2231	3138	739	-	6108	1125	13142	450	-	-	13592	30742	44334
Kumher	44826	3	35	2982	130	300	3450	970	10556	-	-	-	10556	29850	40406
Nadbai	44680	-	-	2516	62	1034	3612	887	22663	-	-	-	22663	17518	40181
Nagar	65438	-	1940	4749	1574	180	8443	2305	17253	-	-	-	17253	37437	54690
Rupwas	53685	646	573	3787	138	174	5318	2450	22295	6161	-	107	28563	17354	45917
Sewar	50256	2854	33	170	-	399	3456	1932	27478	4389	-	30	31897	12971	44868
Weir	59966	6514	1750	3432	151	165	14012	2877	19140	12539	-	-	31679	11398	43077

Source: Groundwater Department

CHAPTER 3

ASSESSMENT OF HYDROLOGICAL BUDGET OF KEOLADEO NATIONAL PARK LANDSCAPE

Following task are fulfilled in this chapter for assessment of hydrological budget of Keoladeo National Park landscape.

a) Assessment of the hydrological budget of Keoladeo National Park watershed, in order to analyse whether the distribution of water is rational, what is the shortfall and why? if the shortfall exists how can it be met with;

b) Ascertaining water budget of Keoladeo National Park wetlands.

The assessment of the hydrological budget of the watershed of Keoladeo National Park is based on secondary information sourced from Bharatpur Circle, Irrigation Department. The methodological approach for ascertaining the water budget of Keoladeo National Park wetlands is detailed later in the chapter.

3.1. Geographic Scope of the Study

For assessment of the hydrological budget of the Keoladeo National Park watershed, the geographical scope is limited to watershed boundaries of the two rivers – the Banganga and the Gambhir draining Keoladeo National Park landscape. This has been detailed earlier in the text. For ascertaining the water budget of Keoladeo National Park wetlands the geographical scope is limited to the 8 sq. km. wetland area of Keoladeo National Park.

3.2. Methodological Approaches

3.2.1. Hydrological budget of the watershed of Keoladeo National Park

For the assessment of hydrological budget of Keoladeo National Park watershed, secondary information was collected on the following:

a) total run-off from Gambhir river basin

b) run-off intercepted by various dams

c) run-off downstream from these dams and other water harvesting structures

d) distribution of water from Ajan Dam

3.2.2. Water budget of wetland of Keoladeo National Park

Water budget is basically a routing procedure that sums the water inputs into a wetland area, the outflows, and the storage. The development of wetland conditions depends on a long term balance between water inflow from the wetland. The source of water may be precipitation which falls directly on the wetland, surface water runoff during rainfall or snowmelt events within the catchment area surrounding the wetland (surface water inflow) periodic flooding caused by elevated water levels in nearby waterbodies, groundwater inflow to wetland or combination of any or all of these sources. Water may be lost from wetland by evaporation from standing water or by saturated soil transpiration from plants or surface water or ground water outflow (derived from WRP Technical Note HY-EV-2. 1; January 1993 & MDOT Drainage manual).

The general Water Budget Equation, therefore, is essentially a mass balance equation:

$I\text{-}O = d\,S/dt$

Where,

I = Total Inflow

O = Total Outflow

DS/dt = Change in storage per unit time

The following factors combine to express the water budget equation

Inflows: 1. Direct precipitation

2. Surface inflows

3. Subsurface inflows

Outflows: 1. Surface outflows

2. Subsurface outflows

3. Evapotranspiration

Expressed in equation form this is:

$P + SWI + GWI = ET + SWO + GWO + dS/dt$

Where,

P = Precipitation

SWI = Surface water inflows

GWI = Ground water inflows

ET = Evapotranspiration

SWO = Surface water outflows

GWO = Ground water outflows

dS/dt = Storage

As Keoladeo National Park is a semi-arid depression monsoonal wetland, the inflows are in the form of precipitation (P) and surface water inflow (SWI). There are no surface outflows from this wetland (therefore, SWO= 0). Groundwater inputs to a site depends on the hydrogeology of a wetland. In case of Keoladeo National Park it is nil as the wetland is situated in a depression and the water table in much lower in the region, the groundwater does not flow into the wetland. As it is a depressional wetland in a semi-arid region and the geology of the region is such that the sub-terrain is alluvial, the unconfined aquifer is much lower than the ground surface, this wetland has no groundwater inflow, but groundwater outflows only (GWO). Other significant outflows are in the form of evaporation from open water and evapotranspiration from the vegetated parts of wetland. The water budget equation adopted for Keoladeo National Park's situation, therefore, is:

$$P + SWI = ET + Ew + Es + GWO + S$$

Where,

P = Precipitation

SWI = Surface water inflows

ET = Evapotranspiration

Ew = Evaporation in winter

Es = Evaporation in summer

GWO = Groundwater outflows

S = Storage

This may further be expanded to the following

Precipitation + Supplementation = ET + Ew + Es + IC + IR + S

Where,

Supplementation = Surface water inflow (SWI)

IC (Infiltration capacity) + IR (Infiltration rate) = Groundwater outflows (GWO)

3.2.2.1. Data Collection

Primary data was collected on various components or parameters of water budget for wetland of Keoladeo National Park. The details are as follows:

Components	**Time period**
Rainfall (Precipitation)	2002- 2005
Infiltration	2002 (sample size- 8; 1 per sq. km. of wetland)
Pan evaporation	2003-2005
Evapotranspiration (for AET ref. section 3.3.2.4)	2003-2004

Secondary data was collected on supplementation of water through Ajan Dam from Irrigation Department.

The methodology for each component of the water budget is detailed separately in sections below:

3.2.2.2. Precipitation

Precipitation was recorded at weather station that was located at the site. For the purpose of recording precipitation the standard raingauge of the Indian

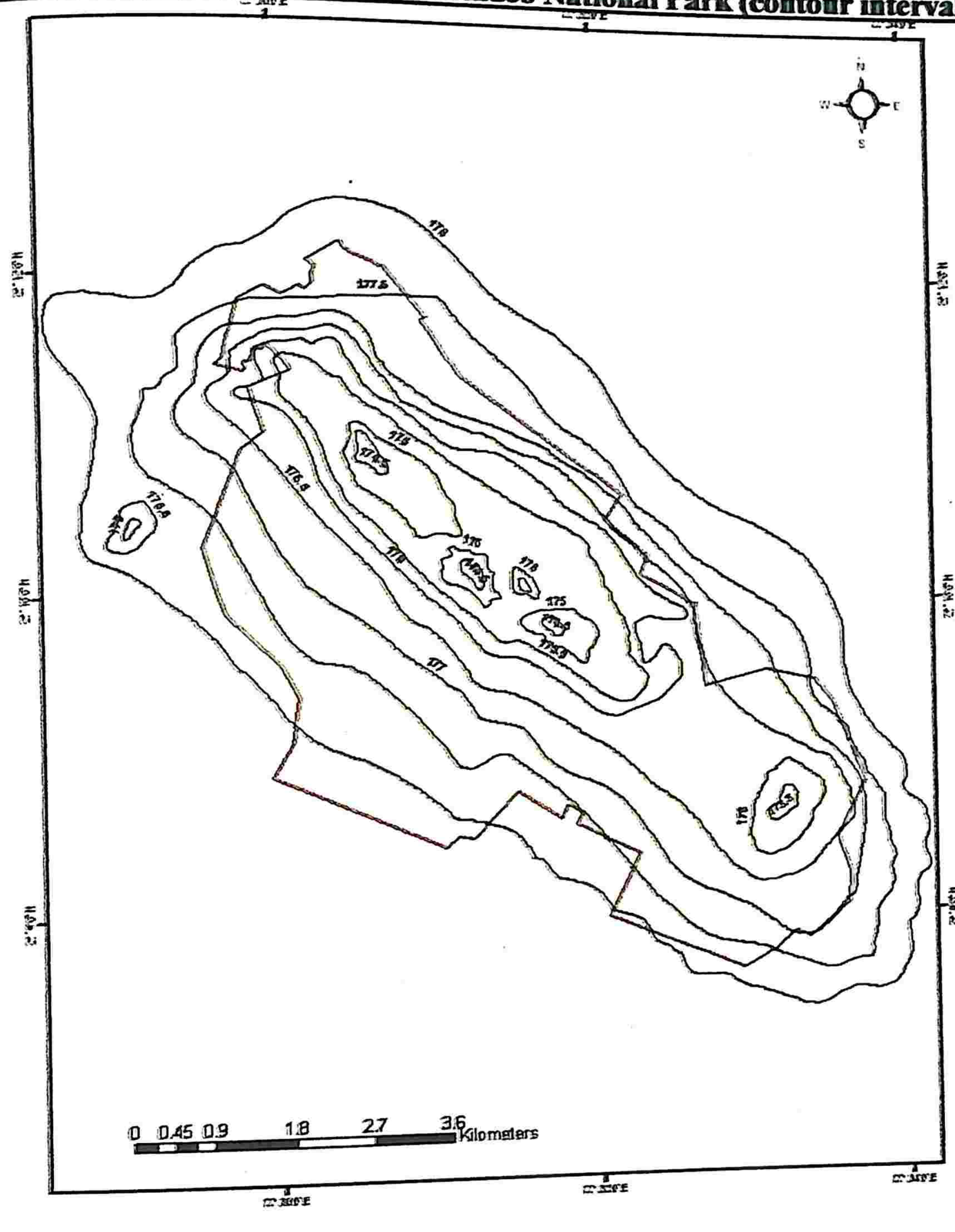
Meteorological Department was installed at site. This raingauge was the Symon's pattern raingauge which has 5" diameter receiver opening made of gun metal and finely finished knife edge top. The cylindrical body, the container and the base were made of 0.8 mm galvanised iron sheets. The rain falling into the receiver was funnelled into 175 mm capacity container that was measured with the help of specially calibrated graduated cylinder with 25 mm capacity.

The rainfall is a direct input into the wetland. However, part of the rain that falls is be intercepted by vegetation over wetland. Depending on the monsoon conditions it may or may not contribute significantly to the water budget.

3.2.2.3. Water Storage

To calculate the water storage or water holding capacity of the wetland a contour map was prepared based on a recent dumpy-level survey of the area (source: office of Director, Keoladeo National Park) and digitised using ArcGIS software for ease of accurate calculation of water holding capacity of wetland area of Keoladeo National Park. The contour interval was 0.5 meters.

Fig. 3.1 Surface contour map of Keoladeo National Park (contour interval 0.5m)



3.2.2.4. Groundwater Outflow

Groundwater outflows are a significant component in the water budget. The wetland recharges shallow groundwater – the water table, as it is situated in a depression in a sandy unconfined aquifer. Because of its location and geology it continually losses water to the ground. The extent and significance of groundwater recharge and maintenance of water table have been discussed extensively in the next chapter. Groundwater recharge occurs through the process of infiltration.

Infiltration: When water falls on a formation first of all, a small part of it is absorbed by the top thin layer of the soil, so as to replenish the soil moisture deficiency. The maximum rate at which a soil in any given condition is capable of absorbing water is called its **infiltration capacity (IC)**. Thereafter, excess water moves downward, where it is trapped in the voids, and becomes groundwater. The rate at which this happens is called the **infiltration rate (IR)**. To measure infiltration capacity and rate a double ring infiltrometer was used, which consisted of two shallow concentric rings of sheet metal. They were placed on the ground with the upper portion projecting above the ground and the lower portion lying under the ground. Water was filled in both the compartments and kept at the same level. The outer ring prevents the water of the inner ring from spreading over a larger area after penetrating below the bottom of the ring. The rate at which water is required to be added to the inner ring, in order to keep a constant level, will directly give us an idea of the infiltration capacity (IC). Once the soil is saturated, the water moves downward at a much slower rate this is the infiltration rate (IR). From this rate total infiltration can be estimated which is sum of IC and IR. (Garg, 1996)

3.2.2.5. Evapotranspiration

Evapotranspiration includes both the surface evaporation of water and transpiration through plants. In wetlands, the evaporation from water surface is usually affected by cover. Evaporation rarely adequately estimates total losses. Pan evaporation rates are used to determine the ratio of total precipitation to total evaporation (P/E) for any specific region. Factors affecting evapotranspiration are exposed water surface area, solar radiation, temperature of air and water, wind speed, and relative humidity (Garg, 1996).

For calculating evaporation from open water surface, Pan evaporation rates were recorded using a standard I.S.I standard pan evaporimeter specified by **IS-5973-1970** of **Bureau of Indian Standards** which is also know as *modified class A pan.* This pan had a 122.5 cm dia, and 25.5 cm depth; it is covered at the top by *hexagonal wire metting* of galvanized iron to protect the water in the pan from birds and also to make the water temperature more uniform during the day and night. The pan is placed over a square wooden platform of 1.225 cm width and 10 cm height, to enable circulation of air underneath the pan. The pan coefficient is around 0.8.

Actual evapotranspiration (AET) in the field was measured by an instrument called lysimeter, which is a water tight tank containing a block of soil, and is installed in a field of growing plants. Same plants are grown in lysimeter as in the wetland/ field. Estimate of actual ET is made by using lysimeters under the same climatological conditions as the wetland. As ET forms significant part of water budget for semi arid monsoonal wetlands, a set of five lysimeters, each 1X1 - m was established near the wetland in Keoladeo National Park. These were seeded with wetland soil from various blocks. To measure accurately the amount of water used and to ensure constant supply of water to the root zone each lysimeter was equipped with clay pots in subsurface connected to a water tank, a modification over the emitter irrigation system. Water utilised by plants in each lysimeter was recorded daily and the water tanks were refilled. The amounts of water required to maintain constant moisture condition within the tank are either measured volumetrically or gravimetrically through an arrangement made in the lysimeter. This value of water required, when averaged over the vegetation period, in mm/day, gave us the value of actual evapotranspiration under specific field conditions.

Equation:

$$\mathbf{ET = W1 - (Wt.1 - Wt.2)}$$

Where,

W1 = Total water used by plants in a growing season

Wt.1 = Wet weight of the plants

Wt.2 = Dry weight of the plants

ET = Evapotranspiration

3.3. RESULTS

3.3.1. Hydrological budget of the landscape

As has been mentioned before, the contributions to the Keoladeo National Park essentially come from river Gambhir. River Banganga, after the construction of Jamwa Ramgarh Reservoir in 1897, has been contributing very little. It was perhaps for this reason that waters of Gambhir were routed to Keoladeo National Park through

Ajan Dam via Pichuna canal. The details of river Gambhir's catchment, as per data received from Irrigation Department, are:

Total catchment area = 4388 Sq. Kms.

Total Agricultural Area = 2738 Sq. Kms.

Tributaries to the Gambhir – Bhadrawati, Jugger, Kukund [intercepted at Panchna, Jugger and Baretha respectively]

Table 3.1 Irrigation Projects in Gambhir Basin

S.no.	Name of dam	Capacity(MCM)	Catchement area (Sq.Km)
1	Zerda	0.3	1.3
2	Madanpur	0.9	10.4
3	Madan sagar	0.6	5.8
4	**Panchana**	52.6	246
5	Mamchari	4.1	28.5
6	Jeewali	0.4	7.8
7	Jhohariwala	0.9	11.1
8	Chandpur	4.8	90.7
9	Bajnrka	0.1	1.7
10	Peedia bandhi	0.6	7.8
11	Nijinwala	0.6	23.3
12	Ramtalab	0.4	10.4
13	Ronsi	1.5	13.2
14	Shayroli	0.6	15.1
15	Telenwala	0.6	18.1
16	Fatehsagar	3.6	80.3
17	Hodaheli	1.7	31.1
18	Kalama	0.6	14.2
19	Jadolao	0.5	3.9
20	Gumansagar	0.8	26.7

21	Mohanpura	4.8	134.7
22	Rajoli	1	5.2
23	Old tank Maheshwa	1	15.5
24	New tank	3.6	72.5
26	Bishan samand	11.6	88.1
27	Bonli	2	19.4
28	Samaspur	0.9	15.7
29	Siswara	2.7	20.7
30	Sikanderpur	1.2	20.9
31	Zerda	2.2	78.6
32	**Jugger**	24.6	227.9
33	Bandhwa	2.4	27.2
34	alsen	1.5	16.8
35	Jatwara	0.6	10.4
36	Kyarda	6.6	50
25	Ballabgarh	0.5	22.3
37	Bhimnagar	0.3	32.2
38	Kamalhose	0.4	10.4
39	Damdama	0.7	10.4
40	Kanawar	0.4	9.1
41	Old kanawar	0.2	25.9
42	Khatnawali	1.2	29.8
43	Bhagorti	0.2	2.6
44	Bidyari	0.5	23.2
45	Guthkae	1.1	63.2
46	Ngala shre singh	0.6	5.2
47	Nagala chitariya	0.6	52.3
48	Dehgoan	0.4	46.1
49	Richoli	1.2	10.1
50	**Baretha**	50.7	223
	Grand Total	**201.9**	**2016.8**

Total runoff from basin = 573.64 Million Cubic Meters (MCM)

Capacity of irrigation projects = 201.9 Million Cubic Meters (MCM)

Water captured by other structures = 159 Million Cubic Meters (MCM) [pokhars, check dams etc.]

Of 2738 sq. km. of catchement 2016 sq. km. is intercepted by these dams.

(Source: Irrigation Department, Rajasthan Government)

As the tributaries are intercepted by the medium sized dams in headwater areas, almost all the water that could contribute to riverflow has been held. The catchment downstream of these dams upto Ajan dam has little to contribute as the terrain is flat and the stream length much less than that in the upstream areas. It has been estimated that the runoff from the remaining catchment is only about 2.83 MCM which is inadequate to address the water requirements of Keoladeo National Park

3.3.2. Water Budget of wetland of Keoladeo National Park

3.3.2.1. Storage (S)

To calculate water storage or water holding capacity of the wetland, a contour map was prepared based on a recent dumpy-level survey of the area. The contour interval was 0.5 meters, as per the contour map. The wetland areas under 176 m contour gets inundated. The total water holding capacity under this contour level is 7.13 Million

Cubic Meters (MCM). In addition to this area, a fringe or ecotone around this contour level develops, an area of about 100 ha, with about 0.5 m water depth, the water required for that is 0.5 MCM, the total water storage is therefore, 7.63 MCM.

3.3.2.2. Surface Inflows (SWI)

3.3.2.2.1. Precipitation (P)

Bharatpur receives widely varying rainfall. Normal rainfall is calculated to be 593.62 mm. This would contribute 4.93 MCM

Table below gives contribution by precipitation for last 10 yrs

Table 3.2 Contribution of precipitation to water budget of Keoladeo National Park

Year	Rainfall	Contribution to water budget in MCM
1995	837.80	6.965
1996	851.00	7.075
1997	716.80	5.959
1998	951.80	7.914
1999	786.00	6.535
2000	38.60	0.3209
2001	78.00	0.648
2002	394.90	3.283
2003	802.90	6.675
2004	556.90	4.630
2005	707.00	5.878

Source: Irrigation department, Bharatpur

3.3.2.2.2. Supplementation

As precipitation forms a fraction of the total water requirement supplementation from Ajan bund is necessary. During a normal rainfall year (660 mm) when rainfall over the area contributes 5.4876 MCM, rest of the water required is supplemented through Ajan Dam. During the study period (2002- 2005) supplementation through Ajan Bund was 6.67 MCM and 4.63 MCM for 2003 and 2004 respectively.

3.3.2.3. Outflows

3.3.2.3.1. Infiltration

The infiltration capacity (IC) for various blocks measured is given in Table 3.3.

Table 3.3 Infiltration Capacity in various blocks of Keoladeo National Park

Block	Infiltration Capacity	Time Taken
D	570 mm	1240 sec..
E	450 mm	1200 sec.
F	430 mm	2460 sec.
K	290 mm	679 sec.
L	460 mm	1095 sec.
B	510 mm	2270 sec.
N	500 mm	1915 sec.

The IC loss on an average is 45.875 cm, occurring over 8314600.00 sq. m area of wetland. Thus, total volume amounted to **3.814 MCM.** It was observed that the rates of infiltration varied between different wetland blocks. It was slowest in F Block and fastest in K block.

Infiltration rates as observed are given in Table 3.4.

Table 3.4 Infiltration rates observed in various blocks of Keoladeo National Park

Block	Infiltration Rate (mm per day)
D	0.141
E	0.143
F	0.095
K	0.195
L	0.156
B	0.136
N	0.143

From the Table 3.4 it was determined that the average infiltration rate is 0.144 mm per day, this is multiplied with the area of the wetland and an average of 253 days of infiltration that corresponds to the retention time of water in the wetland. The total is **3.029 MCM. Therefore total groundwater outflow is 6.843 MCM.**

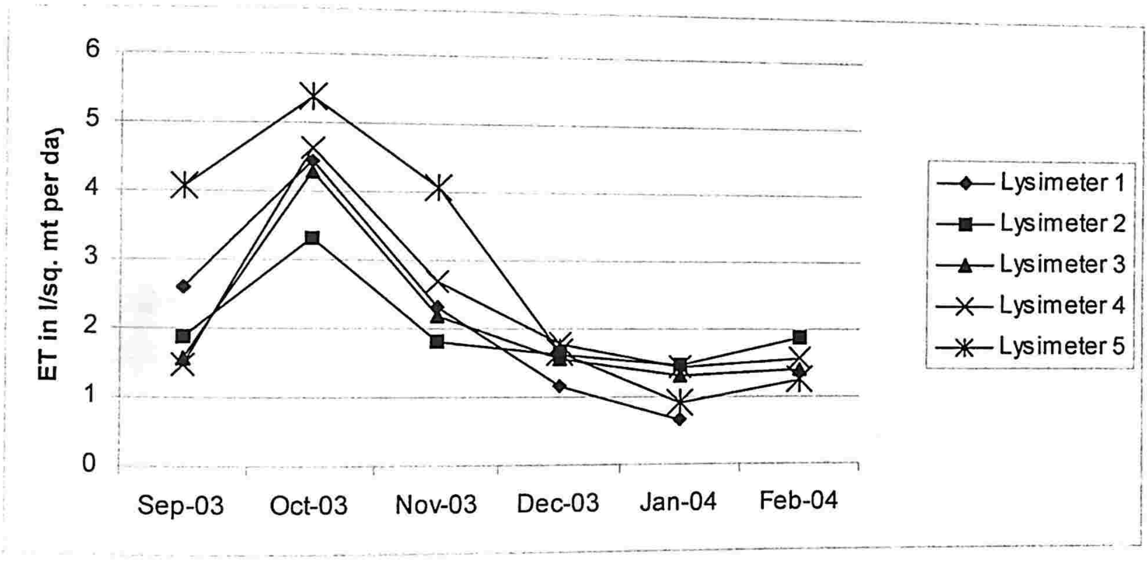
3.3.2.3.2. Evapotranspiration

Two out of five lysimeters developed thick stand of *Paspalum distichum*, and one out of five had *Echinocloa* in association with *Paspalum*, and other two were dominated by *Cyperus rotundus*. Table 3.5 below gives total water utilised in each of the five lysimeters meters.

Table 3.5 Evapotranspiration by some wetland plants in lysimeters

Lysimeter	**1**	**2**	**3**	**4**	**5**
Dominant Species	*Cyperus sp*	*Cyperus sp*	*Paspalum, Echinocloa*	*Paspalum distichum*	*Paspalum distichum*
Total water transpired in litres	305.928	295.140	323.977	365.684	407.628
ET mm/day	1.718	1.658	1.820	2.054	2.290

Fig. 3.2 Average ET in the months of the growing season



Average evapotranspiration per day = 1.908 mm/day

The area under aquatic vegetation is accurately measured using RADAR data which is 3 to 4 times better than optical data in delineating extent of open water habitat, aquatic vegetation categories and also localities of high soil moisture content. The open water area is 96.93 ha and the area under aquatic vegetation was 734.53 ha (Srivastav et. al., 2004).

Coupling this data with the measured AET values, a reasonable estimate of ET losses in the wetland can be calculated.

Therefore, the average actual ET is 1.908 mm/day. This loss takes place from the area under aquatic vegetation from September to March. The total ET losses therefore, becomes **2.984 MCM.**

3.3.2.3.3. Evaporation

The open water areas are those areas that are located in the deeper regions of wetland. These areas are expected to retain water much after drawdown period to form small pools of water during summer. These pools provide habitat and refuge to fishes and turtles and also drinking water to herbivores. The evaporation losses from open water surface was noted to be 4.1 mm per day in summer months and 0.44 mm per day during winters. These calculations are based on evaporation from a standard Pan Evaporimeter.

Evaporation during summer (Es) = 4.1 mm X 154 days X 969300 sq. mt (total wetland area) = **0.612 MCM**

Evaporation during winter (Ew) = 0.44 mm X 153 days X 969300 sq. mt (total wetland area) = **0.066 MCM**

The total evaporation losses during the year are thus calculated to be 0.678 MCM.

3.3.3. Components of water requirements are:

Table 3.6: Summary of components of water budget of Keoladeo National Park

Component of water budget	**Volume in MCM**
Storage (S)	7.132
Recharge from ecotone (fringe around the 176m contour)	0.5
Infiltration capacity(IC)	3.029
Infiltration rate (IR)	3.814
Evapotranspiration (ET)	2.984
Evaporation during winters (Ew)	0.066
Evaporation during summer (Es)	0.612
TOTAL in MCM	18.138

Water balance equation for Keoladeo National Park:

Precipitation + Supplementation = ET + Ew + Es + IC + IR + S

Precipitation + Supplementation = 18.138 MCM

Of this about 5 MCM is provided by rainfall in a normal monsoon year.

Therefore supplementation required from Ajan bund is about 13 MCM in a normal monsoon year. It is noted that water holding capacity of Keoladeo National Park has fairly reduced. It is calculated to be 7.132 MCM whereas it has been reported to be a maximum of 10.36 MCM in 1984 (Vijayan, 1991). It seems that there has been significant increase in water requirements of Keoladeo National Park owing to excessive groundwater withdrawl and increase in macrophytes with in the wetland. It should also be appreciated that during the present study the area faced either a natural or induced drought. In such situation, as the soil moisture both, within the Keoladeo National Park and outside is significantly low, the irrigation demands are higher, leading to excessive withdrawals of groundwater.

Further, of all the components of the water budget equation evapotranspiration and infiltration together form the bulk of requirement. Since this is a monsoonal depression wetland it is characterised by surface inflows and outflows in form of ET and infiltration. Groundwater pumping in the vicinity of the park has significant influence in increasing infiltration and hence, water requirements of the park. This indirectly indicated need of the stakeholder. Water storage and ET signify ecological and management needs of the park. However, it has been observed, noted and recorded by park management that *Paspalum distichum* has now covered most the wetland areas, suppressing growth of other aquatic species, this is probably adding to the water requirements of the protected area.

3.4. DISCUSSION

3.4.1. Hydrological budget of landscape vs hydrological budget for Keoladeo National Park

The total runoff from Gambhir river basin is 573.64 MCM while water requirement of Keoladeo National Park are 18.138 MCM. Therefore, Keoladeo National Park's total requirement is 3.12% of the total runoff from the basin which is only a fraction. Of this, some is met with the rainfall in the natural regime. Remaining requirement in a normal monsoon year is 2.28% of the total runoff of the Gambhir river basin. We also know that the rainfall and water availability to Keoladeo National Park always been varying in proportions. The variability of rainfall has been detailed in chapter 1. Water distribution in immediate catchment is given below.

Table 3. 7: Water distribution from Ajan bund (1981- 2005)

Year	Input Water (MCM)	Release To Keoladeo National Park	
		MCM	%
1981	15.746	14.571	92.5
1982	17.7	9.794	55.3
1983	16.992	14.571	85.7
1984	16.85	9.737	57.7
1985	15.179	9.737	64.1
1986	0.509	0.368	72.2
1987	1.529	0.453	29.6
1988	17.7	13.735	77.5
1989	6.06	5.21	85.9
1990	11.045	13.304	120.4
1991	9.742	13.291	136.4
1992	18.295	16.538	90.3
1993	15.179	16.559	109
1994	20.957	15.018	71.6
1995	15.179	14.632	96.3
1996	10.019	12.254	122.3
1997	6.06	5.109	84.3
1998	17.984	8.399	46.7
1999	13.508	9.73	72
2000	2.875	4.026	140
2001	6.683	5.2	77.8
2002	0.00	0.00	
2003	11.471	7.894	68.8
2004	0.585	0.509	86.9
2005	0.00	0.00	

Source: Irrigation Department, Rajasthan

Water Balance in Keoladeo National Park (1981-2005) is given below:

Table 3. 8: Water Balance in Keoladeo National Park (1981- 2005)

Year	Water released to KNP in MCM	Contribution thru rainfall	Total Volume in Keoladeo National Park
1981	14.571	2.966	17.537
1982	9.794	6.498	16.292
1983	14.571	7.370	21.941
1984	9.736	3.296	13.033
1985	9.737	5.508	15.246
1986	0.368	3.149	3.517
1987	0.453	3.023	3.476
1988	13.735	4.764	18.499
1989	5.210	4.555	9.766
1990	13.304	5.581	18.886
1991	13.292	3.720	17.011
1992	16.538	6.122	22.660
1993	16.560	4.641	21.201
1994	15.018	5.439	20.458
1995	14.632	6.966	21.598
1996	12.254	7.076	19.330
1997	5.109	5.960	11.069
1998	8.400	7.913	16.313
1999	9.730	6.535	16.266
2000	4.026	0.321	4.347
2001	5.201	0.649	5.849
2002	0.00	3.283	-
2003	7.894	6.676	14.570
2004	0.510	4.630	5.140
2005	0.00	5.878	-

Source: Irrigation Department, Rajasthan

The water distribution clearly indicates that if water is received in the Ajan dam a good percent age is released in the national park. This distribution varies from 140% of the water received to 30% of the water received in the Ajan Dam. The higher values indicate additional volume as runoff from its local catchment. ***Particularly in year 2001- (-88% rainfall in bharatpur) the water received is 77.8% of total in Ajan Dam, this was so because the rainfall in upper catchment was normal and water was released from Panchana Dam.*** This suggests that if water is present in the Ajan Dam it can be confidently said that water needs of Keoladeo National Park are secure.

3.4.2. Impact of Hydrology on the Functional Integrity & on the Biodiversity Support Mechanism of Keoladeo National Park

3.4.2.1. Effect of hydrology on wetlands

Water, which is a natural resource and sole determinant of ecological nature/ characteristics of Keoladeo National Park, is increasingly becoming a vanishing resource. Hydrology affects the species composition and richness, primary productivity, organic accumulation, and nutrient cycling in a wetland (Mitsch & Gosselink, 1993). During the past century the park has experienced several droughts and floods which are a common phenomenon in the region, and in all of south Asia. Large variation in hydrology of wetlands caused by the intra- and inter-annual variability of monsoon in South Asia are natural phenomenon. The wetland biota of this region is well adapted to these variations. Alterations in hydrological regimes by anthropogenic activities in wetlands and their watersheds have caused loss and degradation of wetlands, and consequently, the biodiversity is reduced or threatened (Gopal et. al., 2001). Foote, Pandey and Krogman (1996) have identified twelve important kinds of wetland loss in India. These are – agricultural conversion, direct deforestation, hydrologic alteration, inundation, defoliation, altered upper watershed, accumulative water demand, water quality degradation, wetland consolidation, global climate change, groundwater depletion, exotic species and biodiversity. Two of these issues relevant in case of Keoladeo National Park are-, hydrological alterations in the watershed and groundwater depletion in the vicinity of the national park. These factors in conjunction with varying monsoons affect the hydrology of the wetland, which, in turn affects the character, functions, value and appearance of wetland.

While the annual variability of monsoonal flooding and summer drawdown are important for the wetlands of Keoladeo National Park drastic reduction in water supply is leading to changes in the characteristics of the wetland. Some significant changes observed are establishment and proliferation of *Vitiveria zizaniodes* in wetland areas, *Dasmostachya bipinnata* (drought and fire resistant) in shallower areas indicating terrestrialization. Further, in case of prolonged dry condition of the park, *Prosopis juliflora* is gaining ground. Under normal circumstances the young plants were eliminated every year with the flooding of the wetland. During the drought of 2002 these were removed manually and brought under control but the situation has deteriorated since. As past year (2006) was again dry and the chances of removing it successfully manually are less.

3.4.2.2. Water Management in Keoladeo National Park

Traditionally, water was fed into the park twice a year. First by mid-july when enough water accumulates behind Ajan Bund, which would fill the impoundments to a depth of 20-30cm. Depending on the rainfall this water may dry due to percolation and evaporation or water depth may increase in the impoundments. In late September or

October water was again released from the Ajan Bund raising water levels in the impoundments by one meter or more. The discharge of water from Ajan Bund is also necessary for making the land behind the Bund for winter cultivation.

Water in Ajan Bund comes from a) runoff from local catchment (100 sq. miles) b) river Gambhir through Pichuna canal and c) river Banganga through Uchain canal. Of these supply from Uchain canal has been nil or negligible for many years as river Banganga remains dry due to hydrologic interventions in head-waters, supply from Pichuna canal has also been unreliable since the completion of Panchana Dam (designed to impound 100% river flow) in year 2000. Both the rivers have been intervened extensively to meet the demands to growing population and growing agriculture. There are several medium and hundreds of minor water infrastructure on these rivers and their tributaries. River Gambhir has three medium dams- Panchana, Baretha and Jaggar. All these are in the head waters and impound 100% river flows of Panchan, Kakund and Jaggar river respectively, which are tributaries of river Gambhir. Similarly, river Banganga has Jamwa Ramgarh, Senthal, Arvari and Kalako dams across its major tributaries, all dams again in the head water regions. As the terrain immediately downstream of the head-water region is extremely flat, the catchments there have much less to contribute to river flows. Fig. 2.4 shows the location of these structures.

Keoladeo National Park's water problems have been aggravated by declining river flows and multiple demands on the water stored behind Ajan Bund. Groundwater is also heavily exploited for agriculture in the villages surrounding the park. This poses additional demand on the water of Keoladeo National Park as it induces a downward gradient on the water stored in the marshes, increasing infiltration. This not only adds to the water requirement of the park but also induces an earlier and quicker drawdown of the wetland.

3.4.3. Biodiversity of Keoladeo National Park and Hydrologic Connectivity

Keoladeo National Park is unique, given its small size, in having an exceptionally high biodiversity as compared to that of other terrestrial and aquatic habitats in the same semi-arid climate. It has about 10 per cent of total wetland flora of sub-Himalayan India. Ninety species of aquatic and wetland plants have been recorded from the park and 270 terrestrial floral species have been recorded. Of the fifty fish species identified from the park only six reside permanently in the park. Other species include 30 mammals, 21 reptiles, five amphibians and seven turtles.

Several factors contribute to the high biodiversity of the park. As has been mentioned before in the text, the park was initially part of low lying marshes that surrounded Bharatpur fort. It was directly connected to the two river systems- Gambhir and Banganga, and was essentially a floodplain wetland/ grassland annually inundated by Banganga. Ajan Bund was constructed to contain these flood waters to save the fort, the waters stored in the bund was redistributed for irrigation through several sluices and remaining water was stored in 'ghunna', present day Keoladeo National Park. Once the area was converted into dyked impoundments, more than a century ago, its biodiversity increased. Past history of the park as a wetland must have ensured rapid development of wetland communities from the seed banks in the low lying areas, besides the propagules arriving with the water (Chauhan & Gopal, 2001). Water from Ajan Bund (in effect, the river systems) brought with it many species of fish, floating macrophytes such as duckweeds, plant propagules, and eggs, spores etc of many invertebrates. The vast majority of plant species in the park are seed bank species adapted to seasonal dry-wet cycle (Middleton, 1999). Comparative abundance of waterfowl was recorded during 1982-1990 to be highest in January 1986, following maximum water input of 1985 and lowest in December 1986 following minimum water input of 1986 which was a drought year (Vijayan, 1991).

Further, river alterations including water stablization, shifted flood timing, and increased or decreased flooding have taken a tremendous toll on riverine communities. The loss of biodiversity along many streams and rivers is attributable to the inability of species adapted to flowing waters to live in the altered environments produced by dams and reservoirs. Flood pulsing along rivers is important in the regeneration and maintenance of dominant riverine species in monsoonal wetlands in Australia and India (Middleton, 1999). Long-term studies of naturally variable systems show that some species do best in wet years, that other species do best in dry years, and that overall biological diversity and ecosystem function benefit from these variations in species success (Tilman et. al., 1994). A large body of evidence has shown that the natural flow regime of virtually all rivers is inherently variable, and that this variability is critical to ecosystem function and native biodiversity. Rivers with highly altered and regulated flows lose their ability to support natural processes and native species. Thus, to protect pristine or nearly pristine systems, it is necessary to preserve the natural hydrologic cycle by safeguarding against upstream river development and damaging land uses that modify runoff and sediment supply in the watershed (LeRoy Poff et. al., 1997). Recent research has emphasized the importance of riparian ecosystems as centres of biodiversity and links between terrestrial and aquatic systems. Riparian ecosystems also belong among the environments that are most disturbed by humans and are in need of restoration to maintain biodiversity and ecological integrity. To facilitate the completion of this task, researchers have an important function to communicate their knowledge to policy-makers and managers. For this the basic principles proposed are: (1) The flow regime determines the successional evolution of riparian plant communities and ecological processes. (2) The riparian corridor serves as a pathway for redistribution of organic and inorganic material that influences plant communities along rivers. (3) The riparian system is a transition zone between land and water ecosystems and is proportionately plant species-rich when compared to surrounding ecosystems. Translating these principles into management directives requires more information about how much water a river needs and when and how, i.e., flow variables described by magnitude, frequency, timing, duration, and rate of change. It also requires information about how various groups of organisms are affected by habitat fragmentation, especially in terms of their dispersal. Finally, it requires information about how effects of hydrologic alterations vary between different types of riparian systems and with the location within the watershed (Svedmark, 2002).

The park has been known for supporting a large heronry. Success of heronry is primarily dependent on the amount of fish fry entering the park. Even though both rivers are non-perennial, Gambhir has a number of perennial pools in the river course and also in the tributaries. Conservation of these perennial pools is essential to get sufficient fish fry to the park (Ajith Kumar et. al., 1994). For this it is imperative that the rivers continue to flow to form the connectivity between these pools, some of which are downstream Keoladeo National Park, to Ajan.

Further, pulsing hydroperiod of Keoladeo National Park has added to and maintained the biodiversity of the park. Significance of disturbance dynamics has been elaborated by Middleton (1999). Wetland hydroperiods that show greatest differences between high and low water levels that occur seasonally or periodically are caused by flooding 'pulses'. Pulse fed wetlands are often the most productive wetlands and are the most favourable for exporting materials, energy and biota to adjoining ecosystems. Despite that obvious fact, many wetland managers, especially those who manage wetlands for waterfowl, manage for stable water levels (Mitsch & Gosselink, 1993).

It is thus obvious, that, to maintain the biodiversity of Keoladeo National Park, its connection with watershed is important, not only for water, timing of flooding etc but also for receiving seeds, propagules, spores and fish fry. Increasingly, biological reserves throughout the world are threatened by cumulative alterations in hydrologic connectivity within greater landscapes. Hydrologic connectivity is used to refer to water-mediated transfer of matter, energy, or organisms within or between elements of hydrologic cycle (Pringle, 2000). Changes in the land use and land management frequently result in alterations in the hydrology and water chemistry of wetland areas. These landscape level alterations can change the plant community and hence, functions of the wetland (Owen, 1999). Altered wetlands often become dominated by non-native or invasive plant species (Grace and Wetzel, 1981; Weisner, 1993, cited in Owen 1999) which can lower the biodiversity of wetland, decrease its functional value for humans, and other species, and even result in complete wetland loss (Reed and Cahoon, 1995, cited in Owen, 1999). Human perturbations that alter hydrologic connectivity include dams, stream channelisation, associated flow regulation, and water extraction (from both stream channel and groundwater). Hydrologic connectivity must be carefully managed, both within and beyond the boundaries of biological reserves. However, protection and management of hydrologic connectivity have not been given the attention that they deserve by either conservation biologist or resource managers. Hydrologic connectivity is often ignored until water quality and quantity problems reach problematic proportions, because of lack of data on how hydrology fits into the greater landscape. Also, many alterations in hydrologic connectivity are outside the protected area boundaries and beyond the immediate control of managers (Pringle, 2001).

CHAPTER 4

HYDROLOGICAL FUNCTIONS

This chapter deals with the important hydrological functions that the wetlands of Keoladeo National Park perform in its present hydrogeomorphic setting. Every wetland performs certain functions that are subjective to the position of the wetland in the landscape, for example, headwater wetlands maintain base flow in the rivers, contribute to groundwater recharge, etc., coastal wetlands stabilise the shore line and prevent erosion from wave action, inland wetlands regulate water movement through the floodplains. The objectives in connection with hydrological functions are to identify hydrologic functions of Keoladeo National Park wetlands.

Keoladeo National Park is a surface water depression wetland. As it is located in a depression, it is hydrologically and ecologically a 'sink'. Hydrologically there is no surface water outflows. Ecologically the outflows are essentially biomass extraction, an important wetland function and value. Such areas receive surface water inflows only, there are no groundwater inflows. Water outflow is through infiltration and evapotranspiration. Infiltration is the process that leads to groundwater recharge that maintains a high water table in and around Keoladeo National Park.

Further, it has been noted that groundwater can heavily influence some wetlands while in others it may have hardly any effect at all. The recharge-discharge function of wetlands on groundwater resources has often been cited as one of the most important attributes of wetlands, but it does not hold for all wetland types; nor is there sufficient experience with site specific studies to make many generalizations.

Groundwater inflows result when the surface water (or groundwater) level of a wetland is lower hydrologically than the water table of the surrounding land (called a discharge wetland). A wetland can have both inflows and outflows of groundwater as in riparian wetlands. When water level in a wetland is higher than the water table of its surroundings, groundwater will flow out of the wetland (called a recharge wetland). When a wetland is well above the groundwater of the area, the wetland is referred to a being 'perched'. This type of wetland also referred to as 'surface water depression wetland' loses water only through infiltration into ground and through evapotranspiration (Mitsch & Gosselink, 1993). Keoladeo National Park wetlands are typical surface water depression wetlands. A cross section drawn across east-west section of wetland shows relative position of depression wetland with that of water table during summer months.

Utilization of groundwater in the surrounding areas also has profound effect on the hydrology of a wetland. In a case study, Owen (1999) noted that groundwater flow into the wetland was diverted as a result of groundwater pumping in municipal wells next to the wetland, aquifer maps confirm the existence of a 'cone of depression' formed under the influence of high capacity wells.

4.1 Wetland Functions

Wetland functions are the physical, chemical, and biological processes or attributes of wetlands. Three categories of wetland functions can be distinguished: hydrologic, water quality, and life support (Table 4.1).

Table 4.1- Wetland Functions and Effects

Function Category	Functions	Effects
Hydrologic	Groundwater recharge	Aquifer recharge, maintenance of high water table
	Groundwater discharge	Significant for regional hydrological cycle
	Flood flow alteration	Reduced downstream flood peaks, maintenance of base flows
	Shoreline stabilisation	Protect shorelines and stream banks against erosion, hold the soil in place with their roots, absorb the energy of waves, break up the flow of stream or river currents
Water Quality	Sediment retention	Maintenance of water quality
	Nutrient retention/ transformation	Maintenance of nutrient stock within the wetland
Life Support	Biological (primary) production	Food production, wood production, Biomass export,
	Aquatic diversity/ abundance	Maintenance of characteristic plant community
	Wildlife diversity/ abundance	Habitat and ecosystem support

Hydrologic functions include the capacity of wetlands to reduce and desynchronize peak flood discharge, influence base flow, modify groundwater-surface water interactions, and stabilize shorelines (Lewis, 1995)

Wetlands, depending on their position within the watershed or the landscape perform various functions. Wetland functions are subject to the hydrological flux through the wetland system. Hydrology is probably the single most important determinant for the establishment and maintenance of specific types of wetland and wetland processes (Mitsch & Gosselink, 1986).

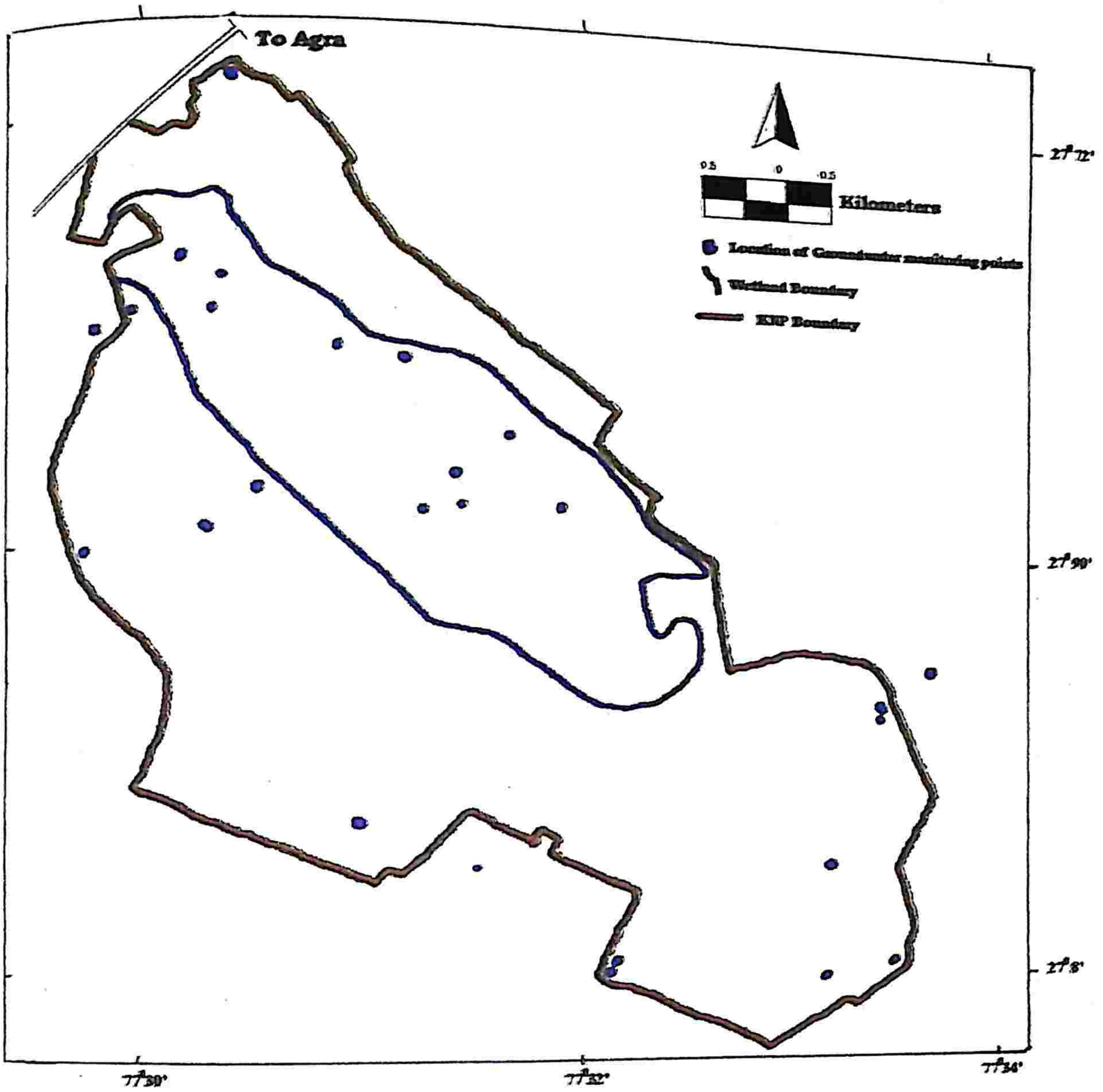
Wetlands play a critical role in regulating water movement of water within watersheds as well as in the global water cycle. Wetlands store precipitation and surface water and then slowly release the water into associated surface water resources, ground water, and the atmosphere. In their paper titled 'Role of wetlands in the hydrological cycle' Bullock and Acreman (2003) have drawn a database from 169 publications to: present an ordered database of published papers on hydrological functions of wetlands; provide a collation of scientific evidence among hydrological measures and wetland type; and to stimulate debate and further research. The focus of the paper is limited to water quantity functions, including impacts on water resource availability, groundwater replenishment and flood control. Some common findings include that wetlands evaporate more water than other forest types, play a significant role in controlling floods, and in monsoonal climates play a significant role in groundwater recharge.

4.2 Methodological Approaches

The water table fluctuations at 37 locations were noted during the study period from May 2002 to April 2005 (Fig. 4.1). Of these 37 locations 11 wells went dry at least once during study period. During the study period the wells that were dry due to drought conditions were not considered for later analysis, data from remaining 25 locations were utilised for analysis. These observation points consist both of existing wells, which were largely undisturbed, as well as groundwater monitoring wells drilled for the purpose. Shallow monitoring wells allow penetration of water through perforations along most of the length of the pipe below ground. Therefore, the water level in a monitoring well reflects the composite water pressure integrated over the long, perforated portion of the pipe. This kind of well is sometimes called an "open-sided well," "observation well" such observation wells were installed using 5 inch diameter PVC pipes perforated all along (WRP technical note HY-1A-3.1, 1993). These were inserted in a section drilled to 30 feet below ground surface. The top was capped and sides of the pipe on the top were sealed using bentonite to prevent any water flowing inside the monitoring wells from the top. Water table readings were taken weekly over the study period, that is, from May 2002 to April 2005. This data is presented graphically to examine the trends that water table follows.

Estimates of local groundwater contours are determined using various sets of three groundwater elevations known from observation wells. From field measurement of static water levels in wells within the park, a water level contour map was constructed. Flow lines, sketched perpendicular to contours, show directions of movement. Convex contours indicate regions of groundwater recharge, while concave contours are associated with groundwater discharge (Todd, 1980). Contours help in understanding the direction of groundwater movement.

Fig. 4.1 Locations of groundwater monitoring points



4.3 Results

Water table fluctuations were recorded at 25 observation points from May 2002 to April 2005. These 25 observation points represent functioning wells. The groundwater contours observed during 2003 (only year when recharge of groundwater occurred) are given below in Fig. 4.2.

The cross sections across wetland have been drawn to show relative position of ground water table in pre-monsoon and post-monsoon season to show the extent of recharge. Fig. 4.3 shows east – west section across the wetland of Keoladeo National Park marking relative position of water table during the pre and post monsoon season of 2003 in Keoladeo National Park. Fig. 4.4 shows North- South section across the wetland of Keoladeo National Park marking relative position of water table during the pre and post monsoon season of 2003 in Keoladeo National Park.

Fig. 4.2 Groundwater levels (Pre-monsoon 2003)

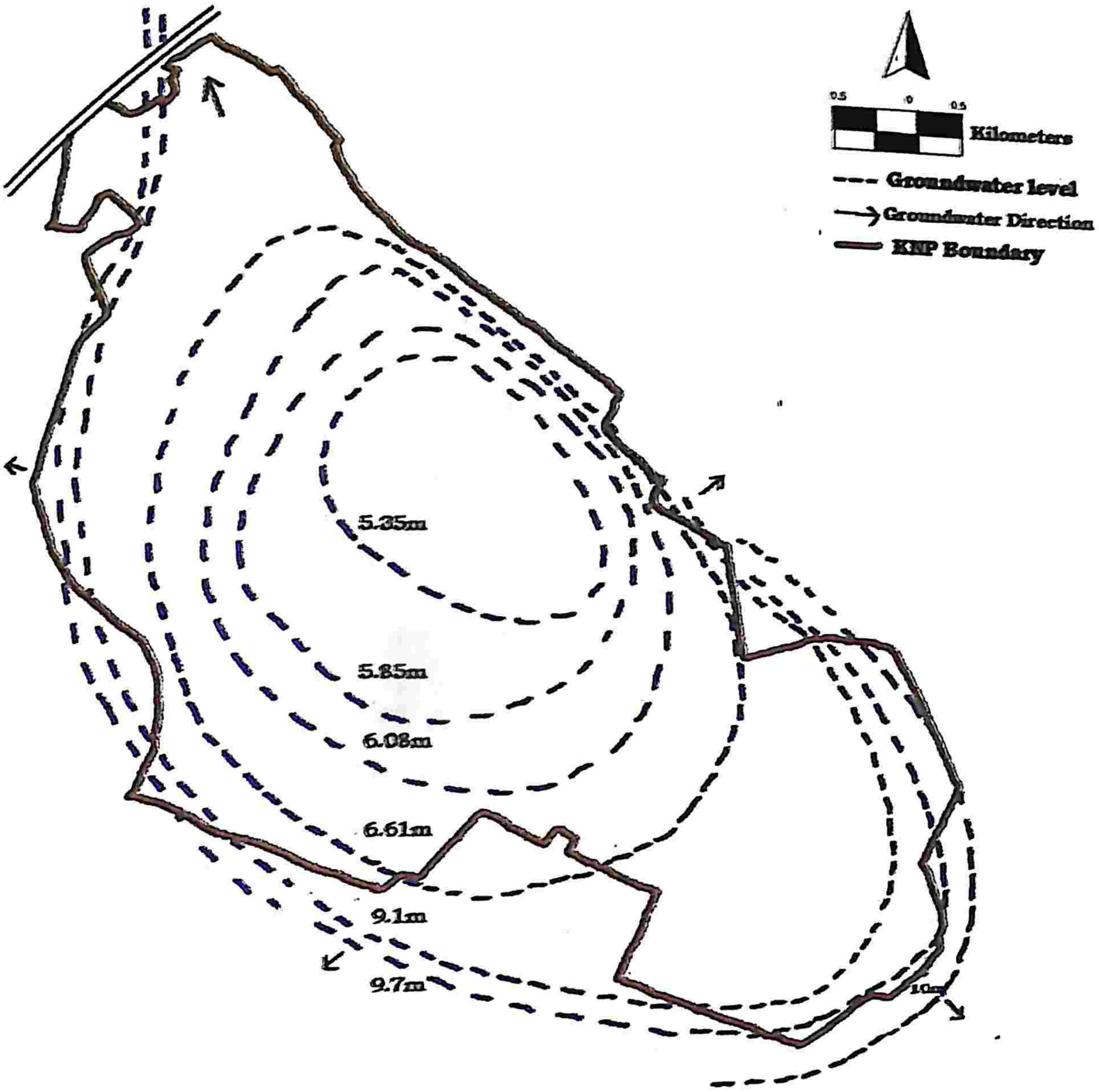


Fig. 4.3 East West Section through the wetland showing water table levels during Pre- and Post monsoon 2003

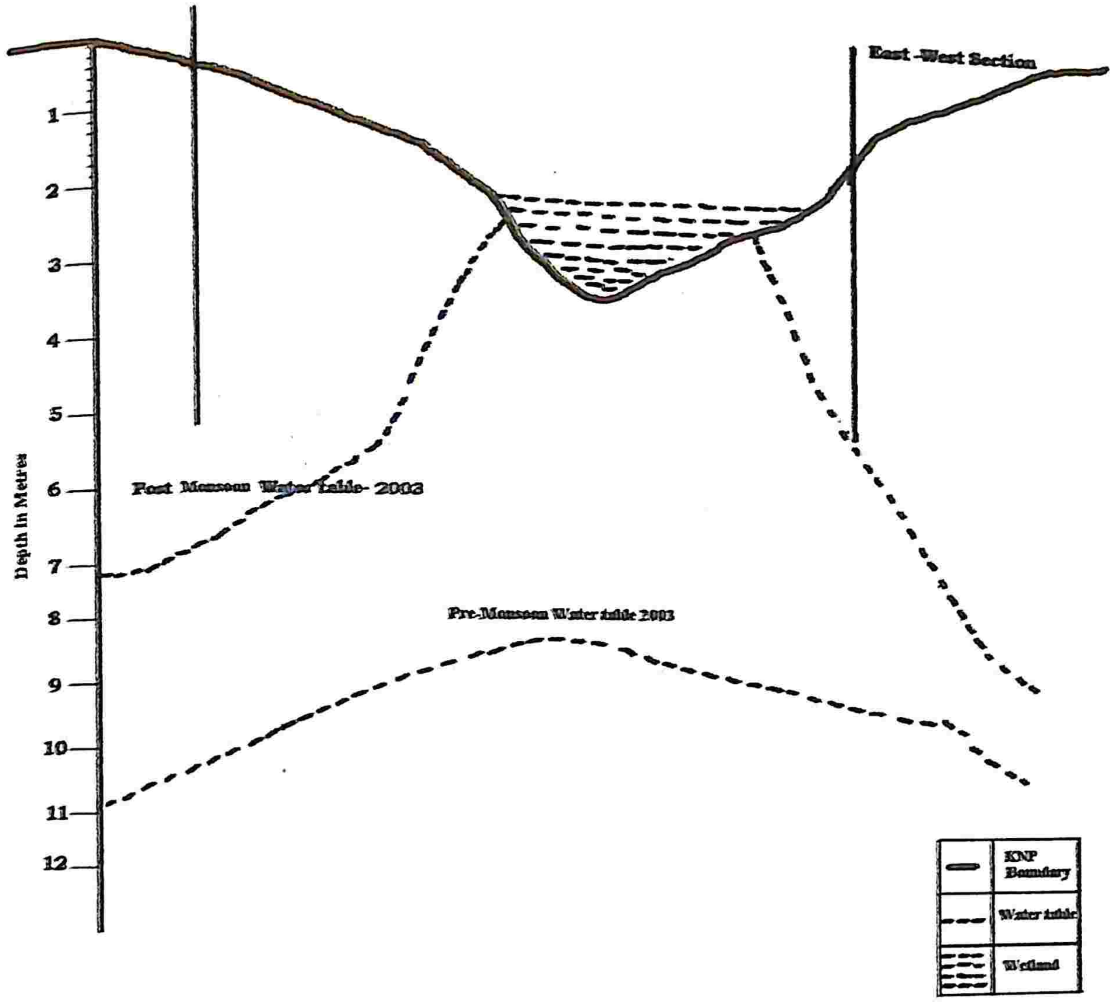
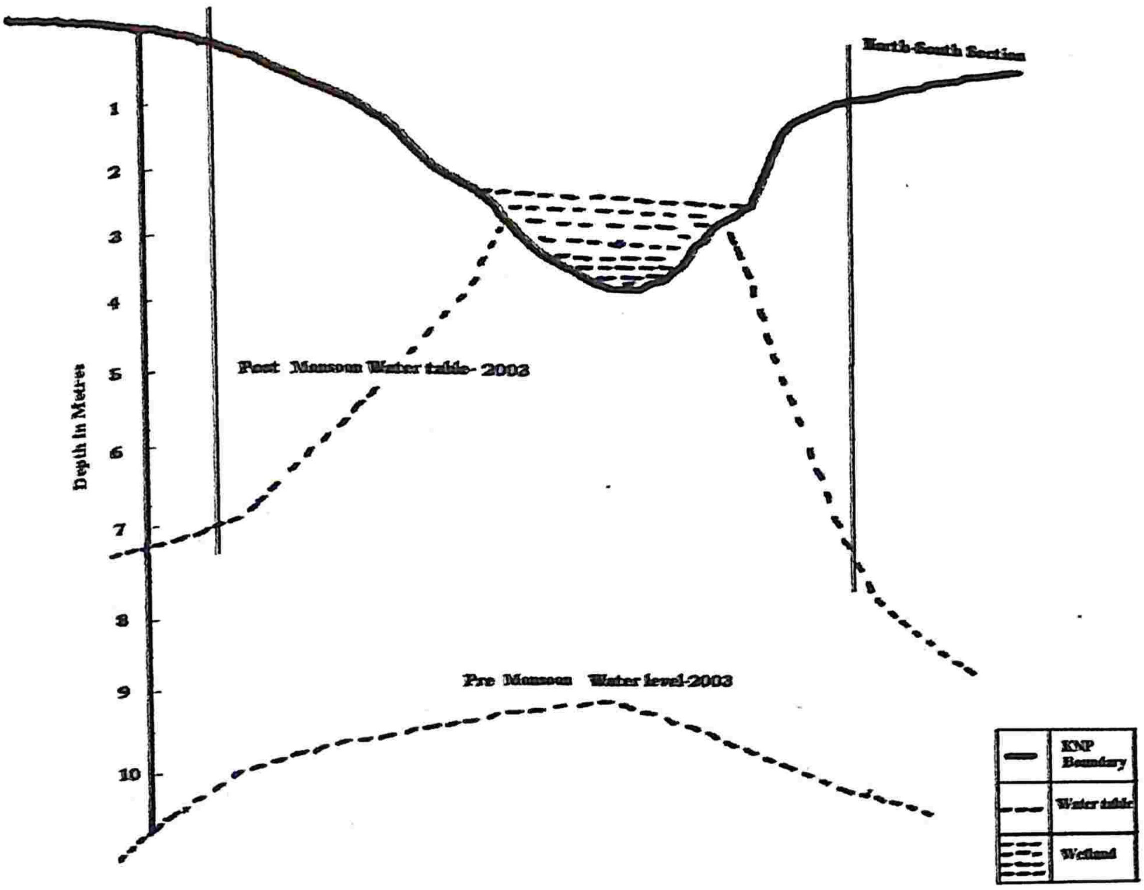


Fig. 4.4 North South Section through the wetland showing water table levels during Pre- and Post monsoon 2003



To study the role of Keoladeo National Park marshes in maintaining water table of the area by aquifer recharge, the water table in and around the wetland were noted over three years, i.e., May 2002 to April 2005. These three years showed significant variation in rainfall as well as water received by the wetland from the watershed. The fluctuations in the water table are represented here graphically (Fig. 4.6), location of these observation points are shown in Fig. 4.5.

Fig. 4.5 Location of observation wells in Keoladeo National Park

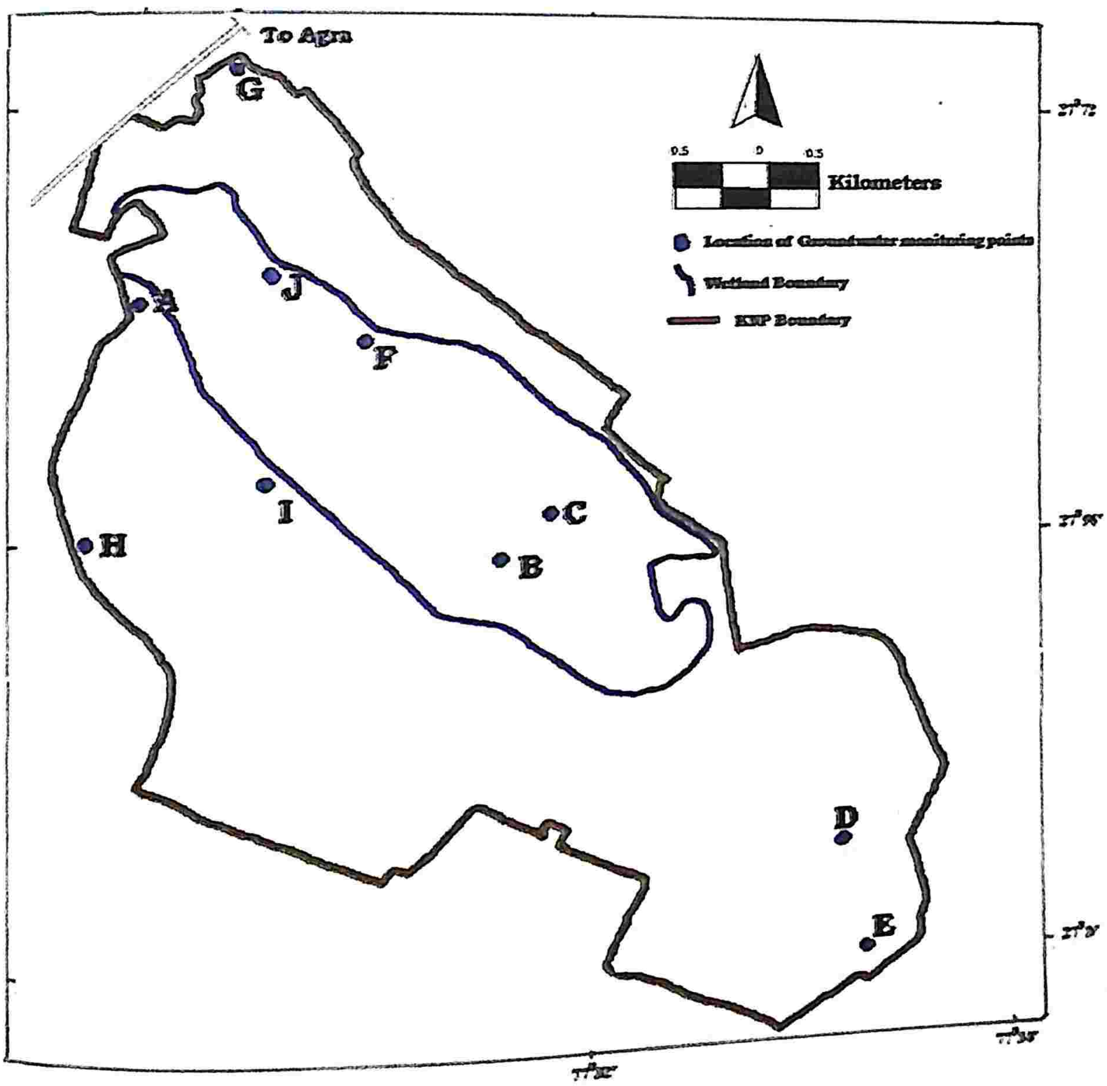
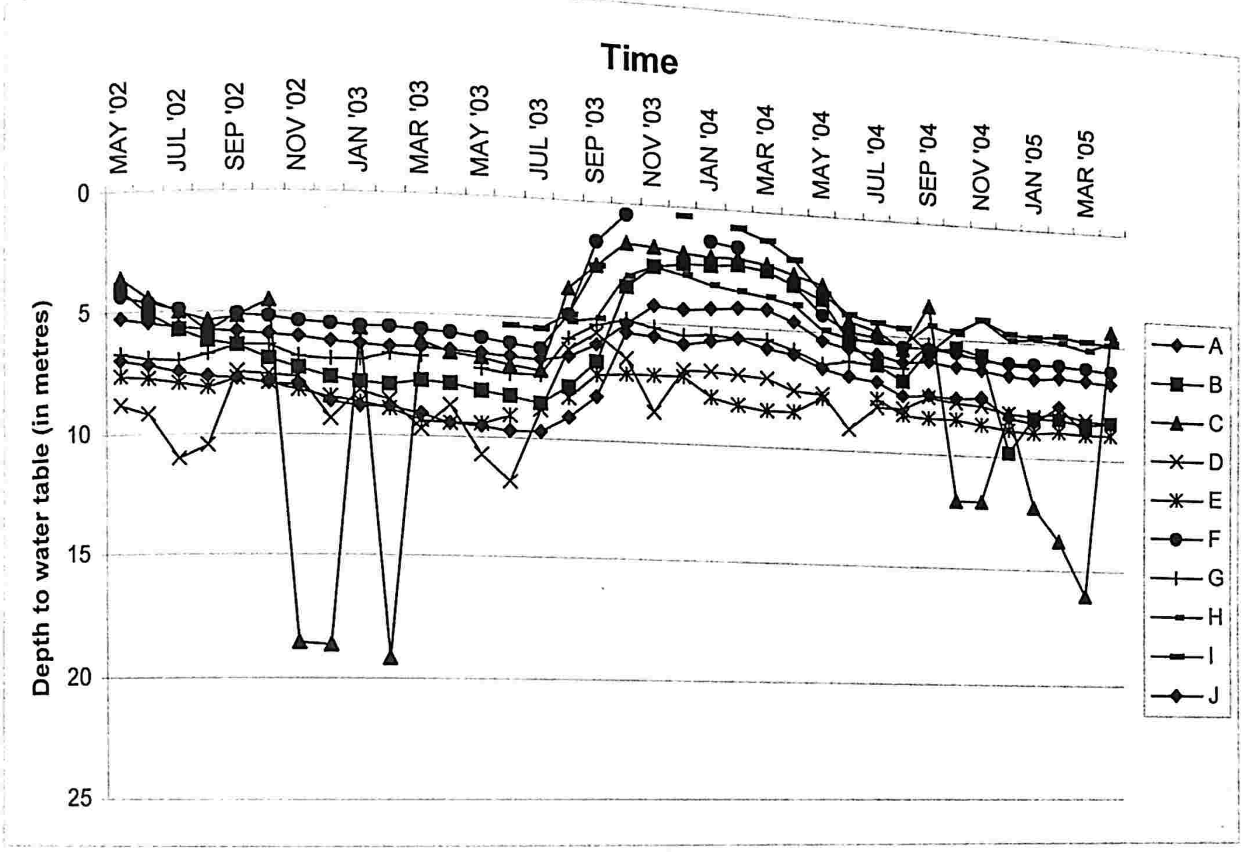


Fig. 4.6 Water table variations in Keoladeo National Park

(May 2002 to April 2003)



The recharge is seen only after monsoon of 2003 as then the wetland received water from Ajan bund. This water was retained, albeit in small pools till March 2004. The observations points, B, C, F and I are situated within the wetland. These show highest water table and also highest recharge [range]. Points A, G, H and J have lower water table as these are situated more than 500 meters away from the edge of the wetland, and, points D & E show the lowest water table as these are situated more than 2000 meters away from the wetland. The points furthest from the wetland not only have lesser recharge, but show a fall in water table earlier than other observation points. For example, at Point H, which is near Ramnagar village, the decline in water table begins as early as December 2004. This could possibly be due to groundwater withdrawal in nearby areas for irrigating the winter wheat of rabi agricultural season. Very high variation in points C, located near Keoladeo Temple, and in point D, located inside the Koladhar Chowki is due to the fact that these wells are used for extraction of water in dry season; former for filling the wetland and latter for providing water in the waterholes as well as for the forest guard posts. These sudden dips in the water table are observed during 2002 and 2004 as during these years the wetlands were dry.

dry season

The general trend observed through this graph is that (a) water table gradually falls as the distance from the wetland increases and (b) while recharging, the water table rapidly rises during monsoon months and continue to do so until late October or November, reaches a plateau during the post-monsoon months and rapidly falls during drawdown months of January-March. This is followed by gradual fall during pre-monsoon months of April-June.

To measure the groundwater recharge during each year 'range' for each observation well was calculated. Range is the highest and lowest measurement in a group of data (Zar, 2006). The range of water table levels is given in Table 4.2.

Table 4.2: Range of water table levels during study period

		May 2002-April 2003	**May 2003-April 2004**	**May 2004-April 2005**
S. No.	**Observation well**			
1.	F Block		2.25	1.05
2.	K Block		5.52	0.16
3.	Keoladeo	3.96	6.22	6.17
4.	Dawri Walla*	20.4	5.55	14.6

5.	Behnera Chowki	1.06	3.55	2.32
6.	Behnera	0.96	1.23	0.44
7.	Koladhar*	5.55	6.95	2.50
8.	Darapur	0.40	2.13	2.80
9.	H Block	1.87	2.54	1.25
10.	Naswaria	1.64	1.83	0.98
11.	L Block	1.5	6.4	2.11
12.	Seeta Ram	3.45	7.65	2.90
13.	Jatoli	2.12	7.1	2.90
14.	Nursery*	3.00	8.5	4.43
15.	Sotan Walla	1.42	1.21	0.77
16.	Main Gate	1.10	2.9	1.36
17.	Kothi	1.33	2.62	1.40
18.	Mallah Chowki	1.27	4.12	1.86
19.	Mallah Village	2.44	4.42	2.72
20.	Agahpur Chowki		2.92	0.09
21.	Ramnagar		3.01	1.34
22.	M2		2.45	1.35
23.	Ls		2.56	1.28
24.	Trail No. 3		5.40	2.58
25.	N Block		5.38	1.00

Note: All figures are in metres.
Range represents the rise and fall of water table.
*This well was used by the Forest department for water extraction, hence it shows a reversal in ranges as compared to other observation points.

The ranges during the year 2003-04 are significantly higher as compared to other two years at all the location except one. This exceptional trend is observed as the well was used by the Forest Department for groundwater extraction during drought years.

On closer examination, water table fluctuations observed at various points show four different trends during the four seasons of the wetland: pre-monsoon, monsoon, post-monsoon and draw-down. Table 4.3 summarises these trends and the locations where each is observed.

Table 4.3: Trends in water table fluctuation in and around Keoladeo National Park (2002-2005)

Seasons/ Group	Pre-monsoon	Monsoon	Post-monsoon	Drawdown	Location
Group 1	Sharp Fall in water table	Sharp rise in water table	A "plateau" is maintained in the water table	Sharp Fall	L Block, K Block, F Block, Keoladeo, Trail no. 3
Group 2	Sharp Fall in water table	Sharp rise in water table	The water table reaches a peak but lack an appreciable "Plateau"	Gradual Fall in water table	Ramnagar, Main Gate, Agahpur, Darapur, Naswaria, H Block
Group 3	Sharp Fall in water table	Gradual but slow rise in water table	Gradual rise in water table continues	Water table reaches a peak an plateau then falls	L-south Block, Kothi, Mallah chowki & village
Group 4	No obvious trend, as these wells were used for withdrawing large quantum of water for various purposes				Dawri, Koladhar, Nursery

The locations in group 1 are all situated inside the wetland, in group 2 are more that one kilometre away from the wetland and those in group 3 are either on the edge of the wetland or within 500 metres of it. Fig. 4.7 below show the trends in each of these groups and Fig. 4.8 gives the location of these groundwater table observation points.

Fig. 4.7 Trends in water table at various locations in Keoladeo National Park

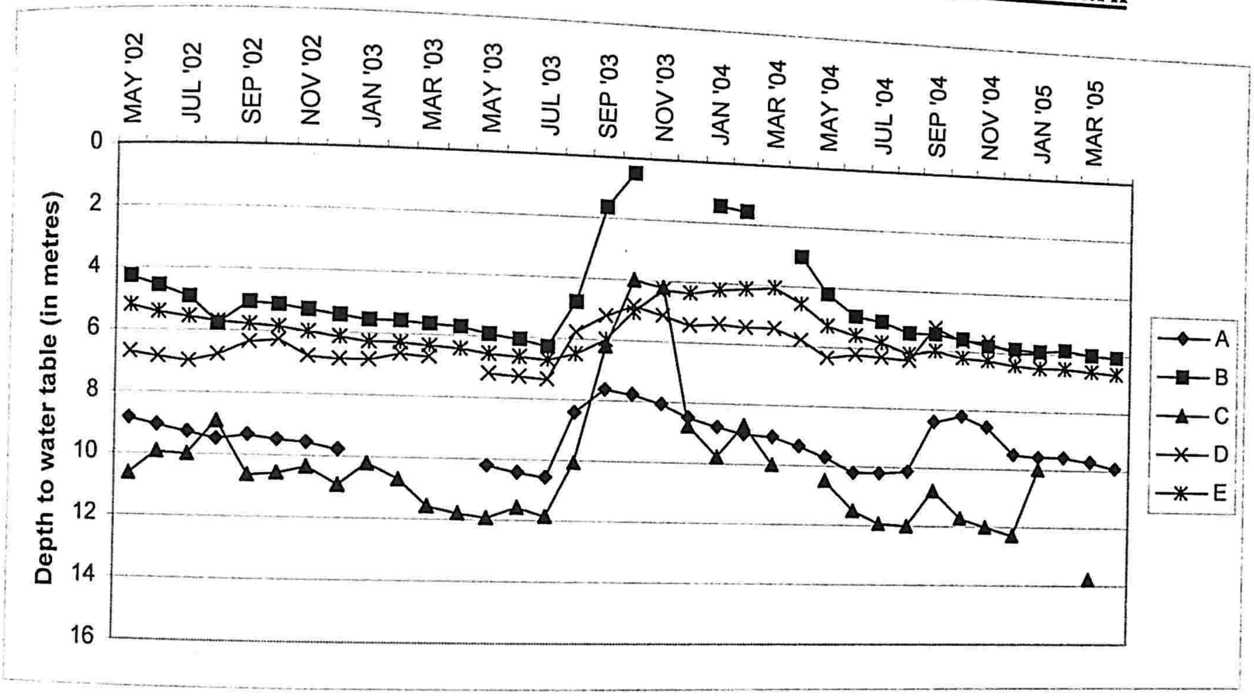
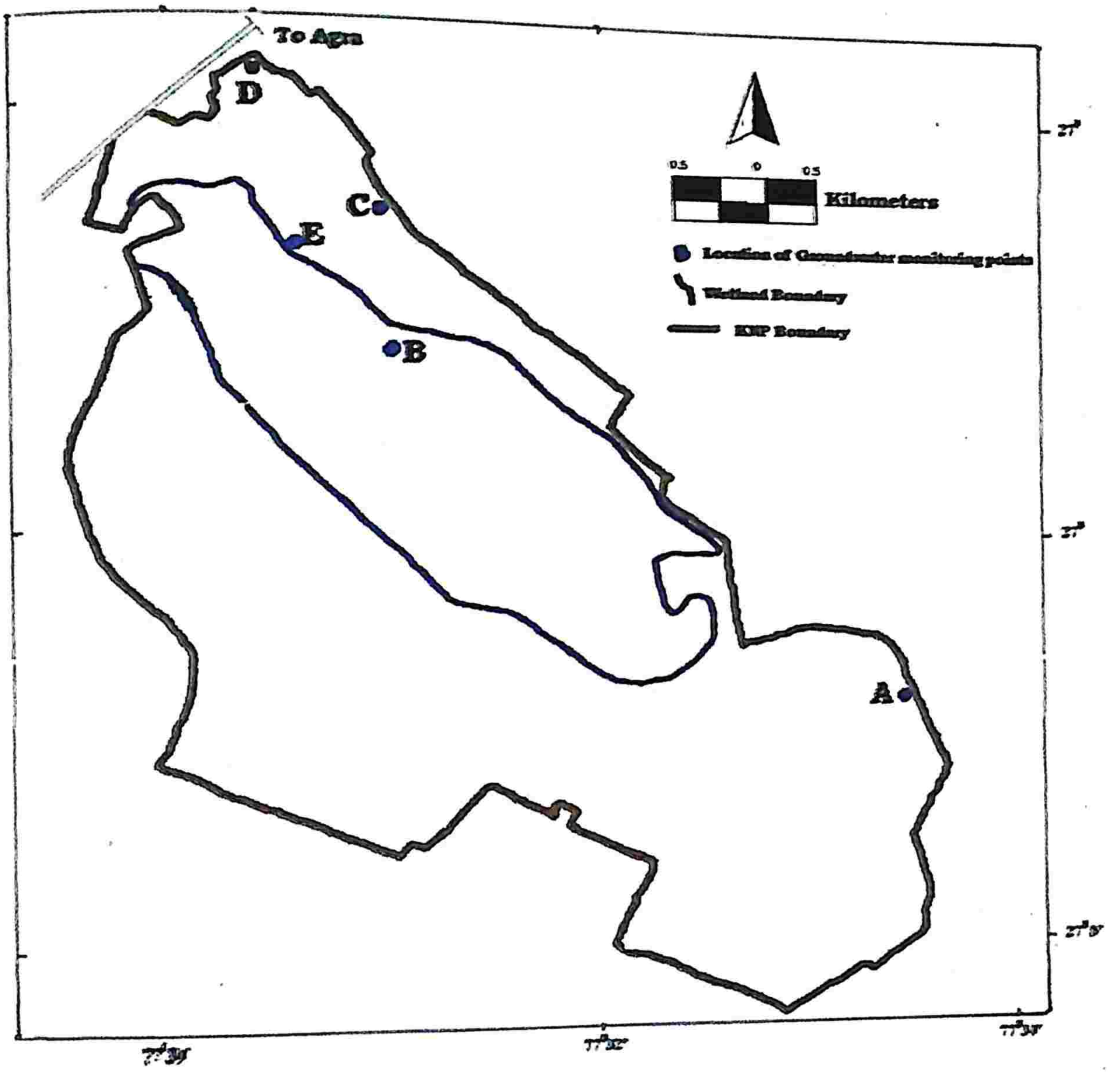


Fig 4.8 Location of observation points



Location A, is near the village of Behnera (from Group 2), shows a sharp rise in water table, reaches a peak in the post monsoon season and immediately starts to fall gradually. This fall in water table coincides with the time of irrigation for winter wheat crop, as the most common mode of irrigation in the vicinity of Keoladeo National Park is tube well irrigation using diesel pump-sets, the water table gradually drops over the irrigation season reaching the lowest in June. Location B is situated within the wetland in L-Block. Here water table shows a sharp fall in pre-monsoon, a sharp rise in monsoon, almost reaching ground surface, then a plateau in post monsoon. The plateau represents a high water table during monsoon months and also in post-monsoon months. During the drawdown it shows a sharp fall as by then the water table further from the wetland has already fallen and sub-surface largely being sandy, the water movement away from the wetland is quick. Location C showed sharp rises and declined as the water was withdrawn from this well to supply to housing and office complex as such, it follows no trend. The recharge is usually quick as it is situated very close to the wetland. Location D is situated near the main gate, at a significant distance from the wetland. It follows a similar trend as that of location 1, but has higher water table as it is closer to the wetland. Location E was situated near the edge of the wetland. Notably it reaches a peak much later than the other locations that were situated within the wetland or significantly away from the wetland. This deviation in trend is dealt with later in the chapter.

Fig. 4.9 demonstrates trend in water table at observation points falling under group 1, that is, those locations which are more than one kilometre away from the wetland. Fig. 4.10 gives the location of these points in Keoladeo National Park.

Fig. 4.9 Water table trend observed at locations under group 1 (More than one kilometre away from the wetland)

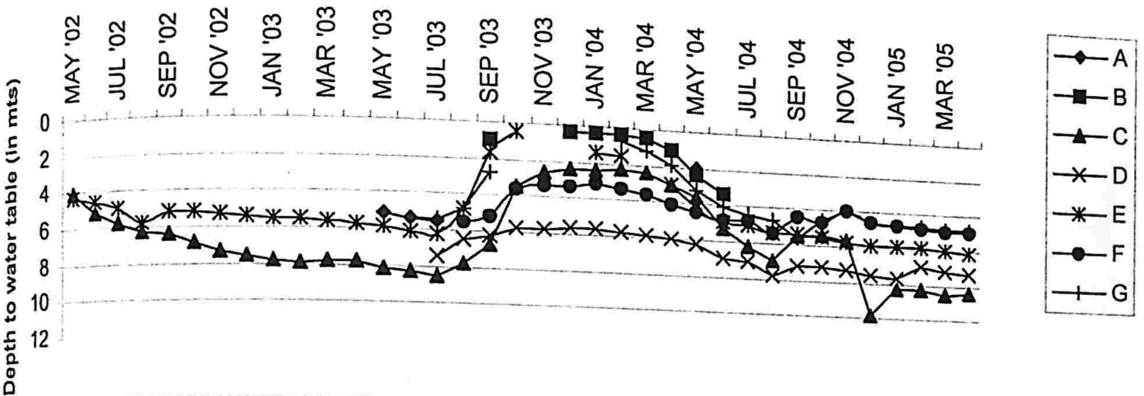


Fig 4.10 Location of observation points

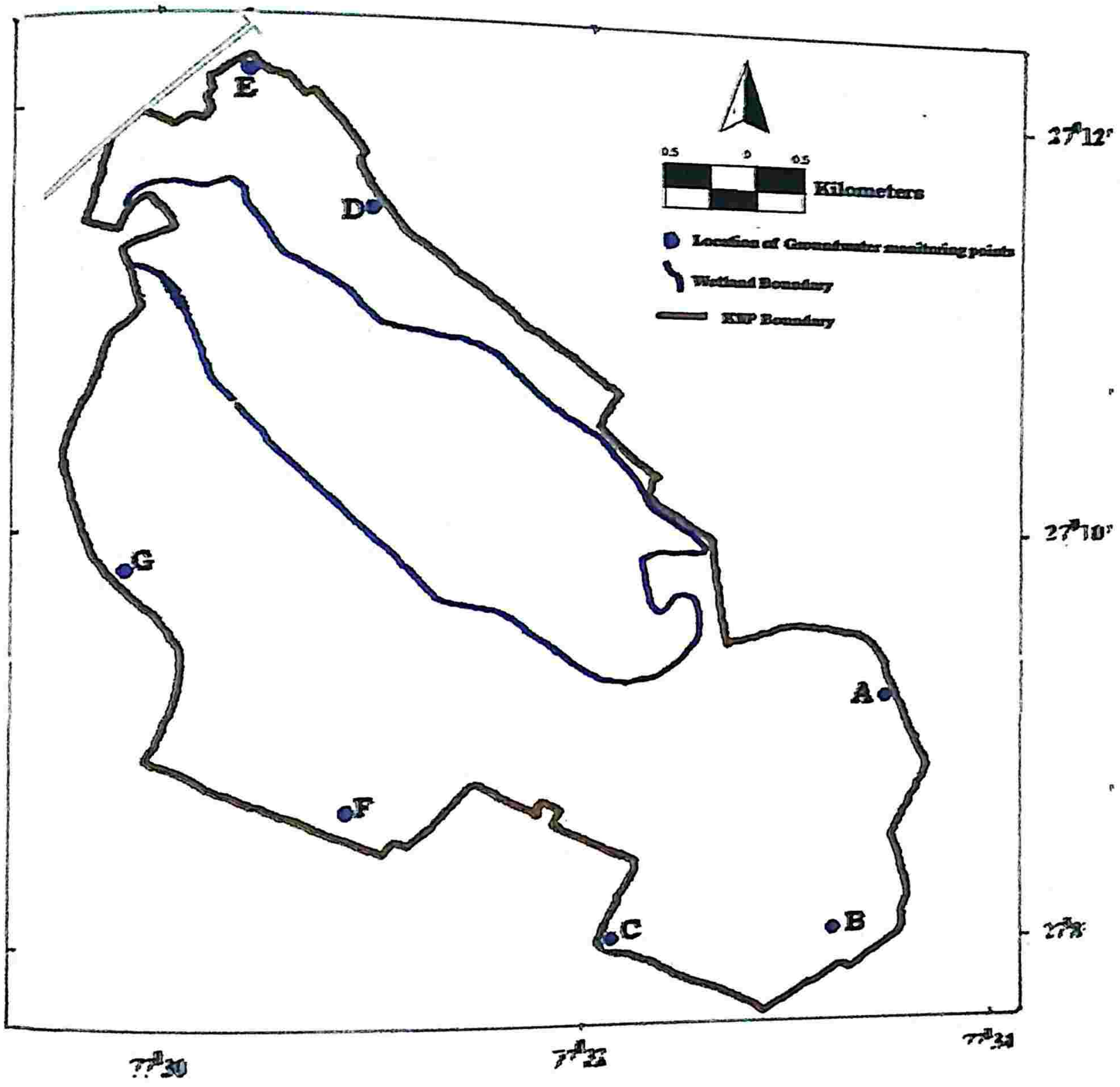


Figure 4.11 below demonstrates trends at observation points falling under group 2. that is, located within the wetland, fig. 4.12 gives the location of these observation points in Keoladeo National Park.

Fig. 4.11 Water table trend observed at locations under group 2 (Located within the wetland)

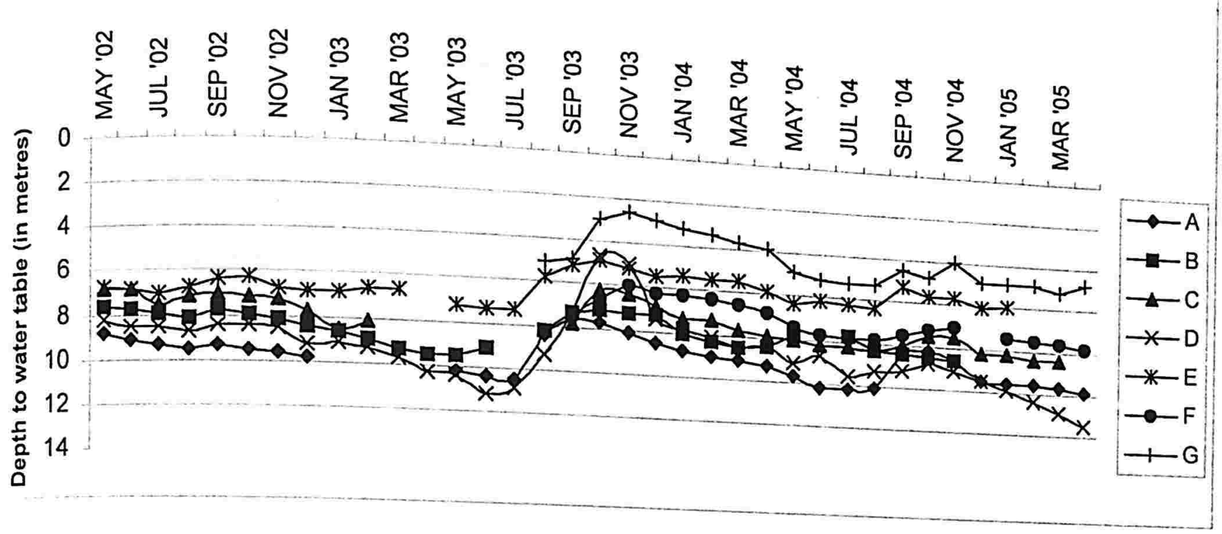


Fig 4.12 Location of observation points

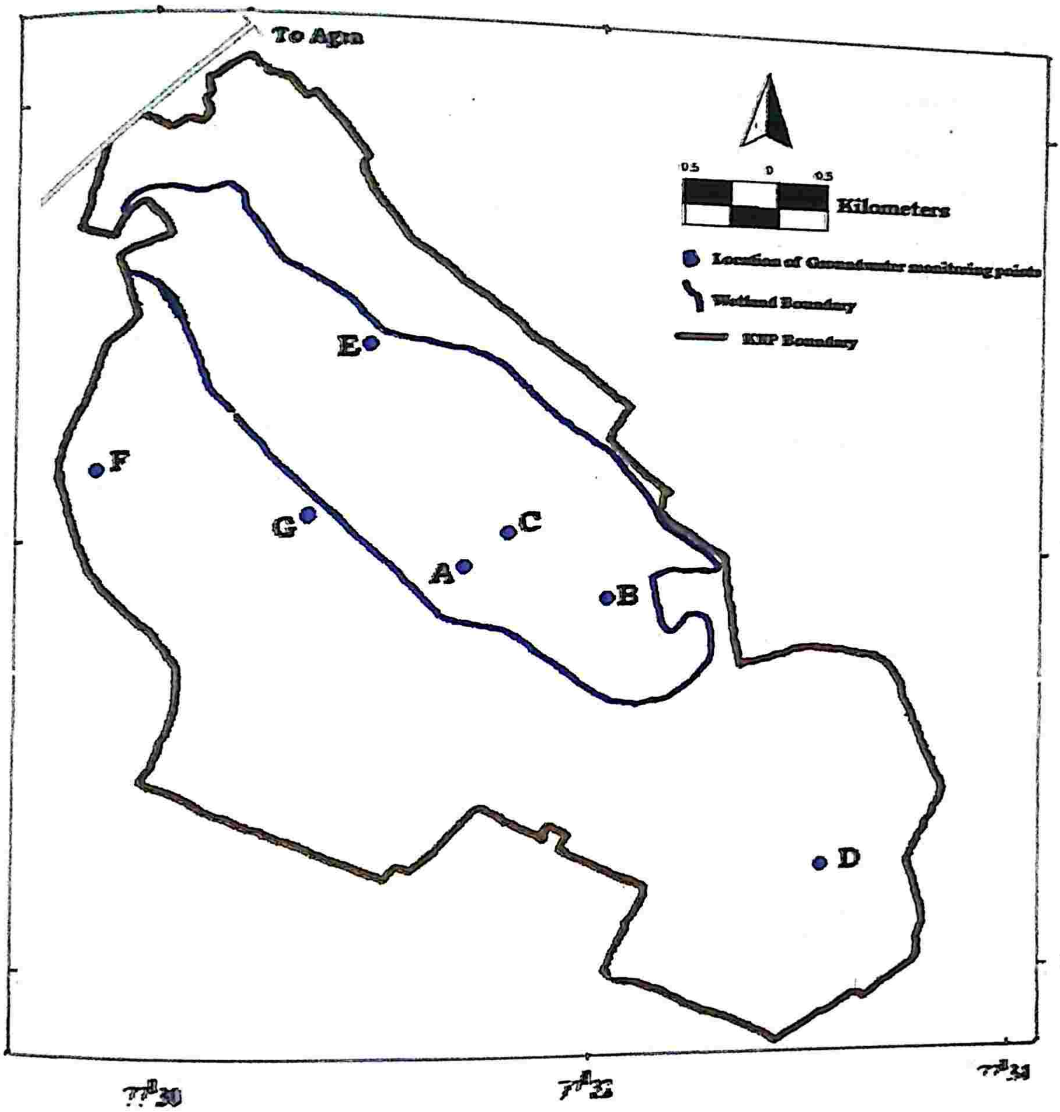


Figure 4.13 below demonstrates trends at observation points falling under group 3, that is, located near the edge of the wetland, fig. 4.14 gives the locations of these points in Keoladeo National Park.

Fig. 4.13 Water table trend observed at locations under group 3 (Located near the edge of the wetland)

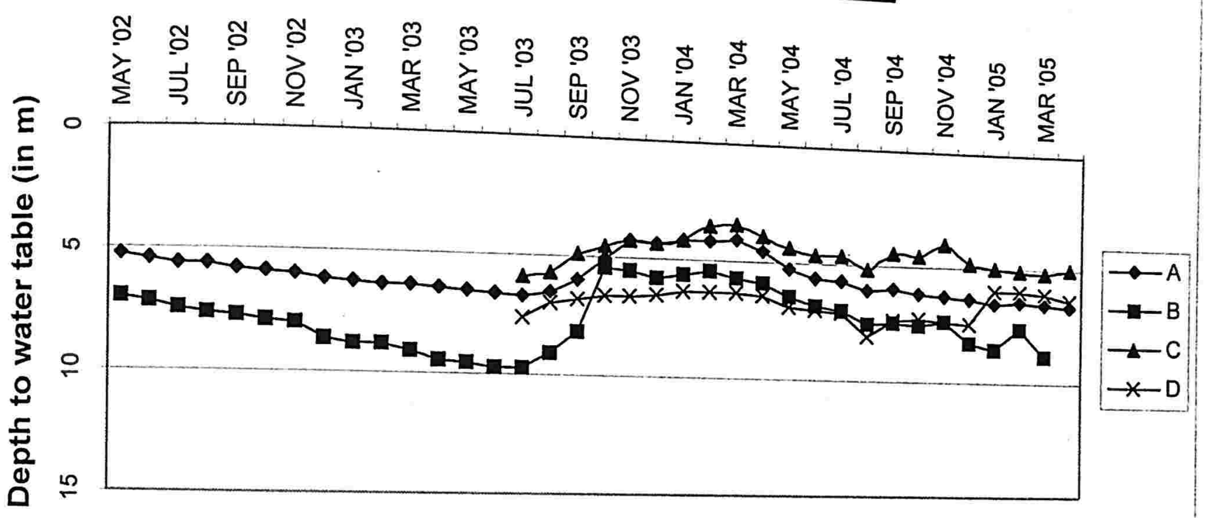
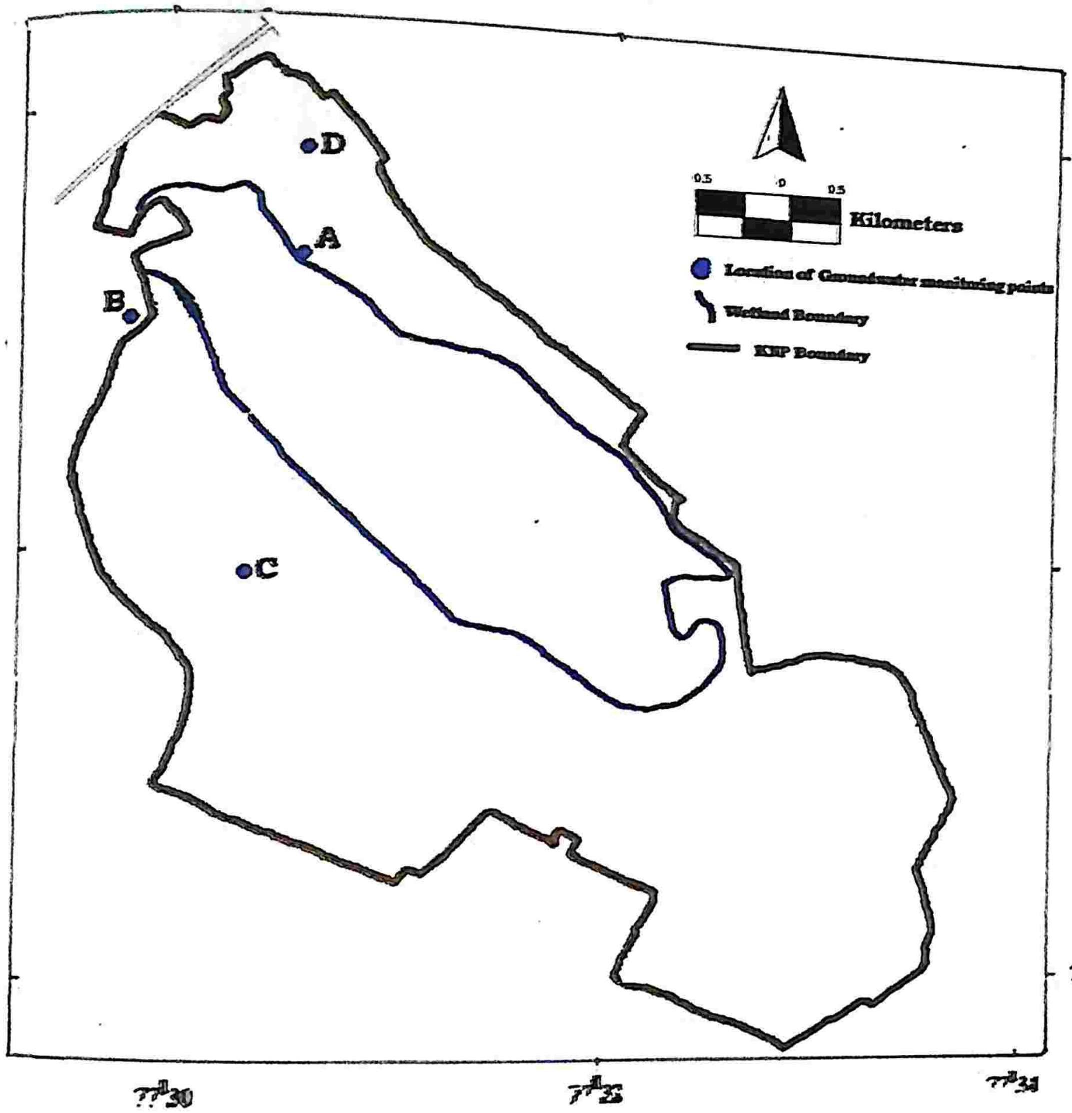


Fig 4.14 Location of observation points



4.4. DISCUSSION

The change in water table depth demonstrate three different trends as mentioned before. The locations near the wetland or with in it get recharged immediately after retention of water in the wetland. These area have a high water table for a longer duration due to lack of extraction of groundwater in their vicinity.

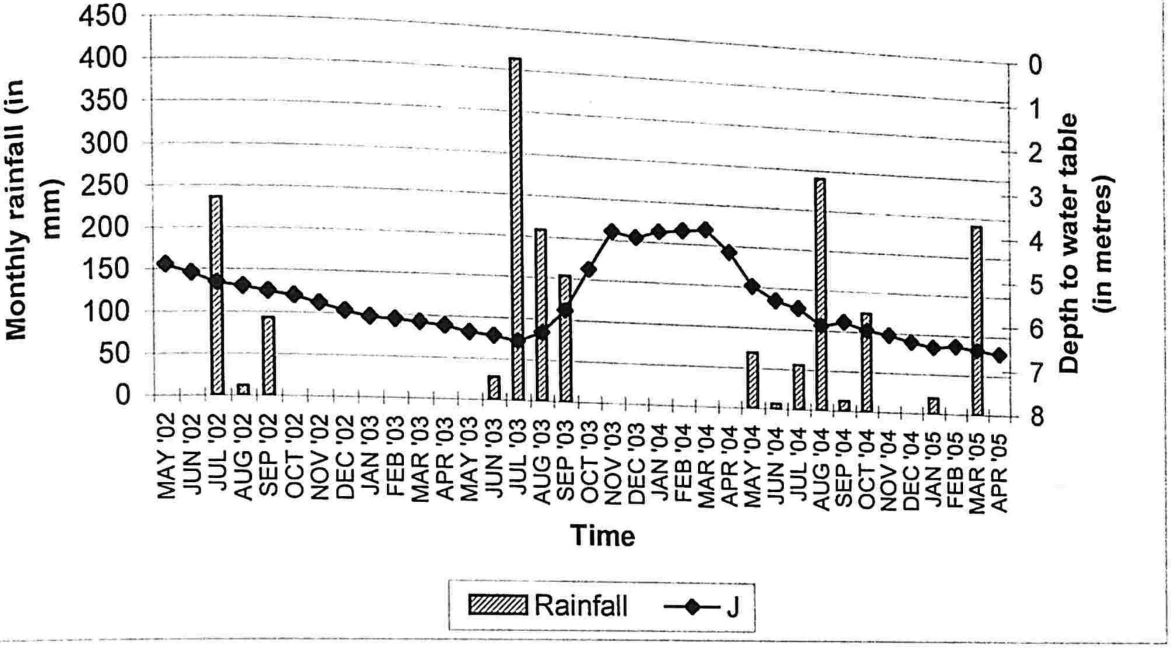
Significantly, the water table at the edge of the wetland rises gradually, attains a peak very late, almost at the drawdown time and falls rapidly. This trend deviates from the other two locations- within the wetland or away from it, where a peak is attained in the post monsoon season. The reason for this deviation could be that there is a “pull” on the water table in this region from both directions that is within the wetland as well as away from it. As the groundwater withdrawal has already started at location away from the wetland, the ground water moves away from the wetland under that influence of that pressure. At the same time the emergent and other grasses are growing rapidly and therefore losing a lot of water through evapotranspiration. This also exerts a pressure on the ground water. It has been observed by researchers that an additional factor in lowering wetland water levels during draw-down and summer is the transpiration of groundwater around the perimeter of the wetland, this process causes depression in the wetland that intercepts groundwater that would otherwise discharge to the wetland and cause water to seep from wetland as well (Winter et al. 2001).

Another significant finding is that the rainfall contributes little to groundwater recharge. It is actually the amount and duration of water retained within the wetland blocks that alone determines groundwater recharge in and around Keoladeo National Park. This is so because although the rainfall during year 2004-05 was significant, 556.9 mm, much higher that year 2002, 345.2 mm, the water table follows the same trend. The rainfall in 2003 was higher than both years but the significant variation during this time was good amount of surface water retained in wetlands. During 2003 287 mcft water was released from Ajan Bund which was retained till early March 2004, albeit in small pools in deeper areas. Fig. 3.3 shows the trend of water table vis-à-vis monthly rainfall. During monsoon of 2004 , although there is good rainfall the water table does not show any recharge, as compared to 2003 when there is significant recharge during the same months. The water table in 2004-05 follows the same trend as in 2002-03 when the rainfall was much less. Table 4.4 gives correlations of well in three groups with cumulative rainfall shows no relation. Fig. 4.15 gives the trend of water table observed during study period vis-à-vis monthly rainfall.

Table 4.4- Correlation of wells in three zones with cumulative rainfall

		CUMRAIN	MALLAH	HBLOCK	KEOLADEO
CUMRAIN	Correlation Coefficient	1.000	-.268	-.193	-.333
	Sig. (2-tailed)	.	.119	.268	.050
	N	35	35	35	35
MALLAH	Correlation Coefficient	-.268	1.000	.679	.911
	Sig. (2-tailed)	.119	.	.000	.000
	N	35	35	35	35
HBLOCK	Correlation Coefficient	-.193	.679	1.000	.683
	Sig. (2-tailed)	.268	.000	.	.000
	N	35	35	35	35
KEOLADEO	Correlation Coefficient	-.333	.911	.683	1.000
	Sig. (2-tailed)	.050	.000	.000	.
	N	35	35	35	35

Fig. 4.15 Water table fluctuation and corresponding monthly rainfall (May 2002-April 2005)



Same trend is followed by water table at all observation points. Graphs of some observation points are drawn demonstrate comparative trends of the water during the three years. The smaller peaks in graph during monsoon and post- monsoon of year 2004 signify the contribution of rainfall in groundwater recharge. These peaks are observed on days following high rainfall days in the area.

The extent of groundwater recharge is denoted by the range of water table. The range observed in the three groups show different trends. In Group 1 the wells were located with in or near the wetland. This group shows highest range signifying maximum recharge.

Table 4.5: Range of water table in Group 1

	May 2002- April 2003	May 2003- April 2004	May 2004- April 2005
Observation point			
A	0	5.52	0.61
B	0	2.25	1.05
C	3.96	6.22	6.17
D	5.55	6.95	2.5
E	1.5	6.4	2.11
F	0	2.45	1.35
G		5.4	2.58

Note: Range represents the rise and fall of water table. All figures are in metres.

Locations in group two i.e., those location that were 500 m to 2000 m away from the wetland show range closer to group 1 as shown in Table 4.6.

Table 4.6: Range of water table in Group 2

	May 2002- April 2003	May 2003- April 2004	May 2004- April 2005
Observation point			
A	1.06	3.55	2.32
B	1.87	2.54	1.25
C	1.642	1.83	0.98
D	2.12	7.1	2.9
E	1.1	2.9	1.36

F	0	2.37	0.9
G	0	3.01	1.34

Note: Range represents the rise and fall of water table. All figures are in metres.

Locations in group 3 i.e., those location that were more than 2000 m away from the wetland show lowest range as shown in table 4.6.

Table 4.6: Range in water table in Group 3

	May 2002-April 2003	May 2003-April 2004	May 2004-April 2005
Observation point			
A	1.33	2.62	1.4
B	2.44	4.42	2.72
C	0	2.56	1.28
D	1.1	2.9	1.36

Note: Range represents the rise and fall of water table. All figures are in metres.

The trend in years that were dry i.e., 2002-03 and 2004-05 show similar ranges. This again re-emphasizes that recharge of groundwater is significant only during 2003-04 when water received from Ajan dam was retained in wetland.

Chapter 5

WATER MANAGEMENT AND RELATED ISSUES

As Keoladeo National Park is located in semiarid region and is fed by ephemeral rivers, the effects of water crisis are acute as well as immediate. The overall water budget calculated in this study, considers the ecological requirement of evapotranspiration, within the Protected Area for its biodiversity value support role and socio-economic or stakeholder (villager) requirement of groundwater recharge and management requirement of water storage within the wetland. Further, the wetlands of Keoladeo National Park perform several important hydrological functions like groundwater recharge that have value not only for sustaining the ecology of the region but also for the surrounding villagers in the area in providing water for irrigation. These functions and values of the national park need to be highlighted.

5.1. Water Management in Keoladeo National Park

The water budget of Keoladeo National Park wetland is calculated to be 18.13 MCM. Of this, the total water evapotranspiration and infiltration contribute most (53.98%) to the outflows in the water budget. It is found that evapotranspiration from vegetated areas is much more than open water areas and that evapotranspiration from *Paspalum distichum* is higher than other species (ref. Fig. 3.2). Further, the values for evapotranspiration reach a peak in October. Since *Paspalum distichum* now covers almost all the wetland area and is a weed its control would have significant implications on the water budget of Keoladeo

National Park. In the present study the quantum of evapotranspiration are significant and this component of the water budget can be fairly reduced by controlling growth of *Paspalum distichum* in Keoladeo National Park.

Secondly, as mentioned in section 3.3.2.3.3., the water holding capacity of the wetlands seems to be significantly reduced. This is probably because of siltation as well as accumulation of biological matter in the wetland. Since there is no significant extraction of biomass from the wetland the biological matter is getting accumulated. Also, *Paspalum distichum* has higher biomass than other species (van der Valk et.al., 1993) therefore; accumulation of biological matter in the wetland is more as compared with a situation where *Paspalum distichum* was not over growing.

Finally, the outflow of water from the wetland that is the recharge of groundwater (see chapter 4) because of which the villagers around the park are significantly benefited needs to be highlighted.

5.2. Inquiry into Hydrological Management for the Keoladeo National Park Landscape and The Protected Area

5.2.1. Water distribution and question of flowing river

In case of Keoladeo National Park main issues are regarding river flow- that is responsible for carrying seeds, propagules, fish fry, invertebrates etc to the wetlands and distribution of water in the larger landscape. As has been mentioned before, river Banganga in the Keoladeo National Park watershed has been dry for a long time now, and River Gambhir has been the primary source of water and other organic matter etc to the park. The first dam on the Gambhir was built as early as in 1865 at Baretha and it today supplies drinking water to the city of Bharatpur even. Another significant dam is Jaggar Tal upstream of Keoladeo National Park. Panchana Dam was constructed in 1980s but was raised and completed in year 2000. Since then, the water flow to Keoladeo National Park has attained problematic proportions. As is discussed earlier, the high biodiversity in Keoladeo National Park has developed due to its connectivity with the river. In absence of flow in the natural and/or man-made surface flow, the perennial pools supporting large variety of fish diversity will be lost, as also the movement of fish to Ajan Bund and thereafter to Keoladeo National Park. Further, plant propagules, invertebrates that contribute to the richness and characteristics of the park would also be lost. It is evident that the ecological integrity off the park relies heavily on its hydrological connectivity with Gambhir River. However, as is always the case in water disputes in a water stress regions human needs are usually placed above the needs of animals (read nature preserves). But in case of river Gambhir it is not only question of sourcing water to Keoladeo National Park but also the issue of functions of a flowing river. The river if it flows supports propagation of biodiversity in terms of floral species as well as faunal. Secondly, as it flows through semiarid region it recharges groundwater in the unconfined aquifer on which irrigation of the region is based. In absence of flow the groundwater table has been constantly falling and affecting communities residing downstream adversely. In addition to sustaining flora and fauna of Keoladeo National Park, River Gambhir has several other values.

a) It recharges ground water downstream of Panchna dam, Ground water potential zone in Gambhir basin of 3650 kilometre square, of which 95% is available alluvial aquifer; infiltration capacity of available aquifer range from 15 to 25-30 CM/day depending upon clay and silt contents (Central Ground Water Authority, Jaipur).

b) Hindon, Bayana and Roopwas block have high silt content that is why it is very necessary to recharge aquifer of basin by releasing water from Panchana.

c) This area has highest drainage density 0.5 to 0.7 Km/Sq Km

d) To feed Sujan Ganga Canal and its 21 'Diggies' which need 28.09 MCM water annually as shallow aquifer of Bharatpur is fed by these structures to reduce salinity.

e) Bayana area, ground water is potable at all level while in Roopwas and Weir areas saline ground water overlies potable ground water but in Bharatpur area, ground water is saline at all level. And Sujanganga, digies, KNP and irrigation tanks fed by Gambir is only source to recharge and reduce the salinity of ground water.

The cessation of flow in river Gambhir has not only affected the biodiversity and management of Keoladeo National Park but has also affected the socio-economy of areas lying between Panchana Dam and Keoladeo National Park. A survey conducted by this researcher, commissioned by the Wildlife Trust of India, during the year 2004 has brought to our notice that the farmers downstream of Panchana Dam are worst hit due to prevailing water crisis (Singh, 2004). A preliminary estimate of irrigation inputs for agriculture shows that due to falling water tables as a result of non-recharge of groundwater has compelled the farmers to dig deeper borewells, increasing water pumping cost. Also, as soil moisture is less they have to irrigate their fields more frequently (press. comm. with villagers). The area surveyed can be divided in three regions for ease of discussion. To begin with, area immediately downstream of Panchana dam lying in Hindon tehsil of Karauli district, second, area under Bayana tehsil and lastly, area surrounding Keoladeo National Park, Bharatpur. A comparative analysis of consequences due to non-release of water from Panchana Dam is summarised in table 5.1 below:

Table 5.1: Comparison of water-related factors in the regions surveyed and in canal irrigated regions

Factors ↓	Hindon, Karauli	Bayana, Bharatpur	Surroundings of Keoladeo National Park, Bharatpur	Area irrigated by canals from Panchana Dam
Average land holding in *beegha*	4.5	5.5	5	10
Fall in Groundwater level in the recent past in feet	Av. 47.5 (max 80)	Av. 46.25 (max 100)	Av. 23 (Max 30)	10 (max 25)
Cost of irrigation per *beegha* in Rupees	Av. 1255 (Max 2240)	Av. 1351(Max 2100)	Av. 650.6 (Max 784)	20
Yield of wheat per *beegha* in kg	1000	560	800	1400
Yield of *bajra* per *beegha* in kg	480	200	240	800
Yield of mustard per *beegha* in kg	480	320	320	600

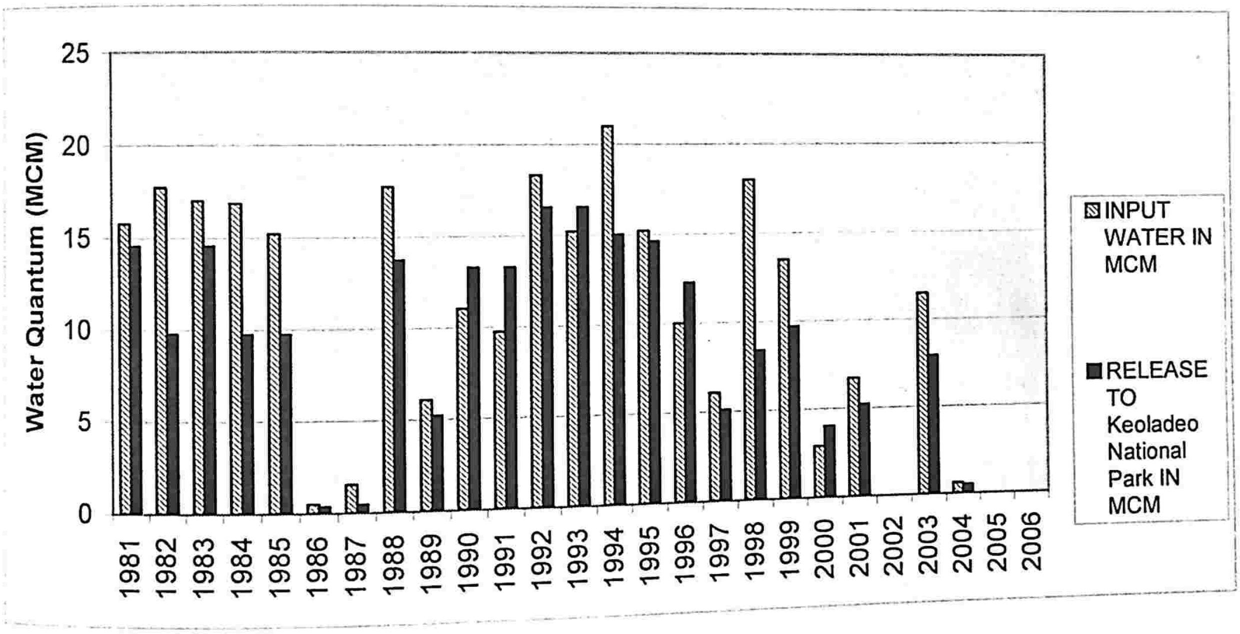
(**Beegha* is the local unit of land holding approx. 80m X 80m)

The findings of the study in the table above clearly indicate that farmers in Hindon and Bayana tehsil are hardest hit by the stoppage of water. The water levels in the region have fallen by an average of 14.3 to 14.6 metre in the downstream regions in past ten years. In the regions surrounding Keoladeo National Park, Bharatpur the fall in groundwater level is not so drastic essentially because some amount of water was retained in the wetlands in the recent past. Retention time in the national park is much more than any of the tanks or other water bodies in the region. This ensures recharge of groundwater. Though the water level has fallen by an of average 23 feet in past ten years because of insufficient amount of water released during past five years. Had Keoladeo National Park, Bharatpur received optimum amounts the situation would not be so grave. ***This also depicts a very important hydrological function performed by the wetland in recharge of groundwater and in sustaining groundwater table.*** Had it not been for this wetland and considering all other factors to be the same the fall in groundwater levels would have been as drastic as it is in other areas – that of Bayana and Hindon.

Given the above mentioned evidences and issues restoring the hydrologic connectivity of Keoladeo National Park with river Gambhir is the only way to ensure ecological integrity of the park. However, the availability of water from the river has, over the past few years has become rare. The water regime has been extensively intervened to divert water for irrigation. As the watershed is inhabited by subsistence farmers the needs of farmers cannot be ignored. The conflict now is with upstream farmers, in the command area of Panchana Dam, residing in 35 villages. As against these there are 388 villages downstream of Panchana Dam that has been directly or indirectly adversely affected due to cessation of water flow in river Gambhir. The matter is highly politicised as well, because of which release of water from Panchana Dam every year is subjective to demonstrations, meetings and will of the government agents both administrators as well as politicians. In such a situation sourcing of water from this Dam is improbable.

Water distribution from Ajan dam to Keoladeo National Park since 1981 is shown in Fig. 5.1.

Fig. 5.1 Water distribution fromAjan dam (1981- 2006)



This water distribution clearly indicates that if water is received in the dam a good percentage is released to the national park. This distribution varies from 136% of the water received to 30% of the water received in the Ajan Dam (ref. table. 3.7). The higher values indicate that volume of water stored behind Ajan dam is contributed by both flows from Gambhir River as well as runoff from its local catchment. This suggests that if water is present in the Ajan Dam it can be confidently said that water needs of Keoladeo National Park are secure. But, here the question is, then, of getting water to the Ajan, for which the primary source is Panchana Dam and Jaggar Tal. Details of water harvesting in Gambhir basin have been detailed earlier. As three dams- Baretha, Panchana, and Jagger are the larger dams, holding maximum amount of water, for river flow in the monsoon season it becomes imperative to source water from these.

5.3 Recommendations

There are several issues that are related to water management of Keoladeo National Park. The issues with in the National Park and its immediate surrounding are: a) water holding capacity of the wetland, b) evapotranspiration losses c) groundwater withdrawl.

Desilting parts of wetland to ensure water depth in some of the blocks should be undertaken. Measures to check further silting in the wetland should be undertaken to ensure long term viability of the wetland.

As has been discussed in preceding sections, approximately 54% water loss is through evapotranspiration and groundwater outflows. Reduction in both would result in maintenance of higher water table that would in turn result in longer hydroperiod of the wetland.

Evapotranspiration losses should be reduced by control of *Paspalum distichum* that has higher evapotranspiration than other wetland plants. As this species has invaded the wetland after extraction of wet grass was banned in the National Park, a mechanism to extract this species should be put in place.

As the groundwater extraction is extensive in agricultural fields around the Park, sustainable methods of irrigation should be promoted in the villages around the Park. Efficient irrigation techniques aimed at water conservation can reduce the extent of groundwater extraction which would result in longer hydroperiods.

Although the distribution of water from the Ajan dam is fair, since the year 2000 release of water from upstream Panchana Dam is an issue with upstream communities. As discussed in preceding sections, release of water from the water shed is important to maintain the biodiversity as well as ensure connectivity with other areas both wetland and terrestrial. Measures need to adopted at regional landscape i.e., watershed of Keoladeo National Park for conservation of water through efficient irrigation techniques. This will ensure larger quantum of water to be released to the Park. As the conflict for water release is directly related to livelihoods of agriculture community, ensuring enough water to them would only help in solving the crisis to some extent. Efficient irrigation is one of the ways in which that quantum of water can be provided to the community while ensuring release of water for the Keoladeo National Park.

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