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Evaluating the Functioning Mechanisms of 'TANK Systems' in Peri-Urban Areas of Chennai, India—Land Use Change as the Determinant

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Abstract: Ensuring the sustenance of water resources that act as sources of water for cities threatened by urbanization and developmental pressures is a crucial problem in peri-urban areas. The objective of this research was to establish the role of change in agricultural land use as a determinant in the evaluation of the existing water management system and to ascertain whether the control by the government or community management can be effective in ensuring the sustenance of water resources in peri-urban areas. The cases selected for the study were the water management systems present in two villages located in the peri-urban areas of Chennai, India. This research adopted a case study strategy with mixed methods of analyses. The analysis traces trajectories of change in the land use of agricultural lands and the common lands related to water management through methods, trend analysis, analysis of spatial patterns of change and the changes in the components of the community management. Results from the analysis indicated that under the context of intensive change from agricultural to nonagricultural land uses, the interlinkages within the traditional community management model had broken up, making community control improbable. The current management model of the government was also found to be inadequate. Results indicated that government agencies with trained personnel engaged in periodic maintenance activities, constant monitoring against encroachment, and pollution, and through the formation of user associations under their control can ensure the sustenance of water resources.

Keywords: peri-urban water resources; spatial pattern of land use change; traditional water management systems; urbanization

1. Introduction

Across the world, cities are stressed for water [1] and depend on the water resources within peri-urban areas [2]. The sustenance of these water resources is an important concern for the welfare of the increasing urban population [3]. Existing water management systems in peri-urban areas have to contend with changes in their contexts due to developmental pressures, significantly fuelling the conflict over the land and water resources between rural and urban areas. A significant manifestation of this conflict is the change in the land use from agricultural (rural) to nonagricultural (urban) land uses [4]. This change in the land use from agriculture to nonagricultural land uses is an important factor as agriculture usually was the major consumer of water in most peri-urban areas and the management of water resources was organized around this requirement [3]. The selection of the management model that can ensure the sustenance of water resources, therefore, needs to take into cognition the situational reality of these systems [5,6], especially under changed conditions as encountered in peri-urban areas [7]. The problem of selecting an appropriate management model for sustaining water resources is complicated due to the dynamic nature of changes in the peri-urban areas, as peri-urban areas tend to be a mix of urban and rural, whereas institutions and management systems tend to be organized based on rural and urban administrative boundaries [8]. Water management in complex situations such as these needs alternative strategies. However, it is difficult to decide which of these strategies will be the most effective [9]. Governance approaches for resource management systems that have existed over a long time have to be selected based on the context in which they are placed [10]. Understanding the relationship between the land use change of agricultural lands to nonagricultural land uses and related changes in the water resources management is the first step in evaluating the effectiveness of a water management system and proposing an appropriate water management system.

Various forms of water management system in India had sustained the supply of water to the people since ancient times [11]. In the state of Tamilnadu, located in the southern part of India, the most prevalent system of water management is connected to 'Tanks' or reservoirs. Here, tank refers to water storage reservoirs of an area of a few hundred square meters to thousands of square meters. The term tank comes from the Portuguese 'Tanque' or the Latin 'Stagnum' [12]. The water management systems are called 'tanks systems' [13–15] or 'tank irrigation systems' [16] based on their prominent feature, the tanks. Like many traditional water management systems of India, the tank systems have also declined and their components are in damaged condition [14,17,18].

The traditional tank system was a complex and interdependent system managed by the community [18,19]. The basis of this interdependency was the interrelationships within the system through benefits acquired by the people related to the existence of agricultural activity, especially paddy cultivation [12,16,18] (Figure 1). The decline of the tank systems was attributed to various factors in the past related to the transfer from community control to state control [5,14,17,18,20,21] and to the lack in their maintenance and protection by these government agencies that control these water resources [14,22,23]. The present management of the components of this interconnected system is by multiple government agencies [22] (Figure 2), supported in some cases by user associations that partially control and maintain some of the components of the system. To arrest the decline, the government had enacted laws and established organizations to protect the water resources [15,24,25]. The Tamilnadu state government law, 'Protection of Tanks and Eviction of Encroachment Act, 2007' (Act 8 of TN G.O.dt.22.05.2007), prohibits the conversion of common lands related to water storage, conveyance and foreshore areas for any other developmental purposes. The state government had also set up a nodal agency WRO-Water Resources Organization under the P.W.D.—Public Works Department for protection and management of water resources. Two agencies of the government play a salient role in the management of the components of the tank systems. The P.W.D.—Public Works Department is a centralized state department with finances and trained personnel to maintain the tanks and its components. This agency, however, has under its control only tanks of water storage area more than 40 acres (16 hectares). Tanks with lesser water storage area and their components come under the control of the Panchayat—the village administrative council. This agency, in general, lacks funds and do not have enough trained personnel to maintain the tanks and related components [15,16,23]. In spite of these measures, urbanization is known to have caused damage to the tank systems [2,14,26].

The technology of the water management is a function related to 'agroclimatic and agrarian contexts' [27] and agriculture also plays an important role in the social dynamics of the tank systems [12,28–30]. Mizushima (1966) [20] and Yanagisawa (2008) [31] traced the connection between the changes in the water management systems and the change in land ownership and administration during the colonial period and after. Studies by Janakarajan et al. (2007) [2], Rodrigo (2004) [26], and Datchayani et.al (2013) [32] further explored this connection between the change in the land use in peri-urban areas and their impact on the changes in the social dynamics of water resources management. However, very few studies have analyzed the relationship between agricultural land use change and the changes in the functioning mechanisms of the tank systems. The aim of this research was to explore this relationship between change in the land use of agricultural lands to nonagricultural land uses and the change in the functioning mechanisms of the tank systems.

This research started with the proposition that change in the land use of agricultural lands to nonagricultural land uses is an important determinant in the success or failure of the water management system. To establish the role of land use change as a determinant, this research undertook two lines of enquiry:

1. The first line of enquiry was related to the existence of the components and interrelationships of the community management system under the context of change in agricultural land use. This line of enquiry was conducted to evaluate the possibility of reviving community management.
2. The second line of the enquiry was related to the current management system. This line of enquiry was conducted to evaluate the effectiveness of the current management system by the government.

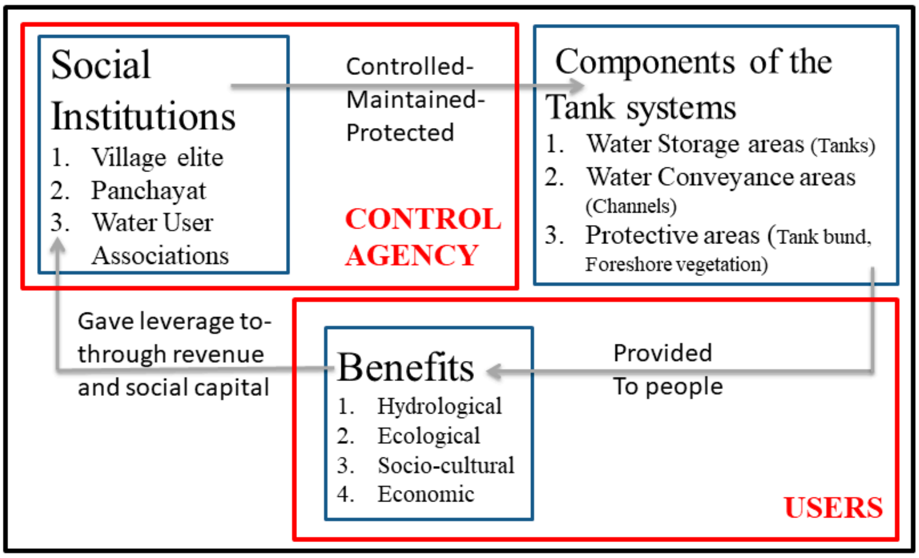

Figure 1. Traditional community managed model of tank systems (source—authors).

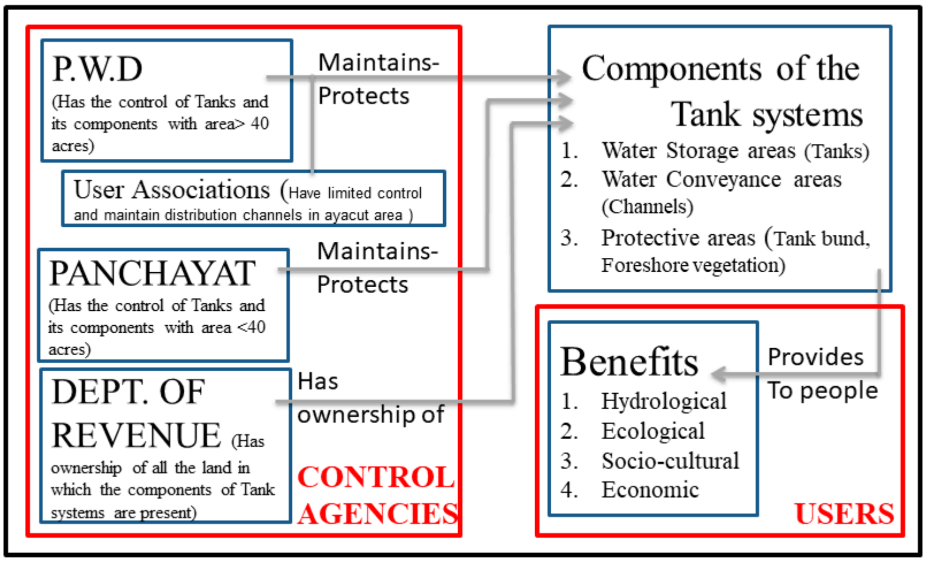

Figure 2. Present government management model of the Tank systems (Source—authors).

2. Materials and Methods

2.1. Study Area

The research undertook a case study of tank systems located within two villages in the peri-urban areas of Chennai city, located in the southern part of India. Chennai is a metropolitan city with chronic water problems. Chennai, like many tropical cities, has the dual problems of flooding [33] as well as water scarcity [34], both due to poor water management. The city depends on its peri-urban areas for water and these peri-urban water resources are deteriorating [2,26,35]. The cases selected are located partly inside and just outside the boundary of the Chennai Metropolitan Area [36] (see Figure 3). One such case is described as follows; a village with significant land use change in the agricultural land to other land uses such as institutional and industrial whereas the other case is a village with a less intensive change in the agricultural lands, i.e., agricultural lands have been converted to sites for residences but they remain as vacant plots of lands (Table 1).

Table 1. Details of area under each land use type.

Case 1						
Land Use Type	**Area-1986 km^2**	**Area-2016 km^2**	**Change in Area (1986–2016) km^2**	**Total % of Land Changed (1986–2016)**	**% of total Area in 1986**	**% of total Area in 2016**
Fallow	5.61	5.13	−0.48	−8.53	37.81	34.59
Paddy	4.27	0.62	−3.66	−85.56	28.80	4.16
Plantation	1.30	0.58	−0.72	−55.62	8.79	3.90
Total agriculture	11.18	6.33	−4.86	−43.44	75.40	42.65
Residential	7.16	0.91	0.19	27.02	4.83	6.13
Vacant plot	0.03	2.42	2.39	8278.66	0.19	16.29
Industrial	0.41	0.82	0.41	98.30	2.80	5.55
Institutional	0.00	1.10	1.10	100.00	0.00	7.41
Others	0.01	0.80	0.79	9371.05	0.06	5.40
Water Storage areas	1.17	1.15	−0.02	−1.60	7.87	7.74
Water Conveyance areas	0.75	0.73	−0.02	−2.47	5.06	4.93
Protective areas	0.13	0.08	−0.05	−36.04	0.87	0.56
Total land area in the village	14.83	14.83				
Case 2						
Fallow	0	38.25	38.25	100.00	0.00	21.89
Paddy	139.49	15.30	−124.20	−89.03	79.84	8.75
Plantation	0.06	11.01	10.95	19716.10	0.03	6.30
Total agriculture	139.55	64.55	−75.00	−53.74	79.87	36.94
Residential	6.79	7.26	0.48	7.04	3.88	4.16
Vacant plot	0	74.45	74.45	100.00	0.00	42.61
Others	0.03	0.03	0.01	21.17	0.01	0.02
Water Storage areas	18.61	18.61	0.00	0.00	10.65	10.65
Water Conveyance areas	6.81	7.30	0.48	7.11	3.90	4.18
Protective areas	1.16	0.65	−0.51	−43.85	0.66	0.37
Total land area in the village	174.72	174.72				

Present government management model of the tank systems (source—authors).

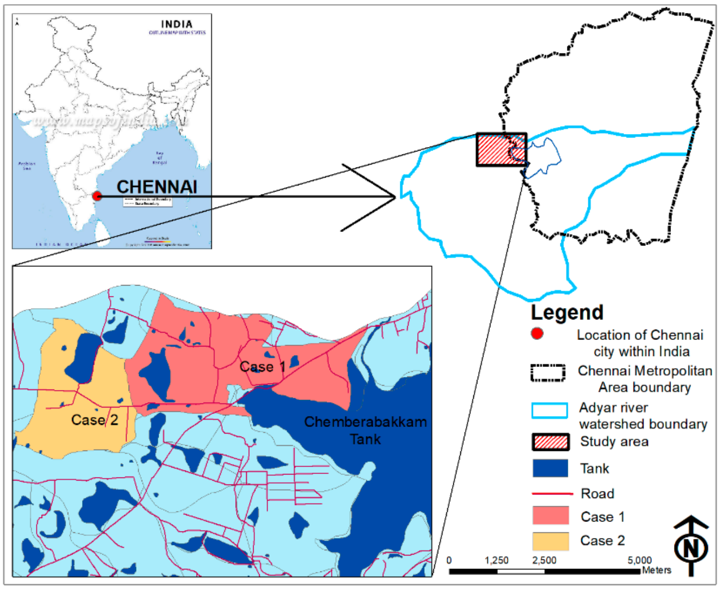

Figure 3. Study area location.

2.2. Data Sources

The components and interrelationships of the tank systems were identified and the model of the tank systems was formulated based on the review of literature on the tank systems, reconnaissance survey, and an open unstructured interview conducted with the administrative personnel and experts about the tank systems. The current status of the components of the community management model was ascertained through a survey of the tank and its components conducted by the researcher in addition to structured interviews conducted with the administrative personnel of the village. The instruments used for the survey and the structured interview (Appendix A) were developed based on the reconnaissance survey and open interviews conducted in the study area, prior to the survey. The interview was conducted with all the administrative officials that control and maintain the tank systems at the village level in both the cases. These consisted of the village administrative officers, the panchayat head, and the assistant engineer in charge of the tanks, in the case of the tanks under the control of P.W.D. Four sets of land use data for the period of 30 years from 1986 to 2016, each representing one decade was created from primary data consisting of revenue, survey, settlement records, and cadastral maps of the two case villages to create the base land use data for analysis. The source for the data were the following departments of the Tamilnadu state government; survey and settlement for the cadastral maps and the record department of the Taluk office for the land use data of the two villages for the four years, one in each decade. The base year 1986 was selected by checking the data from 2016 and going back one decade at a time, till the land use was completely agricultural in case 2 and more than 90% of the agricultural land remained unconverted in case 1.

2.3. Data Processing

The data of the site survey and structured interview with the officials were aggregated and entered as spreadsheets in excel (Appendix E). The status of the tank systems was computed based on the score of the components for each tank: encroachment of water storage area, status of the channel network connected to the tank, condition of the bund with its vegetation, existence and nature of foreshore vegetation including common grazing land, usage of the tank water, usage of the tank and its environs for social and recreational purposes, and extraction of products from the tank and its environs (Appendix B). These scores were then totalled and used for the comparison of the status of tanks and land use change.

GIS has been used for the processing of spatial data and also to link land use data with the spatial data. CAD data was accessed in a GIS environment and then georeferenced. Subsequent to editing errors, aspatial data was joined with spatial data using the union command. Cadastral maps prepared by the department of survey and settlement; the government of Tamilnadu formed the basis for the land use maps. Hard copies of the village maps split into 2 or 4 sheets obtained from this agency were scanned and subsequent to understanding the issues with the maps obtained, such as variation in scales ranging from 1:5000 to 1:10,000, and with due consideration of the flexibility of the software it was decided to use Auto-CAD software for generating digital data.

For creating the spatial land use map of the village, each and every land parcel was assigned with a unique number and survey number as per the hard copy of the map and in par with spreadsheet generated from the land use register for both the cases. The primary unit of data selected for the analysis was taken as a 'plot' with a distinct survey number, following the method by Ramesh et al. (2011) [37], Du xingdong et al. (2014) [35,38], and Ainiwaer et al. (2019) [39] by aggregating the subdivisions of the plot, as many of the plots in the original survey have been further subdivided into 100–200 subdivisions in the subsequent decades. The land use data for each plot from the revenue records were similarly arrived by aggregating the land use of all the subdivisions. In the case of the common lands when they were part of a plot, they were given a unique survey ID.

The land use data were aggregated into a land use classification system following the classification for agricultural lands followed by the Department of Revenue, Government of Tamilnadu, and the land use classification to be used for urban area as per the regulations derived by the department of 'Town and Country Planning' of the Government of Tamilnadu [40] (see Table 2).

Table 2. Land use classification system.

Land Use Classification as Per the Regulations of the Department of Town and Country Planning, Government of Tamilnadu	Land Use Classification followed in this Research
Residential use zone	Divided into two classifications—1. Vacant plot, 2. Residential
Commercial use zone	As this category of land use was very limited in the study area and was merged with land uses that are different from the categories given in this table and classified as Others.
Industrial use zone	Industrial
Educational use zone	Institutional
Public and semipublic use zone	Common lands
Agricultural use zone	Divided into three classifications (1) Paddy. (2) Plantation. (3) Fallow.

Out of the 18 types of common lands found in these two villages, only 10 pertaining to the water management were taken for analysis and aggregated into three classifications based on their function, water storage area, water conveyance areas, and protective area.

2.4. Analysis Methods

This research has adopted a mix of quantitative and qualitative methods for analysis. The method trend analysis is adopted to bring out the underlying pattern of land use change over time as trend analysis facilitates the extraction of patterns from a time series data [41]. To evaluate the effectiveness of the current government model of the water management system, correlation analysis was used to analyze the relationship between the change in agricultural lands and the change in common lands related to water management [42] (Figure 4). As one of the major measures taken by the government for the protection of the water resources is legislation preventing the land use conversion of common lands related to water management, the illegal conversion of land use of common lands to other land uses was deemed as encroachment, and was taken as the major factor for the analysis. For the identification of themes and patterns [43] (Figure 4), the analysis of trajectories of change in common lands related to the water management system, with reference to changes in agricultural lands, was adopted. The method is as follows.

1. Compare the land use map of 2016 with 1986.
2. Apply buffer analysis in GIS using ARC map buffer tool for a distance of 150 and 250 meters.
3. Identify the number of plots of common land plots (related to water storage, conveyance, and protective areas) changed into other land uses.
4. Trace for the changed common land plots, the change in the land use of the surrounding plots and the common land plot in the previous sets of data (1986 (base year data), (1986–1996) and (1996–2006).
5. Identify the trajectories of change.

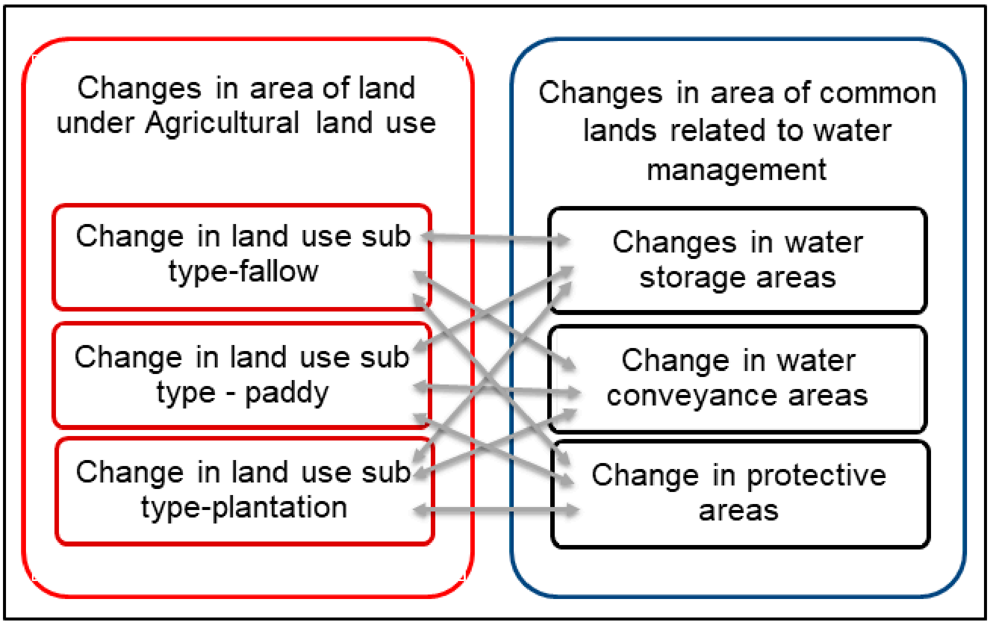

Figure 4. Components of analysis.

To ascertain the existence of the components and the functioning mechanisms of the community management model under the context of change in agricultural land use, a scoring system was followed. The data of the site survey and structured interview with the officials were aggregated and became the basis for the score of the following components for each tank; encroachment of water storage area, status of the channel network connected to the tank, condition of the bund with its vegetation, existence and nature of foreshore vegetation including common grazing land, usage of the tank water, usage of the tank and its environs for social and recreational purposes, and extraction of products from the tank and its environs (Appendix E). These scores were then totaled and the total score of the tank was compared with change in agricultural land use. The presence of the social institutions and the nature and extent of their activities in the village was ascertained through structured interviews with personnel in charge of the tanks. However, there was no presence of social institutions in case 1 and only an informal association of wetland owners having very limited activities was found existing in case 2. Therefore, this aspect was not considered for the scoring of the tanks and for the analysis.

3. Results

3.1. Trends of Land Use Change

Agricultural lands: In both cases, the area under paddy cultivation had a consistent decreasing trend. The land under plantation also had a decreasing trend in case 1, whereas it had a marginal increasing trend in case 2. In case 1, the land area under fallow decreased initially, increased in between and finally decreased. In case 2, the land areas under fallow had an increasing trend (Figures 4 and 5). In case 1, all land uses other than paddy, plantation, and fallow exhibited an increasing trend which clearly showed the presence of developmental pressures and the progression of the case 1 from rural to urban. In case 2, among the nonagricultural land uses, the category 'vacant plot' was only present and had an increasing trend indicating that though the intensity of development pressures is low during the period of study, this may change in the future. The absence of land uses for other purposes such as industrial and institutional indicated that this village has remained predominantly rural during the period of study.

Water resources: In both cases, the water storage area is fairly constant throughout the study period without any noticeable change (Figures 5 and 6). The water conveyance areas and the protective areas showed a declining trend. In case 1, the water conveyance areas showed a notable decline, whereas in case 2, the decline was minor. In both cases, the protective areas had a declining trend, attributed to the significant increase in the conversion of common grazing land to other purposes as the other protective areas such as bund and foreshore remained fairly constant.

3.2. Relationship between Change in Agricultural Land Use and Change in the Land Use of Common Lands

3.2.1. Correlation

A strong positive correlation was observed only in case 1 between the changes in land under the category of protective areas and the total agricultural land, as well as for all the two subtypes—paddy and fallow—under the agricultural land use (Table 3). This encroachment or illegal conversion of the land use of common land meant to act as protective areas for the tanks such as bund and foreshore to other land uses shows the disconnect between the people and the tank system at present. This encroachment is primarily in the community grazing land, as these were not specifically protected by the law and therefore were more vulnerable. A strong negative correlation was observed between the change in the area of lands under the category water storage areas in cases 1 and 2; as the area has not changed, the correlation could not be calculated. In the case of water conveyance areas too, there was a predominant negative correlation. This could be because the tanks and connected channels under P.W.D (Public Works Department) (See Figure 2) control and maintenance have remained free from encroachment and the total area of these was significantly more than the tanks under panchayat control, which have been encroached.

Table 3. Correlation values between change in land under agricultural land use and change in total land area existing as common lands related to water management.

	Correlation Values							
Change in Common Lands Related to Water Management	**Change in the Total Land under Agricultural Land Use**		**Change in the Total Land under Fallow**		**Change in the Total Land under Paddy**		**Change in the Total Land under Plantation**	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
Water storage areas	0.96	No change in water storage areas	0.74	No change in water storage areas	0.86	No change in water storage areas	0.21	No change in water storage areas
Water conveyance areas	0.05	0.91	0.79	0.48	0.21	0.87	0.99	0.66
Protective areas	0.97	0.58	0.72	0.50	0.89	0.96	0.22	0.22

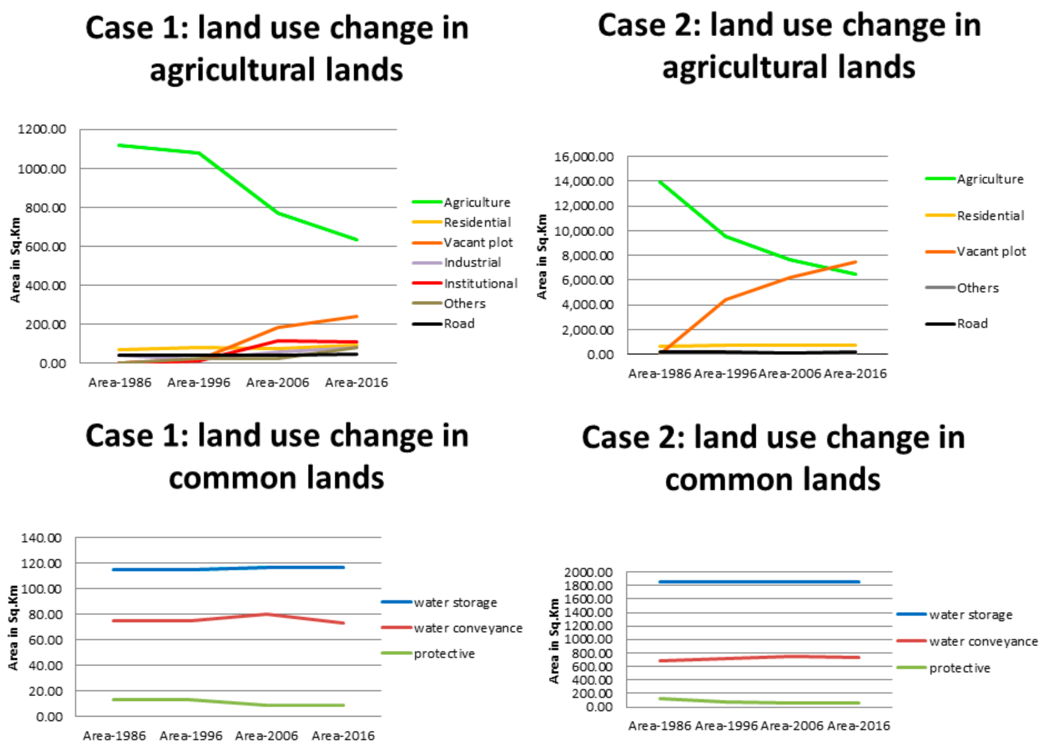

Figure 5. Trends in land use change for case 1 and case 2.

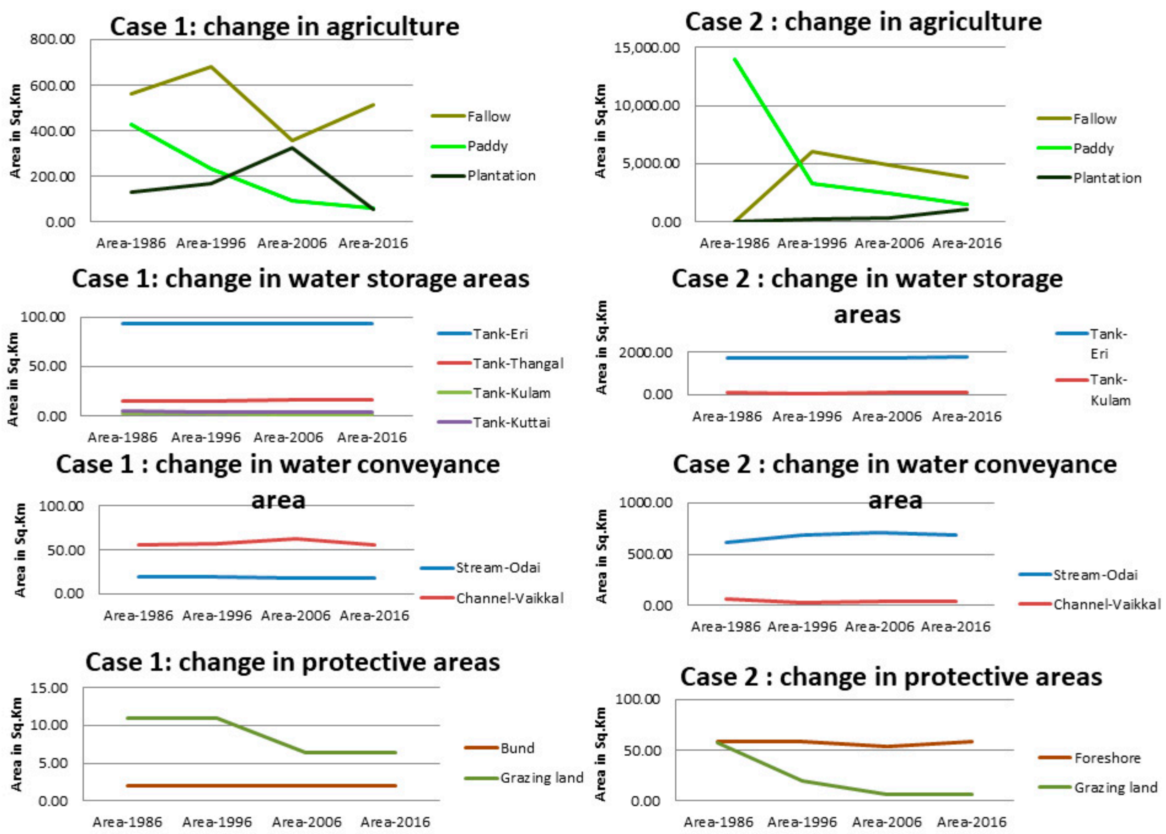

Figure 6. Trends in land use change components within agricultural land and common land for case 1 and case 2.

3.2.2. Spatial Pattern of Change

The analysis of the spatial location of common lands in which land use conversion has taken place showed that a strong relationship between the change in the agricultural lands and the changes in the water resources, as all the changed common land plots, are located within zones of agricultural land use change (Figures 7 and 8). The instances where there were changes (19 out of 26 instances) in land use of the common lands; they were surrounded by agricultural lands which have changed from paddy cultivation to other land uses.

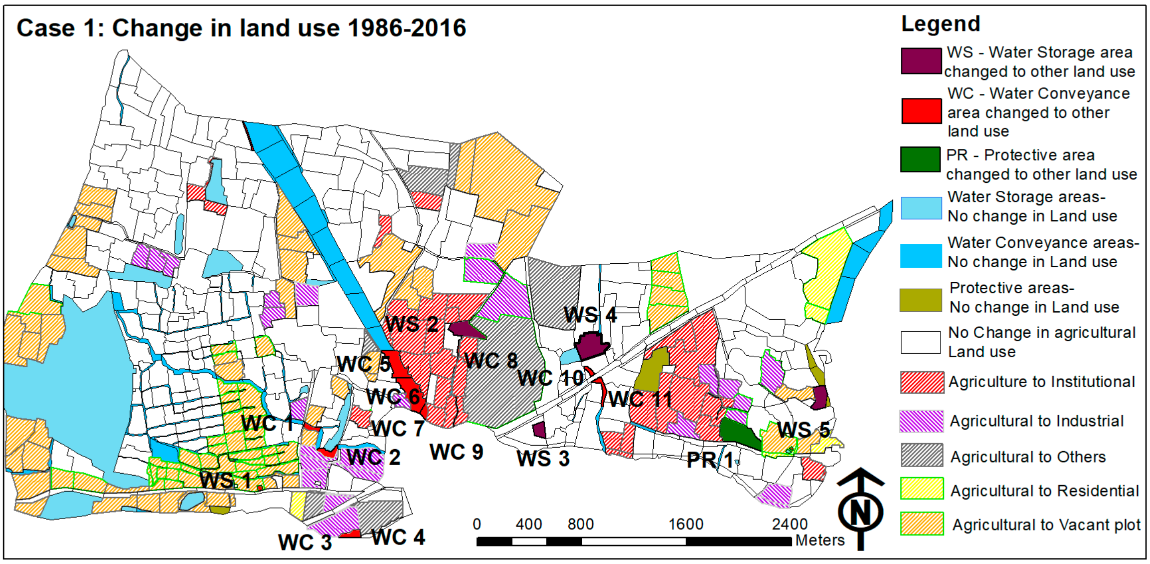

Figure 7. Spatial pattern of land use change of common lands in case 1.

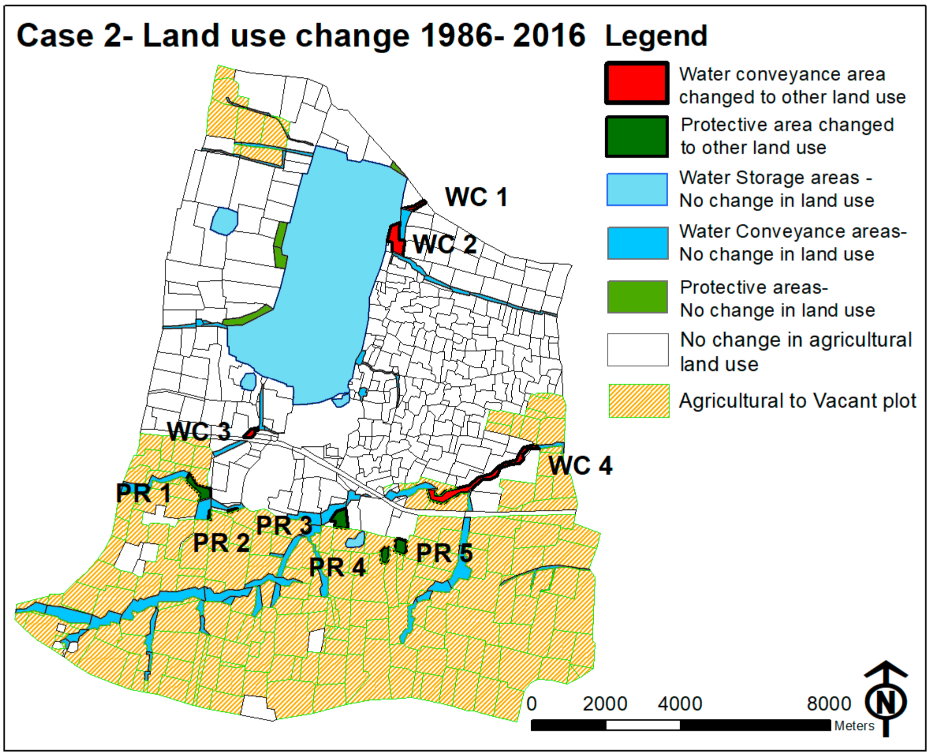

Figure 8. Spatial pattern of land use change in case 2.

3.2.3. Trajectories of Change

The following are the conclusions derived from the analysis of the plots of changed common land and the change in land use of the surrounding agricultural lands over four sets of data across forty years (see Figures 9 and 10 and also Appendix C).

- The predominant trajectory of change in both cases is *Paddy to fallow→conversion of common lands*.
- The change in the common lands is preceded by a change in the agricultural land from paddy.
- The patterns of land use change in the common lands reflect the land use change of the surrounding agricultural lands. In case 2, with less intensive developmental pressures, the land use of common lands has changed to paddy and plantation in the water conveyance areas. The protective area plots that have changed to residential were located nearby the traditional residential areas of the village and also in zones where the agricultural land has been converted to vacant plots.
- In case 1, the instances of changes were similarly related to the land use of surrounding plots, i.e., common lands were converted into institutional when the surrounding land use of the plots had already been converted to institutional. This relationship indicates that the encroachment of the common land is by the surrounding plot owners, which is to be expected. It is clear from this observation that the encroachment of the common land is due more from proximity causes.

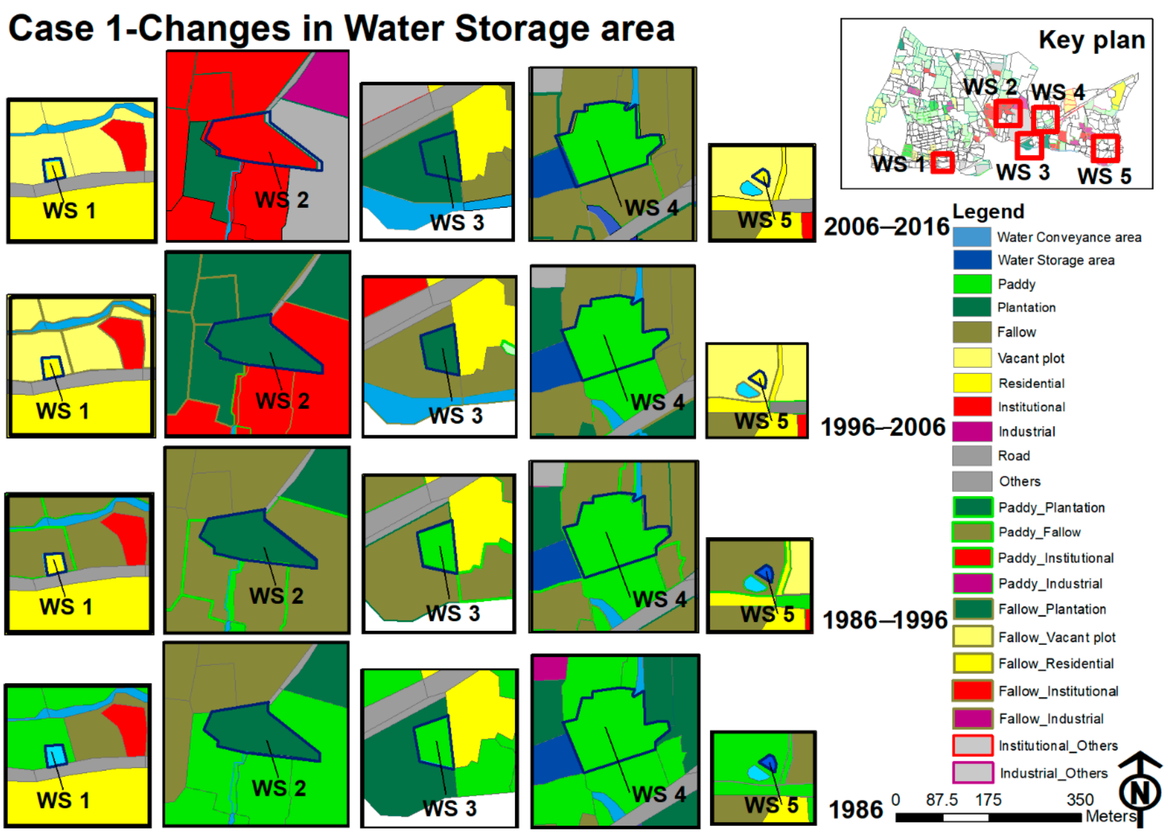

Figure 9. Trajectories of land use change: Case 1—water storage area.

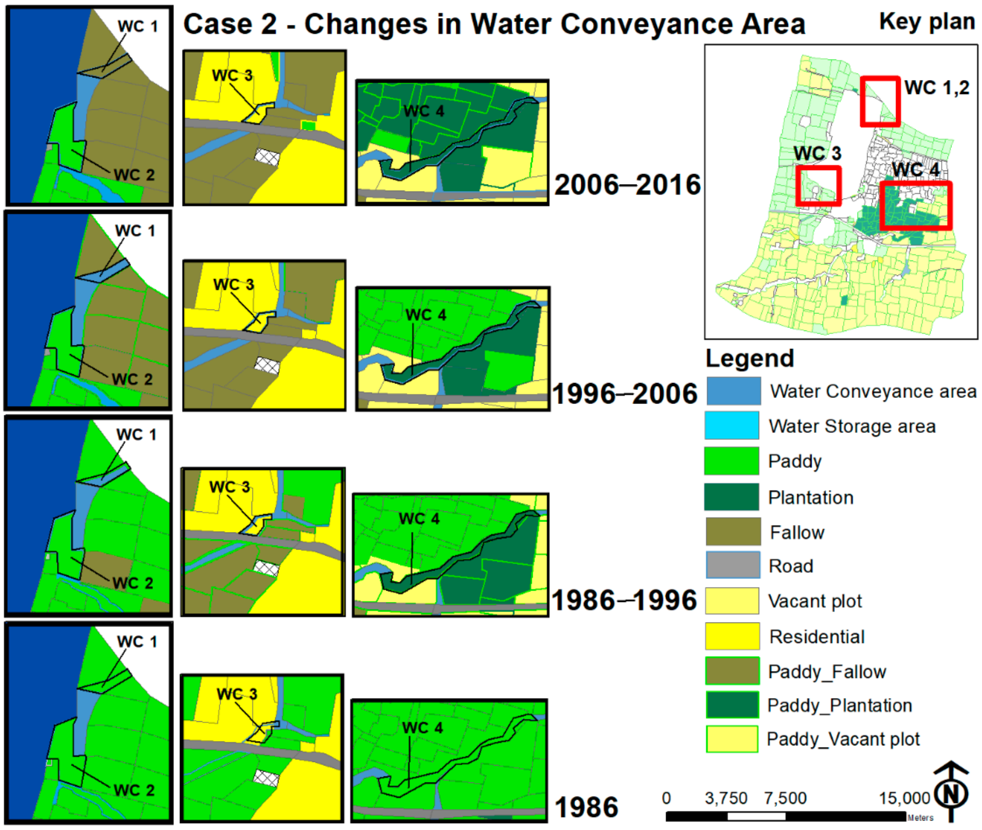

Figure 10. Trajectories of change: Case 2—water conveyance area.

3.3. Relationship between Change in Agricultural Land Use and the Functioning Mechanisms of Community Management

The community control upon the tank system was found to be very weak in the study area. In case 1, there was no existence of social institutions, such as the traditional tank institutions, or the more recent tank user associations. The social institutions were the most essential component of the community management and without them, it is impossible to control the misuse of the system leading to its damage (Figure 1). However, they were notably absent in both the cases. In case 2, there was an informal association of wetland farmers, but it had limited influence and minimal activities. The only activity undertaken by them was decision making regarding the opening of the sluices for irrigation purposes when the major tank in the village gets filled. The officers interviewed were of the opinion that no formal social institutions either traditional or modern had existed in the study area in the last two decades.

The analysis of the total score of the tanks revealed that a distinct variation exists in the status of tank systems between the cases taken for study (Figures 11 and 12). In case 1, the extraction of products part of the benefits from the tank system was absent in all the tanks, except 1. Water is no longer drawn from nine tanks. However, one tank served as a recreational and social venue. In case 2, water was drawn for use from almost all of the tanks. The extraction of products was also carried out in almost all the tanks. There was social and recreational usage of four tanks. The analysis of the tanks, in terms of benefits acquired from them in both cases, clearly indicated there is reduction in case 2 and discontinuance of activities in case 1, which once served as incentives for maintaining the tanks. The condition of the bund and the channels was also found to be poor case 1 and in better condition in case 2. The total number of tanks not used and not existing at present (that is they have been filled up completely) is five in case 1, whereas there are no tanks under this category in case 2. The tanks with the score of 0 in case 1 are all located amidst lands with change in agricultural land use to land uses—Institutional, Industrial, and Others. The tanks with a score of more than 5 were all located amidst lands with no change in agricultural land use and the land use category of Vacant plots (Figures 13 and 14).

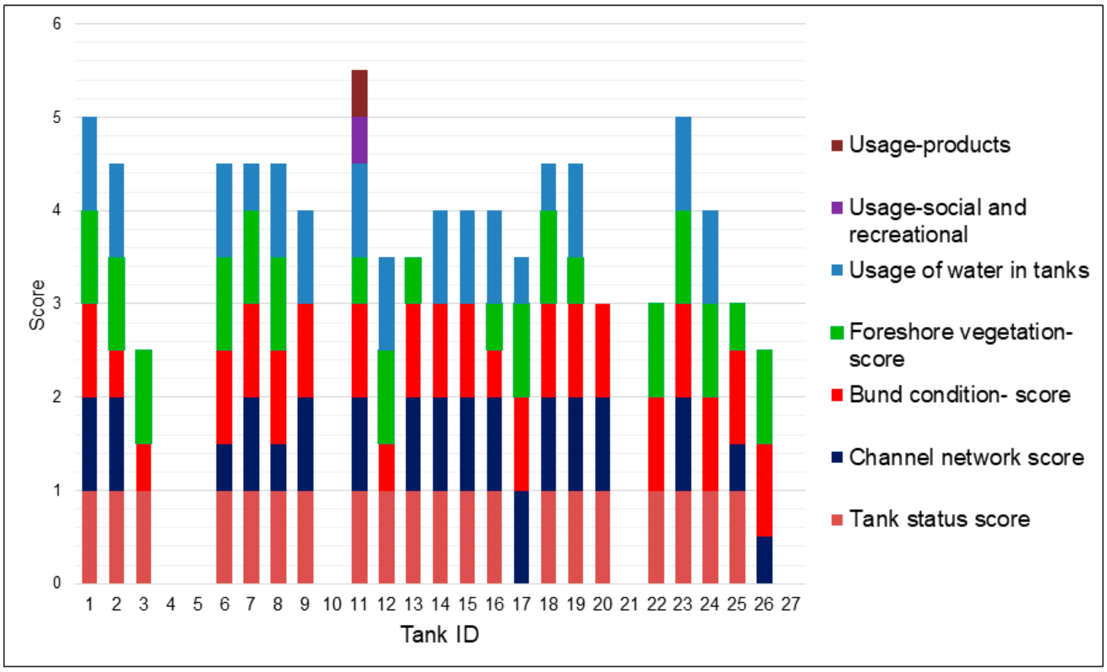

Figure 11. Case 1: Score of tanks based on components.

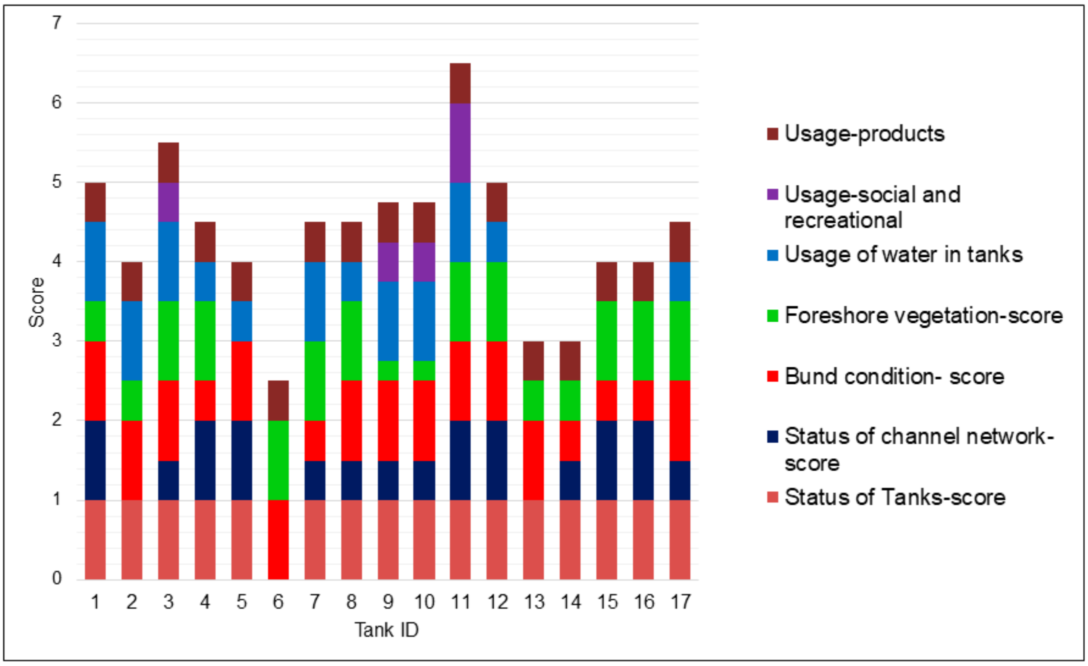

Figure 12. Case 2: Score of tanks based on components.

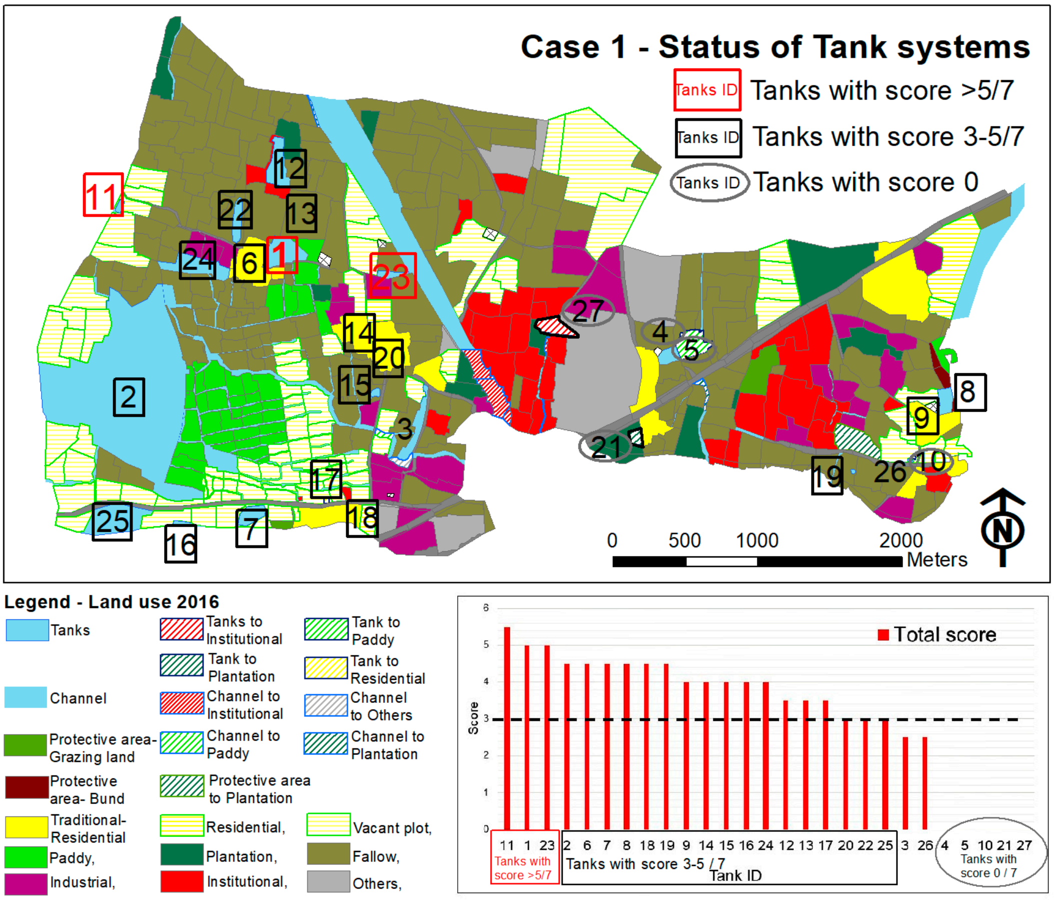

Figure 13. Relationship between change in agricultural land use and the status of the tank systems in case 1.

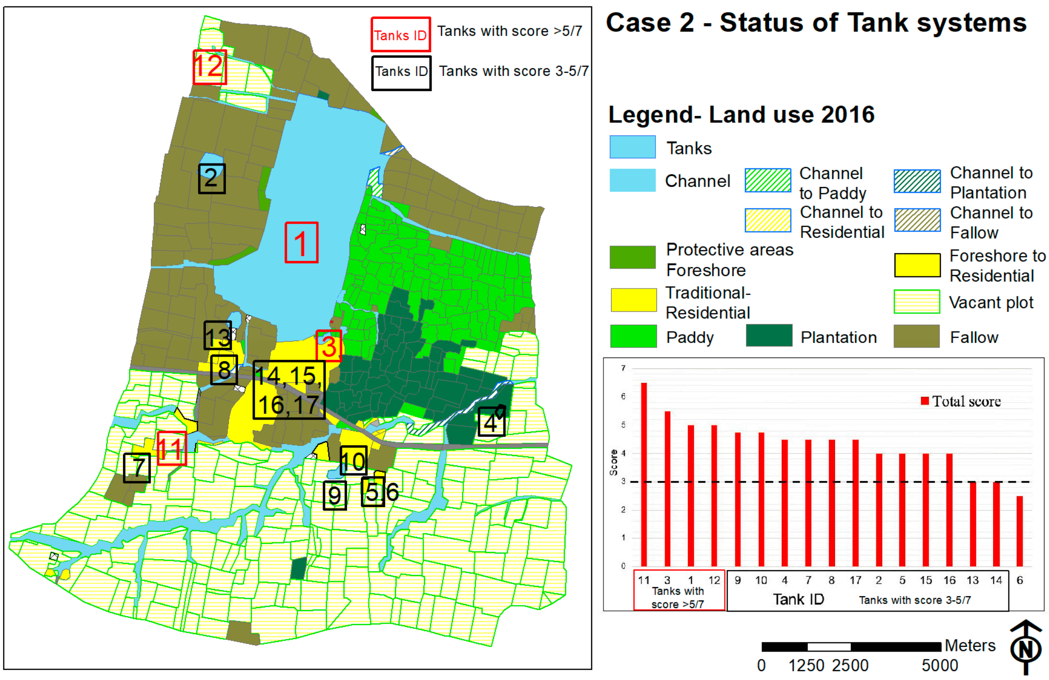

Figure 14. Relationship between change in agricultural land use and the status of the tank systems in case 2.

4. Discussions

4.1. Role of Land Use Change as a Determinant in the Evaluation and Selection of the Water Management System

Water management consists of the set of actions that ensure the sustenance of the water resources. The governance system that undertakes the water management collectively manages both the allocation of the resources and the possible conflicts. This governance system is generally negotiated by social institutions in traditional water management systems [10]. Therefore, the question of the appropriate management system has been primarily addressed as a factor of social relations in previous literature, especially the dynamics of the social relations as a result of changes such as urbanization [2,5,7,21,26]. The sustenance of the water resources was also addressed as a factor of maintenance activities in previous literature [13,16–18]. The role of land use change in affecting both these aspects however had not been previously addressed. In peri-urban areas consisting of a mosaic of both urban and rural land uses [8], the extent and intensity of land use change is an important factor to be considered for management of water resources. The results of this study had indicated that the intensity and extent of land use change are closely related to the changes in the functioning mechanisms of the water management systems. This results from this research indicate that land use change of agricultural lands can be thus be an important determinant to analyze the appropriateness of the existing water management systems.

This research acknowledges that factors, such as demography, policies of the government, market factors, among others, influence land use change and are influenced by land use change and these factors also can influence the water management systems, however they have not been dealt with in this paper as they were beyond the scope of this paper. Further research on the relationship between these factors, land use change and the changes in the water management systems will be of help to evolve more efficient management actions for the sustenance of water resources.

Previous literature on the relationship between land use change and water resources have been with reference to the groundwater depth and quality [39,44,45], water quality in terms of pollution [46], and water quantity due to overextraction [47]. These studies have used remotely sensed data at a large regional scale. The methods used in these studies are not best suited to analyze small variations within a village level that create changes within the functioning mechanisms of local water management systems such as the tank systems. The method used in this research for integration of spatial data and the administrative data sources, such as land use records as well as the data about the actual status of the system through survey and structured interviews, can be applied to other studies of similar scale and complexity. The method used in this research will be of use also to other researchers working with the integration of cadastral and small-scale data into thematic land use maps for analysis. Integration of different types of data has been known to impart clear social understandings and solutions that can provide valuable insights for policy, governance, and management actions [10]. Analysis of spatial patterns over time with the help of GIS [48], in this research, had led to the isolation of events that caused the change in the water management systems. The spatial analysis combining land use maps and data from the survey had imparted clear understanding of the underlying spatial aspects of the land use change. Thus, the method used in this research had primarily enabled the understanding of the functioning mechanisms of the system and the changes in them. The advantage of this method is that it proposes a way through which land use change data can be combined with the data on the status of the system at a micro-level that can provide valuable insights for the decision regarding management policy and actions.

4.2. With Change in the Agricultural Land Use the Functioning Mechanisms of both Community Management and State Control are Ineffective

The break up in the functioning mechanisms of the tank systems was less in case 2 and high in case 1. In case 2, there were only a few instances of common land conversions, and the components of the community management had also not sustained notable damage. There was the presence of a nominal social institution in the form of tank user association, dependence on small tanks for drinking water and other purposes in this case 2. In this case, the conversion of agricultural lands in terms of the area was higher than in case 1, but the conversion was less intensive. The agricultural lands had been only converted to vacant plots which have not been developed. In case 1, with a higher intensity of change in the land use of agricultural lands, there were significant instances of common land conversions. The components of the community management had sustained significant damage too in this case. The secondary activities that had helped in the maintenance of the system in the form of product extraction had been abandoned and do not exist. Social institutions are absent and there is no dependence on tanks for drinking water. Even though a few of the tanks were being used for recreational purposes, this had not led to any social initiative to protect the tanks.

The findings of this research support the argument proposed by Wade [5] and Shah [27]: that need for water and the benefits attained from the system are the basis of the community controlling mechanisms. When there is no need for water from tanks and there is no interest in the extraction of benefits or if the extraction of benefits is denied, the people are no longer interested in protecting the system, making the system vulnerable to exploitation and damage. The conversion of agricultural lands to other land uses is thus a significant factor in the survival of the system, as it controls both the need for the water and the benefits from the system [19]. The state protection through legislation that should have replaced the community protection is hampered by weak enforcement in the cases studied, resulting in the illegal conversion of common land required for the water management to other land uses. Similar issues related to weak state control have been reported by others [20,27,49,50]. However, this research has brought attention to the fact that land use change plays a significant role in the breaking up of the linkages within the system that supported community management by exploiting the weak enforcement of the legislation by the state.

Even though the ownership and control of the tanks and related areas were with the government, whether the community is still dependent on the resources in terms of acquiring benefits from the components was analysed to evaluate the probability of restoring community control. The analysis of the components of the tank systems in terms of the presence of institutions and usage of the tanks in both cases had shown that change in the agricultural land use is strongly related to the breaking up of linkages within the system that had protected the system. In Case 1, with intensive land use change of agricultural lands, there is no presence of social institutions and there is no dependency on the water resources, and this is reflected in the poor status of the water storage, conveyance, and protective structures. In case 2, the status of the water resources is in better condition. The reasons for this are less intensive change in the agricultural land use, the presence of paddy cultivation, the existence of a nominal user association, high dependence on the tanks for water, and extraction of products aiding the maintenance of the tanks. As the need for the water and the benefits to people in terms of products extracted are both connected with agriculture, the change in the land use effectively removes the balance that had ensured the sustenance of the tank systems. The role of some of the tanks had changed to open spaces for recreation. Though it could be argued that this connection with the people can create a new balance of need and costs, it has not led to the formation of any community associations in the study area. Thus, it can be concluded that with an intense change in the agricultural land use, the likelihood of reviving the community management model of the tank systems becomes improbable.

In case 2, with less intensive change in agricultural land use, the illegal land use conversion of common lands was lower in number, leading to the interpretation that the protection afforded by the state through legislation had prohibited the conversion especially in water storage and conveyance areas. Such an argument is further supported by the fact that the conversion had happened predominantly in the common grazing land under the category protective areas in case 2, which are not specifically protected by the law. However, when the intensity of the change in agricultural land use was higher, as in case 1, this protection had not prevented the conversion of common lands in all three categories. In addition, the trajectories of change (see Figures 8 and 9) in case 1 clearly showed that the change in water resources was preceded by or concurrent to the changes in the agricultural land to other land uses that surround them, especially the conversion of agricultural land from paddy cultivation. Another salient aspect is that in the cases studied, the tanks and their components come under two agencies and two different maintenance protocols. The tanks that come under the P.W.D (Public Works Department) with a more active role in maintenance are in better condition than those that come under the panchayat, which has fewer resources to maintain the tanks. Therefore, it is clear that an agency which has an active role in the maintenance of the tanks is required to protect them.

This research had shown that in peri-urban areas with significant land use change, both the traditional model of management and the current management model of the government are ineffective. However, to an extent, the water resources under P.W.D, as the government agency, are in a relatively better condition. The condition of the tanks under P.W.D also cannot be sustained in the long term as the tanks are linked and even though the tanks under P.W.D are free from encroachment, they are affected by the changes in the tanks under panchayat, which act as the feeders for the larger tanks. Therefore, it is proposed that for the sustenance of water resources in peri-urban areas, active involvement of the government is required for all the tanks, channels, and protective areas of the tank system. The agencies that have ownership and control need to be present and engaged in the maintenance of water resources. These agencies require financial and administrative resources to implement measures that can protect and maintain water resources.

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Appendix A

Appendix A.1. Questionnaire used for the Structured Interview and format for the collection of Data about Tanks to be Collected at Village Level

1. Is there any irrigation or other schemes for bringing/transfer of water operational here? (for example—Telugu Ganga scheme)
2. Tank memoirs for this area available? If so for how many years back? Historical data?
3. Tanks in the village—List and categories—P.W.D or Panchayat or Private?

Appendix A.2. For Each Tank

1. Name of Tank
2. Control agency
3. Catchment area of the tank: total area and location
4. Purpose of Tank—If Irrigation or others.
5. For Tanks used for irrigation: Is it still used for irrigation—If yes questions in section a, if not question in section b.
6. Section A:

    a. i: Ayacut area (current and historical data)
    b. ii: Sluice and distribution Channels details:

   c. iii: Who maintains channels and sluices?
   d. iv: Who takes care of distribution? Opening of sluices etc?
   e. V: Any Tank user associations present? If so, what are their activities?

7. Section B:

   a. i: Was it used for irrigation before?
   b. ii: if yes till when and why isn't it used for irrigation now?
   c. iii: What is the purpose of the tank now?

8. For Tanks used for other purposes:

   a. i: What is the purpose of the tank?
   b. Ii: was it used for other purposes before?

9. What are the activities carried out by the side of the tanks/in tank bed/in bund by the people?

   a. Routine:
   b. Religious
   c. Communal
   d. Recreational

10. What is the source of water supplied to households? How is it distributed?
11. Are there any products collected from the tank and its surroundings?

   a. Fruits/fodder/wood from Trees:
   b. Grass cutting/Grazing
   c. Roofing material
   d. Silt from tank bed
   e. Clay from the tank bed:
   f. Others:

Appendix B

Table A1. Tank system status—scoring system.

No.	Aspect	Criteria	Score
1.	Water Storage area	Water storage area not changed in the last decade	1
		Water storage area partly reduced due to conversion for other purposes. A reduction in area of <50% was included in this category.	0.5
		Water storage area completely converted for other purposes/Water storage area reduced by more than 50%	0
2.	Status of the channel network connected to the tank	Clear	1
		Area reduced	0.5
		Obstructions	0.5
		Blocked	0.5
		Filled in	0

Table A1. *Cont.*

No.	Aspect	Criteria	Score
3.	Bund with its vegetation	Present on all three sides	1
		Partly present	0.5
		Damaged/not present	0
4.	Foreshore vegetation	Wooded	1
		Shrubs	0.5
		Scrub	0.5
		Grass/Ground cover	0.25
		No vegetation	0
5.	Common grazing land	Present	1
		Part of the area existing	0.5
		Occupied for other purposes	0
6.	Social and recreational	Frequent activity	1
		Occasional activity	0.5
		No activity	0
7.	Usage of the tank water	For original purpose	1
		Changed to lower purposes (e.g., drinking to washing/cleaning)	0.5
		Not used/not usable	0
8.	Extraction of products	For Revenue (fees collected for extraction of products)	1
		For Personal purposes	0.5
		No extraction	0

Appendix C

Table A2. Trajectories of change.

ID of Changed Plots	Land Use of Surrounding Agricultural Land	Year	Land Use of Common Land	Trajectory
		Water Storage areas		
WS1	Paddy, Road	1986	WS	Paddy to fallow → WS to residential
	Fallow	1986–1996	To residential	
	Vacant plot	1996–2006	Residential	
	Vacant plot	2006–2016	Residential	
WS2	Fallow, Paddy	1986	Plantation	Fallow to institutional → WS to Plantation to institutional
	Fallow, to fallow	1986–1996	Plantation	
	To plantation, to institutional	1996–2006	Plantation	
	To others, Institutional	2006–2016	Institutional	
WS3	Paddy, plantation, residential	1986	Paddy	Paddy + Plantation+ Residential→WS to paddy to plantation
	Paddy, To fallow, residential	1986–1996	Plantation	
	Paddy, fallow, residential	1996–2006	Plantation	
	Paddy, fallow, residential	2006–2016	Plantation	
WS4	Paddy, plantation	1986	Paddy	Paddy to fallow → WS to paddy
	To fallow, plantation	1986–1996	Paddy	
	Fallow, plantation	1996–2006	Paddy	
	Fallow, plantation	2006–2016	Paddy	
WS5	Paddy	1986	WS	Fallow to vacant plot → WS to residential
	To fallow	1986–1996	WS	
	To vacant plot	1996–2006	Residential	
	Vacant plot	2006–2016	Residential	
		Water Conveyance areas		
WC1	Fallow	1986	WC	Fallow to vacant plot → WC to paddy
	To vacant plot	1986–1996	Paddy	
	Vacant plot	1996–2006	Paddy	
	Vacant plot	2006–2016	Paddy	

Table A2. *Cont.*

ID of Changed Plots	Land Use of Surrounding Agricultural Land	Year	Land Use of Common Land	Trajectory
WC2	Fallow	1986	Others	Fallow → WC to others
	Fallow	1986–1996	Others	
	To industrial	1996–2006	Others	
	Industrial	2006–2016	Others	
	Land use of Surrounding agricultural land	**Year**	**Land use of common land**	**Trajectory**
WC3	Fallow	1986	Paddy	Fallow → WC to Paddy
	Fallow	1986–1996	Paddy	
	To industrial	1996–2006	Paddy	
	Industrial	2006–2016	Others	
WC4	Fallow	1986	WC	Fallow to institutional → WC to Plantation to others
	Fallow	1986–1996	WC	
	To industrial	1996–2006	To plantation	
	Industrial	2006–2016	To others	
WC5	Fallow, paddy	1986	Paddy	Fallow → WC to Paddy
	Fallow, to fallow	1986–1996	Paddy	
	To plantation, to institutional	1996–2006	Paddy	
	plantation, institutional	2006–2016	To institutional	
WC6	Paddy	1986	Paddy	Paddy → WC to Paddy
	To fallow	1986–1996	Paddy	
	To plantation, to institutional	1996–2006	Paddy	
	plantation, institutional	2006–2016	To institutional	
WC7	Paddy	1986	WC	Fallow to plantation, others → WC to institutional
	To fallow	1986–1996	WC	
	To plantation, to others	1996–2006	To Institutional	
	plantation, others	2006–2016	Institutional	
WC8	Paddy	1986	WC	Fallow to plantation, institutional → WC to paddy to institutional
	To fallow	1986–1996	WC	
	To plantation, to institutional	1996–2006	To paddy	
	Institutional	2006–2016	To institutional	
WC9	Paddy	1986	WC	Fallow to institutional to others → WC to institutional
	To fallow	1986–1996	WC	
	To institutional	1996–2006	To Institutional	
	Institutional, to others	2006–2016	Institutional	
WC10	Paddy, Fallow	1986	WC	Paddy, fallow → WC to Paddy
	Paddy, Fallow	1986–1996	WC	
	Paddy, Fallow, to plantation	1996–2006	WC	
	Paddy, Fallow, plantation	2006–2016	to road	
WC11	Plantation, paddy	1986	Industrial	Plantation, paddy → WC to industrial to plantation
	Fallow, paddy	1986–1996	Industrial	
	Fallow, to plantation	1996–2006	Plantation	
	Fallow, plantation	2006–2016	Plantation	
		Protective Areas		
PR1	Paddy, fallow, plantation	1986	PR	Fallow to institutional→ PR to plantation
	To fallow, fallow, plantation	1986–1996	PR	
	To institutional, fallow, plantation	1996–2006	Plantation	
	To institutional, fallow, to industrial	2006–2016	Plantation	
	Land use of Surrounding agricultural land	**Year**	**Land use of common land**	**Trajectory**
		Water Conveyance areas		
WC1	Paddy	1986	Paddy	Paddy to Fallow → WC to paddy to WC to fallow
	Paddy	1986–1996	WC	
	To fallow	1996–2006	WC	
	Fallow	2006–2016	Fallow	
WC2	Paddy	1986	Paddy	Paddy → WC to paddy
	Paddy	1986–1996	Paddy	
	To fallow, paddy	1996–2006	Paddy	
	Fallow, paddy	2006–2016	Paddy	
WC3	Residential, paddy	1986	Residential	Residential, paddy → WC to Residential
	Residential, fallow	1986–1996	Residential	
	Residential, fallow	1996–2006	Residential	
	Residential, fallow	2006–2016	Residential	
WC4	Paddy	1986	Paddy	Paddy to plantation → WC to Paddy to plantation
	To Plantation, paddy	1986–1996	To plantation	
	Plantation, paddy	1996–2006	Plantation	
	Plantation, to plantation	2006–2016	Plantation	

Table A2. *Cont.*

ID of Changed Plots	Land Use of Surrounding Agricultural Land	Year	Land Use of Common Land	Trajectory
		Protective Areas		
PR1	Paddy	1986	PR	
	To fallow, vacant plot	1986–1996	To residential	Paddy to fallow, vacant plot → PR to residential
	Fallow, vacant plot	1996–2006	Residential	
	Fallow, vacant plot	2006–2016	Residential	
PR2	Paddy	1986	PR	
	To fallow, vacant plot	1986–1996	To residential	Paddy to fallow, vacant plot → PR to residential
	Fallow, vacant plot	1996–2006	Residential	
	Fallow, vacant plot	2006–2016	Residential	
PR3	Paddy	1986	PR	
	To fallow, vacant plot	1986–1996	To residential	Paddy to fallow, vacant plot → PR to residential
	Fallow, vacant plot	1996–2006	Residential	
	Fallow, vacant plot	2006–2016	Residential	
PR4	Paddy	1986	PR	
	To fallow, vacant plot	1986–1996	PR	Paddy to fallow, vacant plot → PR to residential
	Fallow, vacant plot	1996–2006	To residential	
	To vacant plot	2006–2016	Residential	
PR5	Paddy	1986	PR	
	To fallow, vacant plot	1986–1996	PR	Paddy to fallow, vacant plot → PR to residential
	Fallow, vacant plot	1996–2006	To residential	
	To vacant plot	2006–2016	Residential	

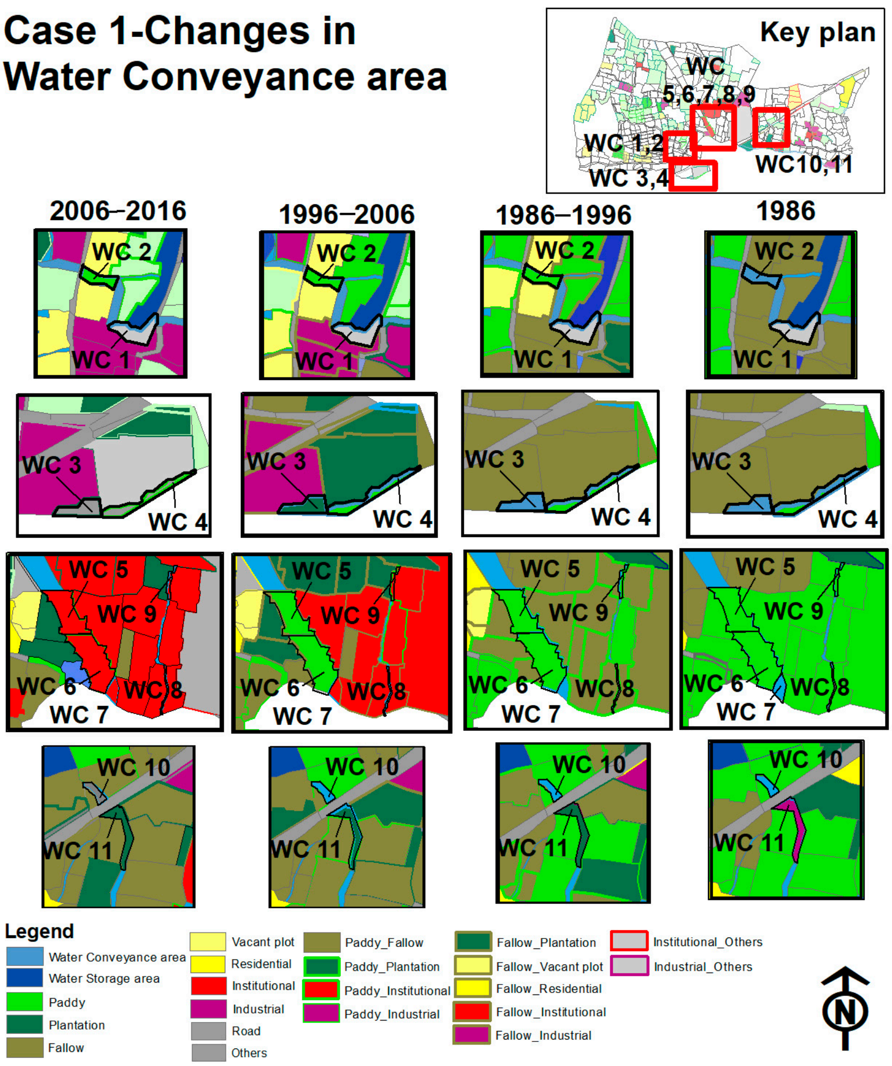

Figure A1. Trajectories of change: Case 1—water conveyance area.

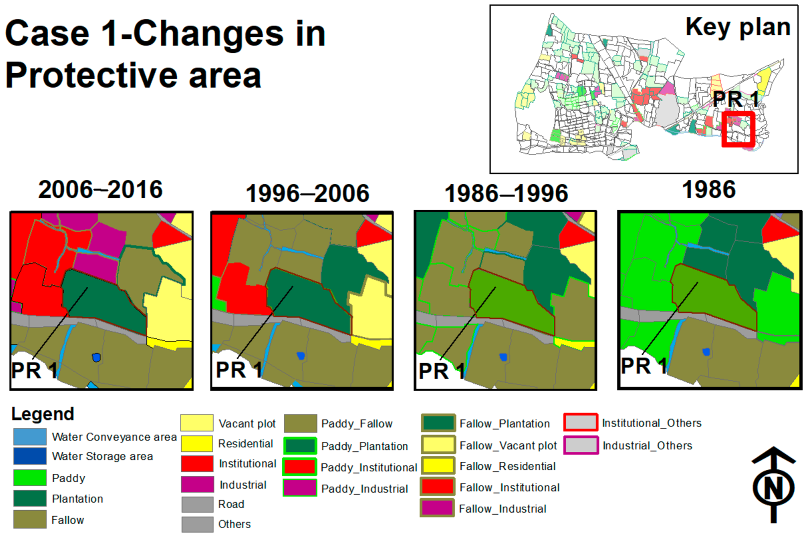

Figure A2. Trajectories of change: Case 1—protective area.

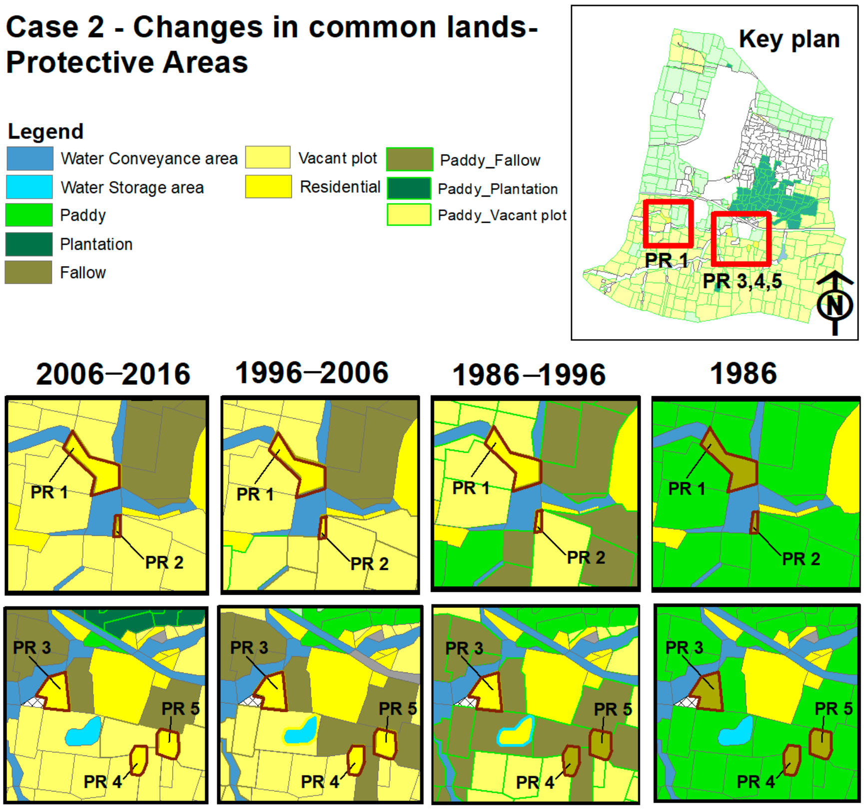

Figure A3. Trajectories of change: Case 2—protective area.

Appendix D

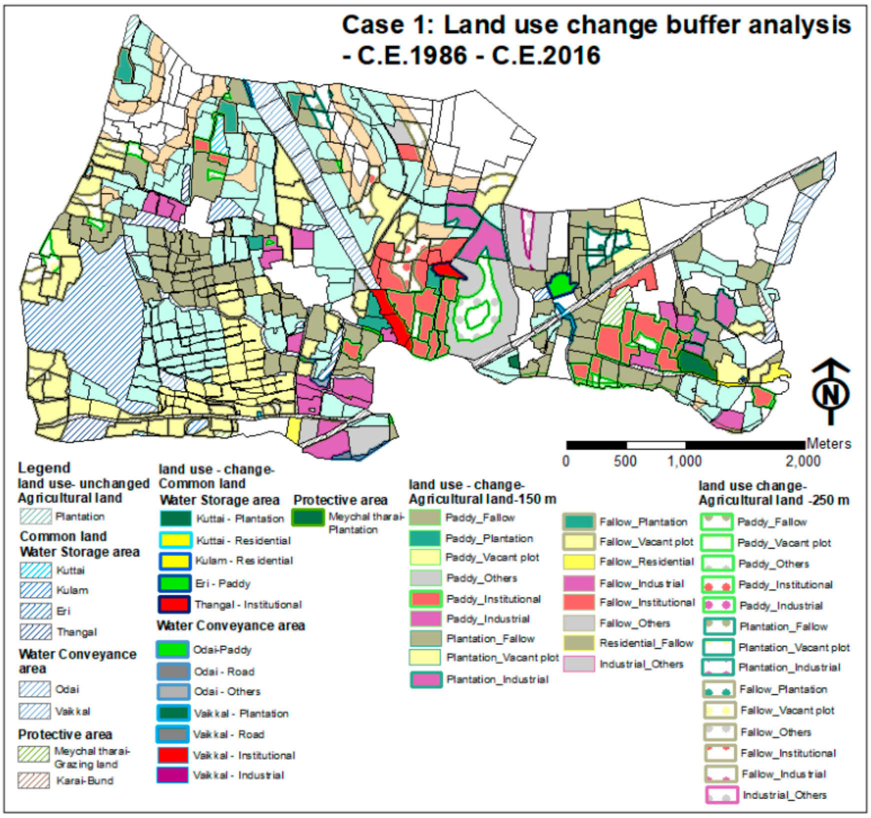

Figure A4. Output of buffer analysis—Case 1.

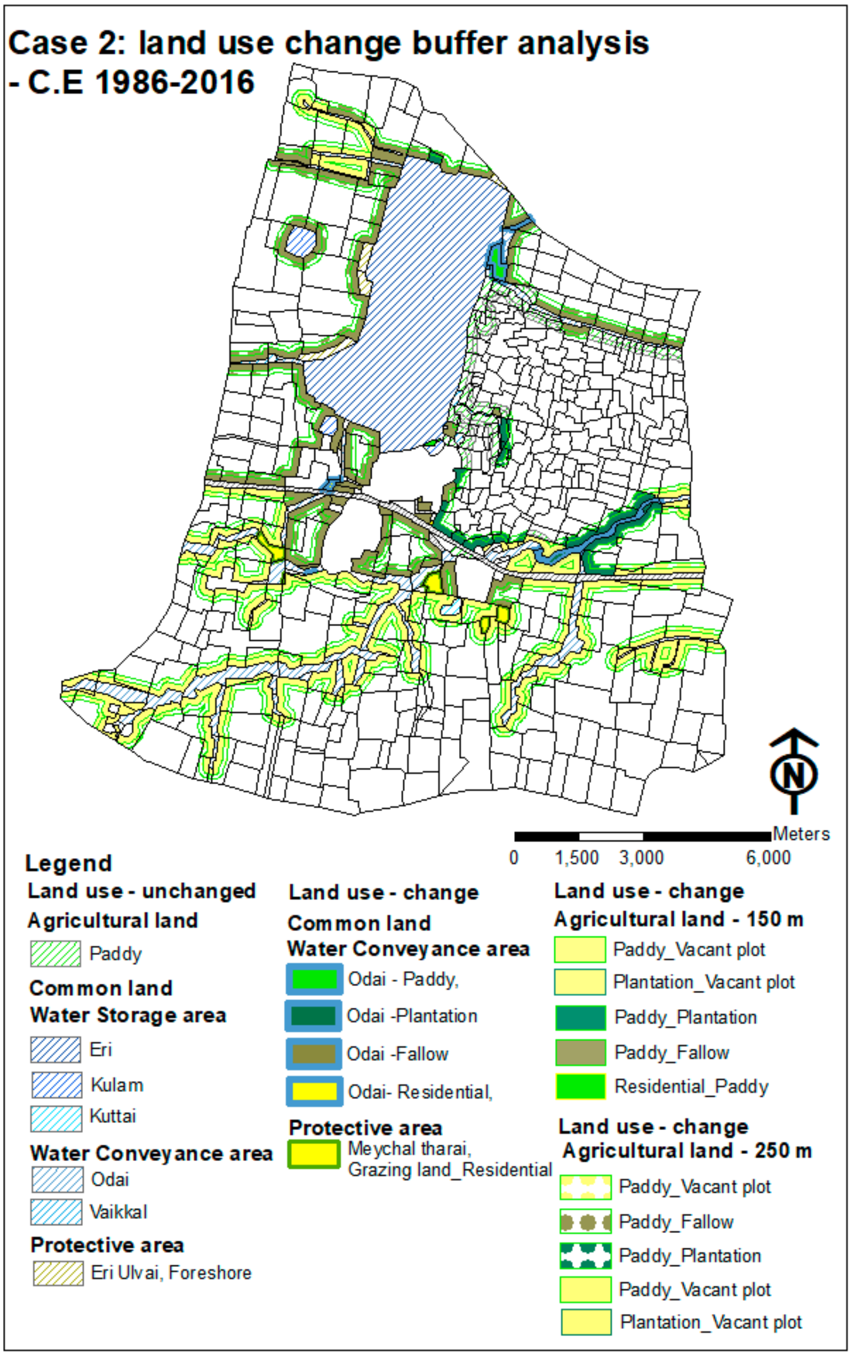

Figure A5. Output of buffer analysis—case 2.

Appendix E

Table A3. Consolidated data from the interview for all the tanks in both cases.

No.	Survey No.	Name of the Tank	Type of the Tank	Control -Agency	Area (m^2)	If Irrigation Tank	Purpose-Now	Purpose-Earlier	Activity	Frequency
I		Case 1:								
1	116	Un eri	Eri	P.W.D	24,082.49	yes	IRR	IRR	cultural activities around	high
2	195	Mevalurkuppameri	Eri	P.W.D	748,668	yes	IRR	IRR	agricultural and cultural activities around	high
3	287	Kattagaram Eri	Eri	Panchayat	22,340.10	yes	NO	IRR	no major activities around	low
4	171	Kulam 1	Kulam	Panchayat	981.79	no	Wa	Wa	no major activities around	high
5	249	Kulam 2	Kulam	Panchayat	17,426.58	no	Wa	Wa	no major activities around	na
6	280	Katan kulam	Kulam	Panchayat	3336.10	no	Wa	Wa	cultural activities around	high
7	400	Kannadiyanpalayamkulam	Kulam	Panchayat	4387.92	no	Wa	Wa	cultural activities at occasions	high
8	14	Kalkuttai	Kuttai	Panchayat	2493.18	no	Ca	Ca	cattle grazing	low
9	38	Kuttai 2	Kuttai	Panchayat	22,585.50	yes	IRR	IRR	no major activities around	low
10	40	Easwarankoilkuttai	Kuttai	Panchayat	3715.12	no	NO	SA	cultural activities around	low
11	126	Arasankalanikuttai	Kuttai	Panchayat	5,166.28	no	Wa	Wa	no major activities around	high
12	131	Karpagaviyagarkoilkuttai	Kuttai	Panchayat	4727.99	no	SA	SA	cultural activities around	low
13	234	Kuttai 2	Kuttai	Panchayat	3454.64	no	Wa	Wa	cultural activities around	festive seasons
14	251	Kakkukuttai	Kuttai	Panchayat	8481.46	no	Wa	SA	cultural activities around	low
15	254	Sudukattukuttai	Kuttai	Panchayat	835.91	no	Cr	Cr	cremation	very low
16	421	Sri Palliyaththamman koil kuttai	Kuttai	Panchayat	1871.63	no	SA	SA	cultural activities around	low
17	4a	Papankalanikuttai	Kuttai	Panchayat	4284.02	yes	NO	Wa	no major activities around	very low
18	23	Thangal 1	Thangal	Panchayat	13,153.37	yes	NO	IRR	no major activities around	very low
19	45	Sakaraithangal	Thangal	Panchayat	2242.50	no	Wa	Wa	no major activities around	low
20	176	Vannirthangal	Thangal	Panchayat	15,518.53	yes	IRR	IRR	no major activities around	low
21	214	Thangal1	Thangal	Panchayat	41,829.37	yes	Dy	IRR	dumping waste and garbage	high
22	401	Konnerithangal	Thangal	Panchayat	1997.63	no	NO	Wa	dumping waste and garbage	low
II		CASE 2:								
1	186	Periyaeri	Eri	P.W.D.	724,900	Yes	Wa	IRR		
2	211	Vannankulam	Kulam	Panchayat	5637	No	Wa	Wa		
3	254	Nallathanikulam	Kulam	Panchayat	11,133	No	Dr	Dr	Fishing is prohibited for some time now	
4, 5	331	Kulam	Kulam	Panchayat	10,292	Yes	St	IRR		
6	367	Mandhaivelikulam	Kulam	Panchayat	2997	Yes	Ca	IRR		
7	369	Mandhaivelikulam	Kulam	Panchayat	1366	Yes	St	IRR		
8	490	Kulam	Kulam	Panchayat	1744	Yes	St	IRR		
9	247/A	Annanagarkulam	Kulam	Panchayat	1515	No	Wa	Dr		
10	405, 289	Nallathannikulam	Kulam	Panchayat	10,075	No	Dr	Dr		
11	497, 499	New water body	Kulam	Panchayat	5469	No	Dr	Dr		
12	198	Kuttai	Kuttai	Panchayat	122	Yes	St	IRR		
13	242	Kuttai	Kuttai	Panchayat	6361	Yes	NO (Dry)	IRR		
14	254	Kuttai	Kuttai	Panchayat	2717	Yes	St	IRR		
15	254	Kuttai	Kuttai	Panchayat	1858	Yes	Gr	IRR		
16	254	Kuttai	Kuttai	Panchayat	1343	Yes	Gr	IRR		
17	273	Kuttai	Kuttai	Panchayat	3293	Yes	St	IRR		
18	415	Kuttai	Kuttai	Panchayat	12,594	No	St	St		
19	182 b	Kuttai	Kuttai	Panchayat	96,158.96	Yes	St	IRR		

Dy—dump yard, Wa—washing clothes, IRR—irrigation, NO—no usage, Ca—cattle feeding, SA—serves water for temple, Cr—serves water for crematory rituals, Dr—Drinking Water, St—Overfow Storage, Gr—Storage of Grey water.

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