# Impact of India's watershed development programs on biomass productivity

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[1] Watershed development (WSD) is an important and expensive rural development initiative in India. Proponents of the approach contend that treating watersheds will increase agricultural and overall biomass productivity, which in turn will reduce rural poverty. We used satellite-measured normalized differenced vegetation index as a proxy for land productivity to test this crucial contention. We compared microwatersheds that had received funding and completed watershed restoration with adjacent untreated microwatersheds in the same region. As the criteria used can influence results, we analyzed microwatersheds grouped by catchment, state, ecological region, and biogeographical zones for analysis. We also analyzed pre treatment and posttreatment changes for the same watersheds in those schemes. Our findings show that WSD has not resulted in a significant increase in productivity in treated microwatersheds at any grouping, when compared to adjacent untreated microwatershed or the same microwatershed prior to treatment. We conclude that the well-intentioned people-centric WSD efforts may be inhibited by failing to adequately address the basic geomorphology and hydraulic condition of the catchment areas at all scales.

## 1. Introduction

[2] Watershed development (WSD) in India is largely governed by a set of guidelines released by the Ministry of Rural Development that are revised regularly, the latest revision being in 2008. Successive guidelines have used a remarkably consistent set of implementation arrangements and criteria through which areas are selected for restoration [*Bhalla et al.*, 2011]. WSD is an important component of India's poverty alleviation and rural development efforts with livelihoods being considered a "core objective" [*Joshi*, 2006]. Restoration activities recommended by the guidelines are designed to generate local employment. They target recharge of aquifers, afforestation of catchment areas, rain water harvesting for increasing soil moisture and irrigation, stabilization of slopes, sediment retention, and revegetation of degraded lands [*Government of India*, 2008]. These activities often result in obstruction of natural flows and increasing evapotranspiration [*Batchelor et al.*, 2003; *Calder et al.*, 2008].

[3] WSD elsewhere, particularly in North America, differs in being largely concerned with meeting water quality standards and protecting water resources. In this respect the western version of WSD is centered on restoration of watershed function [*Cairns*, 1989]. Much literature on watershed restoration is therefore related to hydraulic function and processes, covering transport of sediments [*Anbumozhi et al.*, 2005; *Behera and Panda*, 2006; *Fowler and Heady*, 1981; *Tripathi et al.*, 2003], nutrients and pollutants [*Cullum et al.*, 2006], and impacts of land use changes on stream flow and ground water recharge [*Allan*, 2004; *Bonell et al.*, 2010; *Bruijnzeel*, 2004; *Cao et al.*, 2009; *Randhir and Hawes*, 2009; *Scanlon et al.*, 2007]. Geographic information system (GIS) and remote sensing applications have been used extensively in hydrological modeling [*Setegn et al.*, 2008; *Tobin and Bennett*, 2009] with examples from India as well [*Gosain and Rao*, 2004; *Gosain et al.*, 2006; *Jain et al.*, 2000; *Rao et al.*, 1991; *Rao and Kumar*, 2004], albeit with some limitations [*Madon and Sahay*, 1997].

[4] Comprehensive datasets to facilitate scientific management and long-term monitoring of watershed restoration are increasing in number [*Frissell and Ralph*, 1998]. This has led to studies where analysis has been undertaken with the broad objective of "preserving ecosystem integrity while maintaining sustainable benefits for human populations" [*Montgomery et al.*, 1995]. This approach to WSD moves from treating symptoms to treating causal processes that operate at landscape scales. Various authors have highlighted the advantage of watershed level restoration as opposed to microinterventions [*Frissell and Ralph*, 1998;

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*Kerr*, 2007; *Wohl et al.*, 2005] l however, the latter remains a norm in India.

[5] Stakeholder-based collaborative watershed management has become part of national policy in many countries. This includes Australia and North America [*Curtis et al.*, 2005; *Ferreyra and Beard*, 2007] and more recently in Europe under the European Union (EU) Water Framework Directive [*Bruen*, 2008]. The Indian policy for watershed management took a similar route since the Hanumantha Rao Committee report in 1994 [*Government of India*, 1994]. However, there is a fundamental difference. In the west, stakeholders operate at a policy level leaving the implementation to technical teams. In India, stakeholders are expected to act as implementers while policy decisions are left to experts.

[6] The dependence of rural poor on natural resources is well documented internationally [*Bruce and Mearns*, 2002; *Jodha*, 1995; *Millenium Ecosystem Assessment*, 2005; *World Resources Institute*, 2005]. This is the basic premise for linking WSD and poverty alleviation. The latest set of guidelines emphasizes increased returns from natural resources through interventions in areas that have higher productivity potential [*Wani et al.*, 2006]. The National Rainfed Area Authority has been created as a crucial component of the new watershed policy. There are some reservations to this approach [*Reddy et al.*, 2004; *Reddy*, 2006] and the association made between WSD and increased agricultural productivity [*Hope*, 2007; *Turton et al.*, 1998]. Studies on WHD programs in India have raised a number of fundamental concerns that contribute to their poor performance. These include iniquitous sharing of benefits [*Kerr*, 2002; *Kerr et al.*, 2002], overemphasis on institutional aspects at the expense of application of appropriate technology [*Vaidyanathan*, 2006], contradictions in management and restoration that arise from different scales at which optimal interventions can be made [*Kerr*, 2007], failure to address functional aspects of watershed restoration [*Joy et al.*, 2006], inconsistencies in criteria used to select microwatersheds for treatment [*Bhalla et al.*, 2011], and added cost and liability due to overreliance on nongovernment organizations [*Chandrashekar*, 2005; *Deshpande*, 2008].

[7] The primary objective of this paper is to determine whether India's WSD programs have succeeded in their major premise of increasing primary productivity.

## 2. Material and Methods

### 2.1. Hypothesis

[8] We tested the above premise of WSD, namely—that it leads to higher productivity. We adopted an approach based on remote sensing and a spatially explicit all India data set on completed watershed projects. Normalized difference vegetation index (NDVI) in treated, and adjacent, untreated microwatersheds were compared before and after restoration (Figure 1). The NDVI provides a robust index of productivity as it measures chlorophyll content on a scale from $-1$ to 1. It is calculated using the formula $NDVI = (NIR - Red)/(NIR + Red)$ where NIR is the near infrared band and red corresponds to the red band in the image. It has been used in studies on net primary productivity [*Matsushita and Tamura*, 2002] and related ecosystem and hydrological services [*Krishnaswamy et al.*,

2009] extensively across the world (see *Pettorelli et al.* [2005] for a brief glossary). NDVI values have also been used extensively for land cover mapping. Various studies have deduced values corresponding to thick vegetation, scrub, barren soils, and water bodies and moist soils.

[9] Successful WHD projects are expected to result in an increase in biomass (grazing lands, fuel, fodder, tree cover), agricultural productivity, reduced soil erosion, increased soil moisture, and increased ground water recharge [*Government of India*, 2006]. All these positively influence vegetative cover, albeit, there can be seasonal effects or lags. For instance, increasing groundwater recharge should lead to increasing NDVI as rising water table will improve tree growth as well as bringing shallow wells back into production for nonsurface supplies of water [*Heuperman et al.*, 2002].

[10] NDVI data have been used for a range of land use/ land cover change detection studies [*Lunetta et al.*, 2006]. Our application, however, is simpler as it merely looks at whether NDVI has increased or decreased and the marked response of NDVI in vegetated as opposed to unvegetated areas is sufficiently sensitive for the purpose [*Friedl et al.*, 2002]. We have dealt with seasonal aspects by using 16 day composites for four periods of the year and used the higher 250 m resolution images to ensure there were sufficient pixels per sampling unit, the microwatershed.

[11] We were faced with a rather daunting set of subhypotheses—there were 1025 prewatershed and postwatershed comparisons and 4839 pairs of treated and untreated microwatersheds in our data set. Each microwatershed contained hundreds to thousands of NDVI pixels. Within those comparison there was the issue of choice of a test statistic. The explicit hypothesis was that the posttreatment watershed would have greater productivity, and thus we initially used the greater than criterion as a baseline. The one-tailed criterion exacerbates the chance of finding significance where none really exists, so we also ran two-sided tests for all comparisons. The data regularly failed standard tests of normality, but not always. So we also used Wilcoxon tests. Consistent results across the tests would confirm that the signal in the data was consistent, and inconsistent results would suggest that method might be driving the results.

[12] The following hypothesis was tested:

[13] 1. NDVI values for the treated microwatersheds would show a greater increase than the control microwatersheds, or $\delta NDVI_{ctrl} < \delta NDVI_{treated}$ where $\delta NDVI = NDVI_{post} - NDVI_{pre}$.

[14] 2. The NDVI values of treated watersheds should not be significantly different from untreated watersheds before the treatment but should be higher than control watersheds after WSD, or

[15] i. $NDVI_{ctrl(pre)} \sim NDVI_{treated(pre)}$

[16] ii. but $NDVI_{ctrl(post)} < NDVI_{treated(post)}$.

[17] 3. NDVI values of treated watersheds should be higher after treatment, but this should not be so for control watersheds, or

[18] i. $NDVI_{ctrl(pre)} \sim NDVI_{ctrl(post)}$

[19] ii. but $NDVI_{treated(pre)} < NDVI_{treated(post)}$.

### 2.2. Data Preparation

[20] The list of microwatersheds where work had been completed in the period between 31 December 2006 and 31
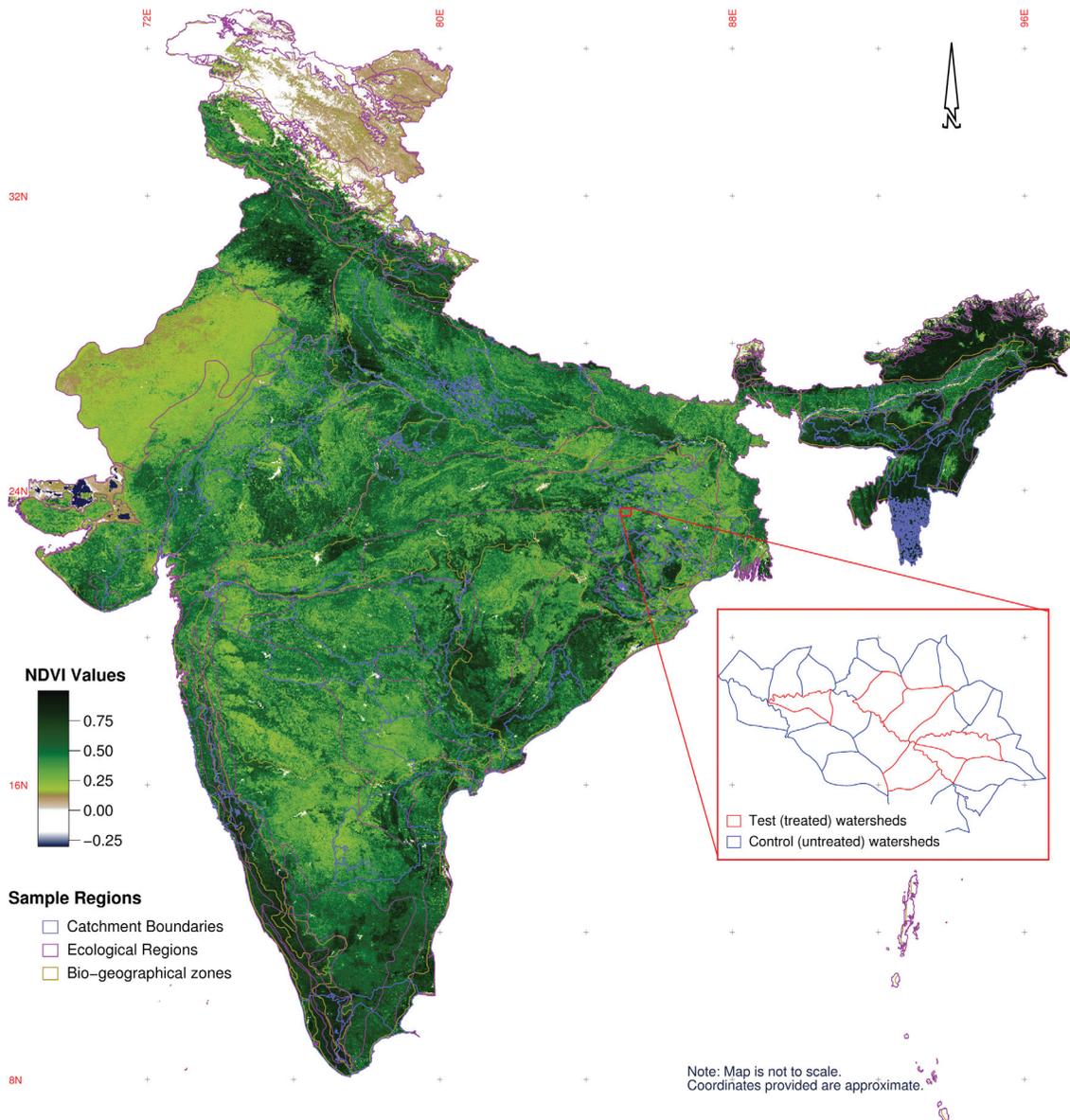
**Figure 1.** Mosaicked MODIS-Terra NDVI values on a map of India showing the boundaries for biogeographical zones, catchments, ecological regions, and states.

December 2010 was compiled from the watershed programs monitoring information system [*Department of IT, Ministry of Communications and Information Technology, GOI*, 2012]. We selected pairs of treated and neighboring untreated (control) microwatersheds to account for local variations. The analysis was grouped across administrative boundaries of states, catchment boundaries, ecological regions [*Olson et al.*, 2001], and biogeographical zones [*Rodgers and Panwar*, 1988]. We thereby tried to capture any patterns that were on account of different state policies, watershed catchments, and ecological or climatic factors. To ensure that seasonal variations in NDVI were covered, we used images composites for the dates of 23 April, 29 August, and 19 December for the years 2006 and 2011. We used the minimum, maximum, and mean values of NDVI for all the data sets to ensure that aggregation of values did

not bias the results. Only those microwatersheds that contained over 30 pixels were selected. Further, we removed all data sets where there were fewer than 30 pairs to ensure the statistical analysis was more reliable. We then categorized the NDVI values into four responses corresponding to water (NDVI<0), barren areas ($0 < \text{NDVI} \leq 0.1$), shrub and grassland ($0.1 < \text{NDVI} \leq 0.3$), and green vegetation and crops (NDVI>0.3) [*Herring and Weier*, 2000], and reran the analysis.

[21] Microwatershed maps and administrative boundaries from the National Remote Sensing Center's BHUVAN facility [*NRSC/ISRO*, 2011] were used along with MODIS/ Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid [*NASA Land Processes Distributed Active Archive Center (LP DAAC)*, 2011]. These images are preprocessed and are suitable for analytical purposes. They have a range
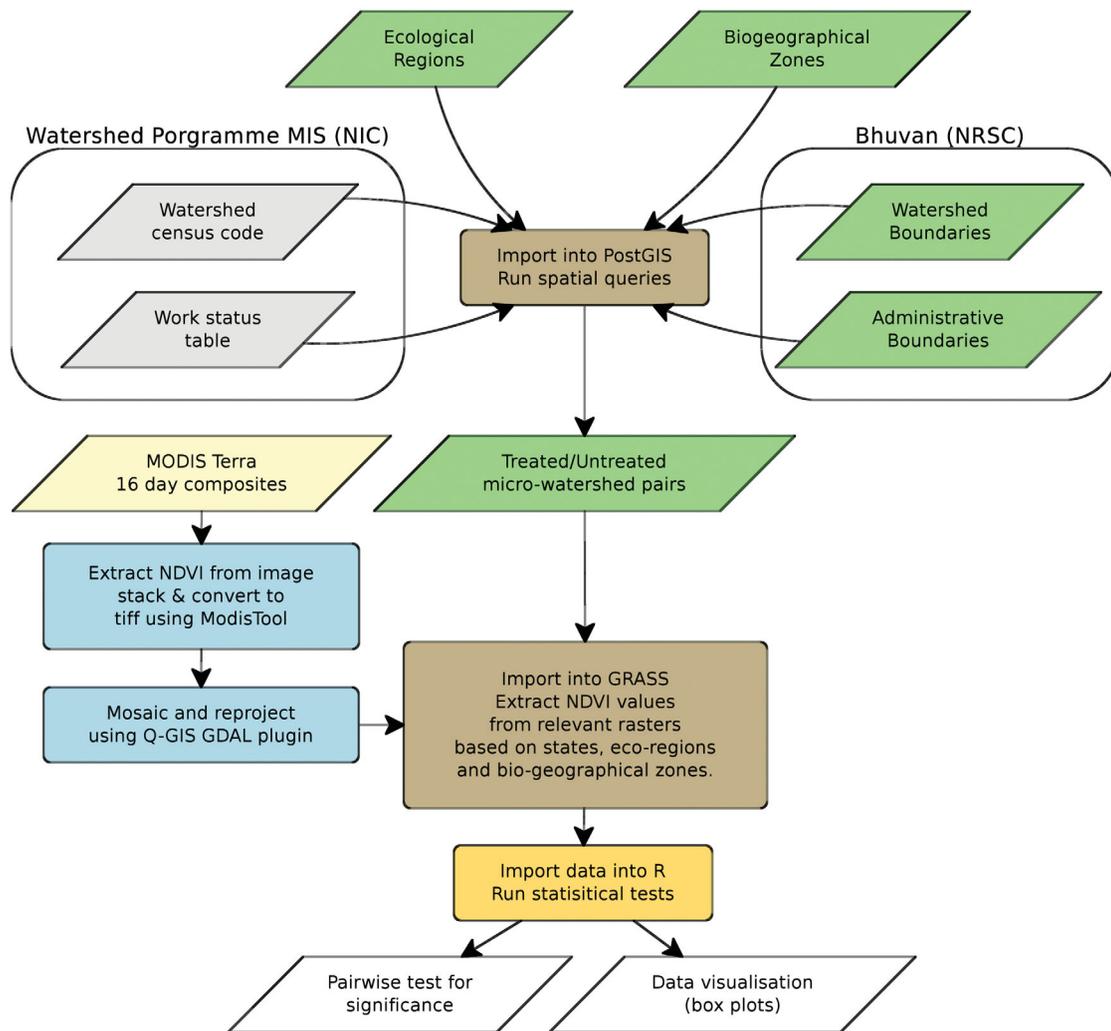
**Figure 2.** Procedure followed for compilation of data and analysis. The steps involved: (1) Downloading relevant datasets, both vectors (green), data (gray), and imageries (yellow). (2) Spatial queries (brown) to derive control and treated microwatersheds based on date of project completion and adjacent (control) microwatersheds. (3) Raster operations (blue) to extract minimum, mean, and maximum NDVI values falling under catchment areas, biogeographical zones, ecological regions, and state boundaries. (4) Importing data into R and performing statistical tests (orange) (5) Exporting aggregated results as box plots and histograms (white).

of −2000 to 10,000 and can be rescaled to actual NDVI values by multiplying with a scale factor of 0.0001. A map showing some of the data sets is presented in Figure 1.

### 2.3. Analysis

[22] Software used for the analysis included the PostGIS geospatial database system [*Ramsey*, 2005], the Geographical Resource Analysis and Support System [*GRASS Development Team*, 2008], and the R system for statistical computing with additional packages [*Conway et al.*, 2012; *Fox*, 2005; *R Development Core Team*, 2008]. The steps involved in the analysis are provided in Figure 2, and the data and R script used for analysis are presented in the supporting information. The script loops through all the factors, namely states, biogeographical zones, ecoregions, and catchments and outputs the results to database tables. In addition, it tests for the two-sided, less and greater alternative of the paired and unpaired tests. This generated thousands of results (Table 1) and over 300 graphical outputs for each of the hypothesis and permutations of the options listed above. The script executes a number of SQL statements, and a compressed backup of the database has been included so the reader may validate the analysis and modify the queries.

### 3. Results

[23] Figures 3–12 present a comparison of the *P* values for the three hypothesis using a two-sided alternative for pairwise and unpaired comparisons of *t* test and paired Wilcoxon tests (signed rank tests with and without continuity correction) and unpaired Wilcoxon rank sum test (equivalent to the Mann-Whitney test).

[24] We summarized the results of all the tests by transforming the *P* values using a $\log(1/P - \text{value})$ transform. This spreads out the values falling in the significant range.

**Table 1.** Summary of Results Showing Proportion of Significant and Nonsignificant Results for the Less and Greater Alternative at a $P$ Value of 0.025 and 0.05 (Corresponding to 0.05 and 0.1 on a Two-Sided Alternative)

| Hypothesis | Result | Number of $P$ Values | $P$ Value $\leq 0.025$ (%) | | $P$ Value $\leq 0.05$ (%) | |
|---|---|---|---|---|---|---|
| | | | Less | Greater | Less | Greater |
| Hyp. 1: $\delta\text{NDVI}_{ctrl} < \delta\text{NDVI}_{treatment}$ | Raw NDVI | 6370 | 9 | 5 | 11 | 7 |
| where $\delta\text{NDVI} = \text{NDVI}_{post} - \text{NDVI}_{pre}$ | Responses | 1288 | 1 | 2 | 2 | 4 |
| Hyp. 2a: $\text{NDVI}_{ctrl(pre)} \sim \text{NDVI}_{treated(pre)}$ | Raw NDVI | 4947 | 7 | 8 | 9 | 12 |
| | Responses | 847 | 1 | 13 | 2 | 15 |
| Hyp. 2b: $\text{NDVI}_{ctrl(post)} < \text{NDVI}_{treated(post)}$ | Raw NDVI | 6341 | 8 | 6 | 10 | 8 |
| | Responses | 1325 | 0 | 14 | 0 | 18 |
| Hyp. 3a: $\text{NDVI}_{ctrl(pre)} \sim \text{NDVI}_{ctrl(post)}$ | Raw NDVI | 2958 | 12 | 16 | 13 | 18 |
| | Responses | 1197 | 3 | 17 | 4 | 21 |
| Hyp. 3b: $\text{NDVI}_{treated(pre)} < \text{NDVI}_{treated(post)}$ | Raw NDVI | 2847 | 12 | 16 | 13 | 18 |
| | Responses | 1097 | 3 | 17 | 4 | 22 |

Box plots of the $P$ values were then plotted for the various hypothesis using the less alternative on the negative and greater alternative on the positive $x$ axis. The region between the dashed lines indicates nonsignificant values at $P = 0.05$ (0.025 at either tail). Paired $t$ tests and the signed rank test with continuity correction provided similar results while the other tests, namely, one sample $t$ test, Wilcoxon signed rank test, and the rank-sum test with continuity correction showed varying results. Part of this is due to the effect of binning the data into responses, which resulted in ties that violate one of the assumptions of the Mann-Whitney test, i.e., the data should be continuous variables and therefore have no ties. Also, the paired Wilcoxon test depends on pairwise differences that are zero for some of the pairs, which invalidated some of the comparisons.

### 3.1. Do Treated Watersheds Show a Higher Positive Change in NDVI?

[25] Tests for difference in NDVI values before and after treatment ($\delta\text{NDVI} = \text{NDVI}_{post} - \text{NDVI}_{pre}$) for control and treated watersheds showed that there was no significant difference for the majority of microwatersheds irrespective of grouping (Figure 3) or response (Figure 4).

### 3.2. Are Pretreatment NDVI Values for Treated/Control Watershed Any Different Than Posttreatment?

[26] Tests between control watersheds and treated watersheds in 2011 (posttreatment) and 2006 (pretreatment) are summarized in Figures 5–8. The differences between NDVI values prior to treatment of both the treated and nontreated watersheds were not significant for the bulk of the microwatersheds across both grouping (Figure 5) and after binning the NDVI into responses (Figure 6). A comparison of NDVI values of treated and control microwatersheds after the treatment period showed that the bulk of the values was nonsignificant across groups (Figure 7) and when binned into responses (Figure 8).

### 3.3. Are NDVI Values Higher Posttreatment for Treated but Not for Control Microwatersheds?

[27] Results for the third hypothesis are summarized in Figures 9–12. Most microwatersheds did not show a significant difference between 2006 and 2011, regardless of treatment. NDVI values of tests between control watersheds in 2006 and 2011 were expected not to be significantly different. This was the case regardless of whether the microwa-

tersheds were grouped (Figure 9) or the NDVI values binned into response categories (Figure 10). On the other hand, the treated watersheds were expected to exhibit lower NDVI values in 2006 when compared to 2011. This was not the case either when NDVI values were tested across groups (Figure 11) or binned into responses (Figure 12).

### 3.4. Summary of Results

[28] The majority of comparisons showed that the differences between the combination of control and treatment and before and after were nonsignificant. Furthermore, many of the results showed a greater proportion of control or pretreatment responses had higher significance than treated microwatersheds or posttreatment microwatersheds (Table 1). In other words, there is no evidence that productivity of microwatersheds treated as part of WHD projects is greater than untreated regions nor has there been an increase in productivity of the same microwatersheds after WHD when compared to a period prior to treatment.

## 4. Discussion and Conclusions

[29] The poverty-alleviation centric approach to WSD in India would lead one to expect that performance of such projects is measured in enhanced delivery of ecological services, if hydrologic and ecological goals are more than nominal. Changes in hydrologic services associated with improved ecological function of watersheds are used to justify a number of large restoration programs. Such an approach cannot work in India as information required to measure changes in hydrological and ecosystem functions is severely lacking, both on a temporal and a spatial scale. Most online portals for India, which are expected to provide such information remain bereft of data and most agencies, still share their information through paper maps, and hydrological gaging stations are usually limited to dam and barrage sites on major rivers. The resolution of other datasets, such as meteorological measurements, soil, geology, land use, and topography, is insufficient for most models forcing researchers to interpolate or derive "reasonable" values through modeling routines provided by software. This diminishes the accuracy of model predictions and therefore renders them less useful for planners.

[30] Given these limitations, the easiest way to measure the success of interventions in watersheds is to determine their impacts on overall productivities rather than hydrological
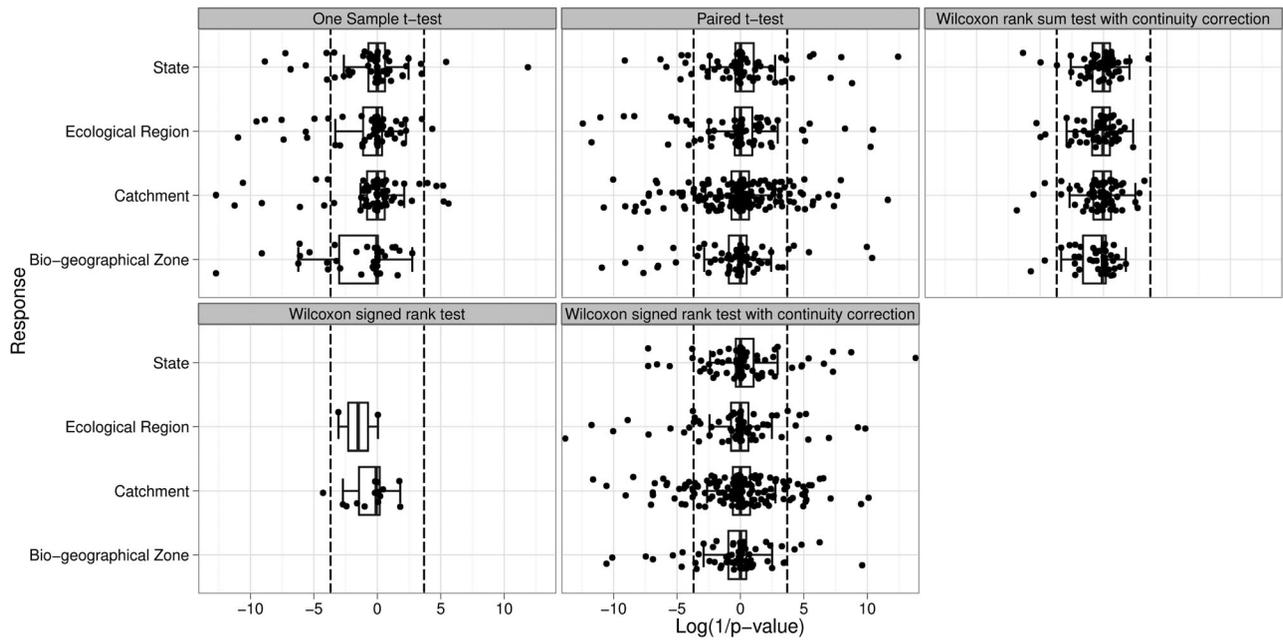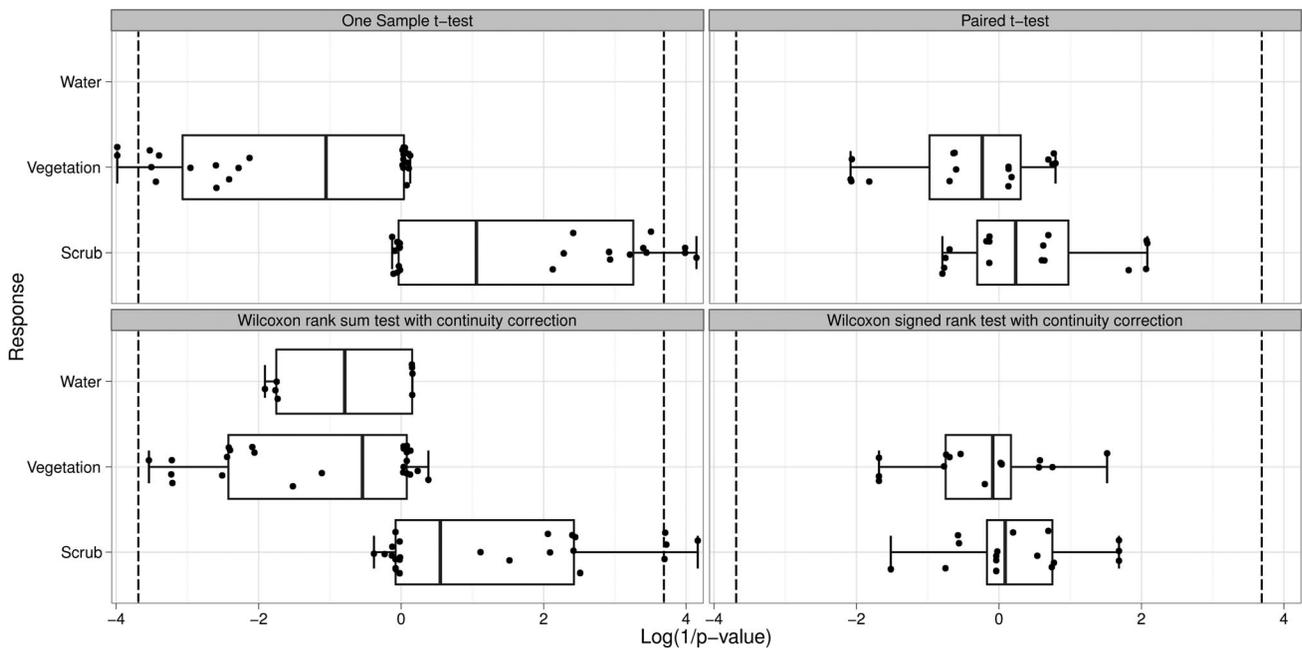
**Figure 3.** Box plots of $P$ values for pairwise and unpaired tests using the less alternative on the negative and greater alternative on the positive $x$ axis. Regions outside the dashed lines are significant at $P = 0.05$. Hypothesis 1: $\delta\text{NDVI}_{\text{ctrl}} < \delta\text{NDVI}_{\text{treatment}}$ where $\delta\text{NDVI} = \text{NDVI}_{\text{post}} - \text{NDVI}_{\text{pre}}$ on NDVI values. Most values lie between the dashed lines showing they were nonsignificant. Similar number of values lie on other sides of showing that the number of microwatersheds where NDVI values increased after treatment was similar to the numbers showing a significant decrease in NDVI.



**Figure 4.** Box plots of $P$ values for pairwise and unpaired tests using the less alternative on the negative and greater alternative on the positive $x$ axis. Regions outside the dashed lines are significant at $P = 0.05$. Hypothesis 1: $\delta\text{NDVI}_{\text{ctrl}} < \delta\text{NDVI}_{\text{treatment}}$ where $\delta\text{NDVI} = \text{NDVI}_{\text{post}} - \text{NDVI}_{\text{pre}}$ on responses. Bulk of the values lies between the dashed lines indicating they are nonsignificant. Some microwatersheds show a significant decrease in vegetation and a significant increase in scrub.
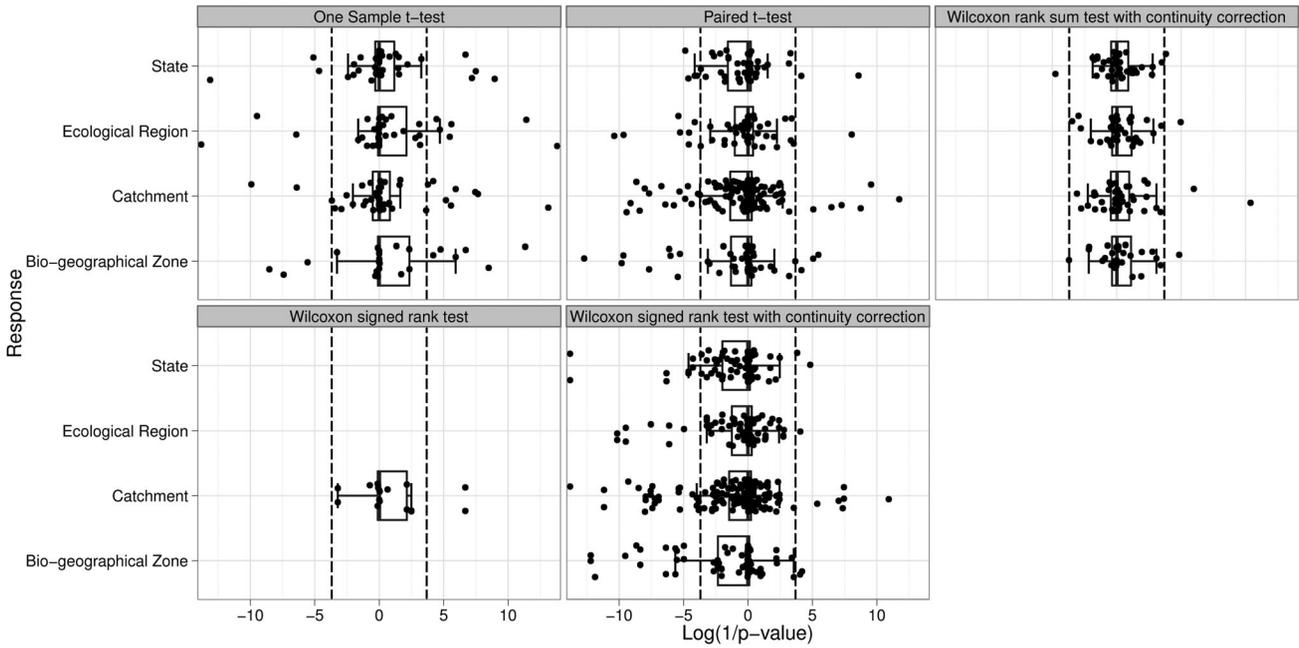
**Figure 5.** Box plots of $P$ values for pairwise and unpaired tests using the less alternative on the negative and greater alternative on the positive $x$ axis. Regions outside the dashed lines are significant at $P = 0.05$. Results for hypothesis 2a: $\text{NDVI}_{\text{ctrl(pre)}} \sim \text{NDVI}_{\text{treatment(pre)}}$ on NDVI values. A large number of points lie between the dashed lines showing they are no significant differences between the control and treatment prior to watershed restoration. Of the significant values, the majority lie to the left of the dashed line, indicating that some control microwatersheds had higher NDVI values prior to treatment.
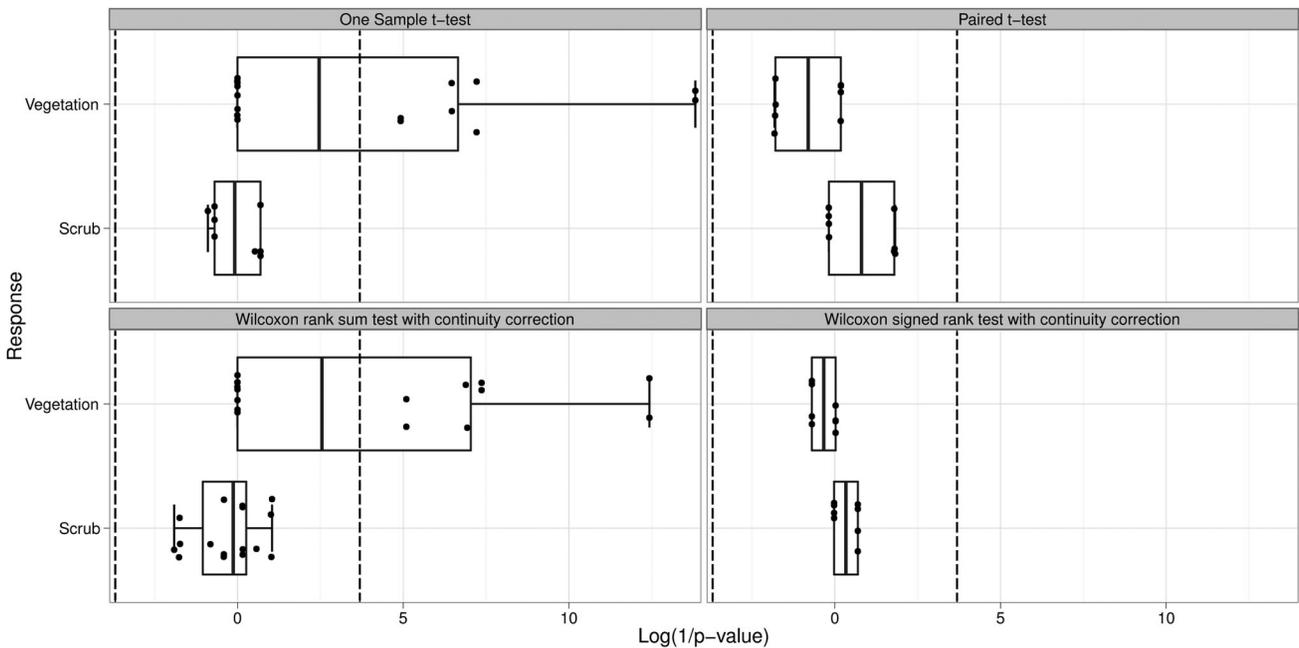
**Figure 6.** Box plots of $P$ values for pairwise and unpaired tests using the less alternative on the negative and greater alternative on the positive $x$ axis. Regions outside the dashed lines are significant at $P = 0.05$. Results for hypothesis 2a: $\text{NDVI}_{\text{ctrl(pre)}} \sim \text{NDVI}_{\text{treatment(pre)}}$ on responses. Most microwatersheds showed no significant difference in NDVI values between control and treatment prior to watershed activities. Among the significant values, a greater number of microwatersheds in the treatment group showed more vegetation prior to watershed restoration activities.
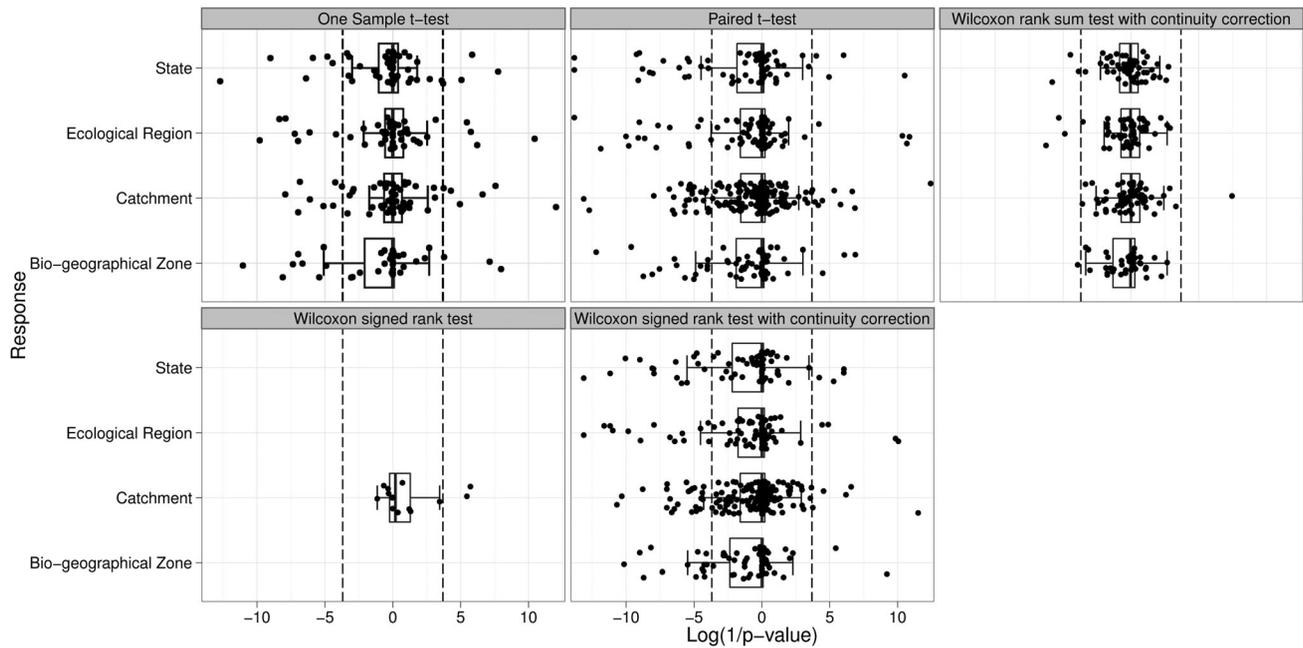
**Figure 7.** Box plots of $P$ values for pairwise and unpaired tests using the less alternative on the negative and greater alternative on the positive $x$ axis. Regions outside the dashed lines are significant at $P = 0.05$. Results for testing hypothesis 2b: $NDVI_{ctrl(post)} < NDVI_{treatment(post)}$ on NDVI values. Bulk of the values is not significant. Among the significant values, most lie to the left of the dashed line, indicating that control (untreated) microwatersheds showed a greater increase in NDVI than those that were treated under the watershed program. The results are very similar to those of microwatersheds prior to WHD.
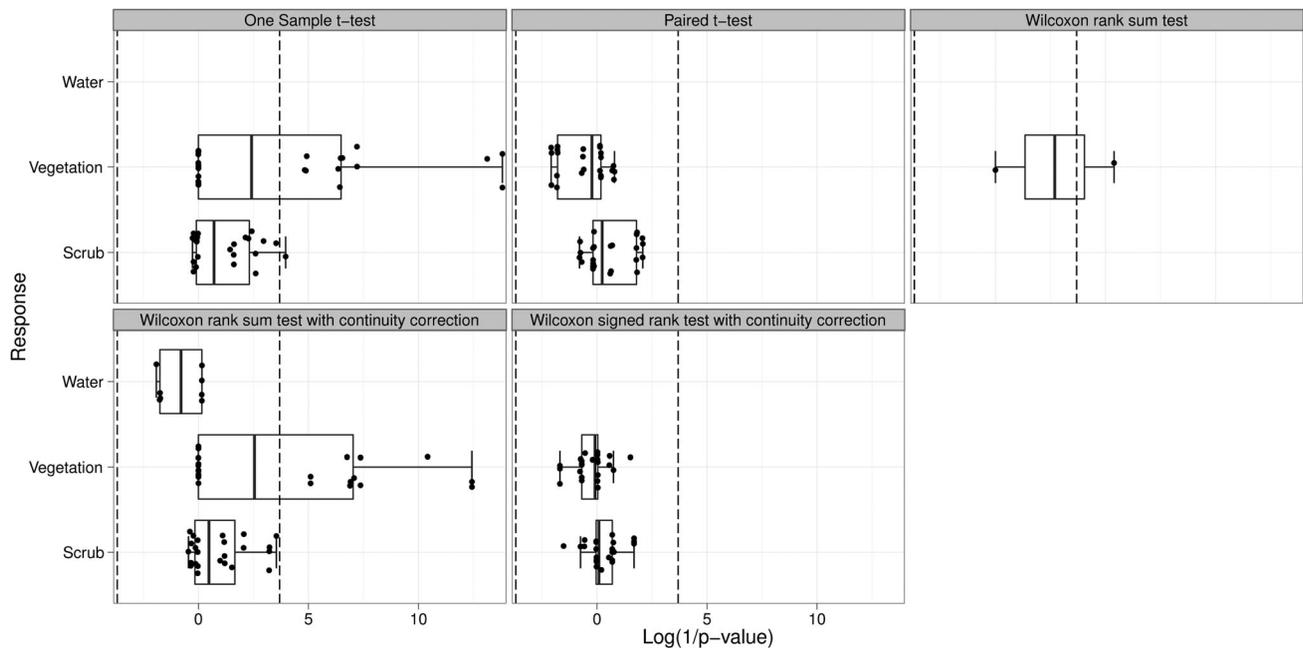


**Figure 8.** Box plots of $P$ values for pairwise and unpaired tests using the less alternative on the negative and greater alternative on the positive $x$ axis. Regions outside the dashed lines are significant at $P = 0.05$. Results for testing hypothesis 2b: $NDVI_{ctrl(post)} < NDVI_{treatment(post)}$ on responses. Most treated microwatersheds do not show any significant difference after watershed restoration when compared to untreated (control) watersheds. Some however show that there is an increase in vegetative cover and scrub in the treated watersheds when compared to the untreated controls. The results are nearly identical to those prior to initiation of watershed restoration.
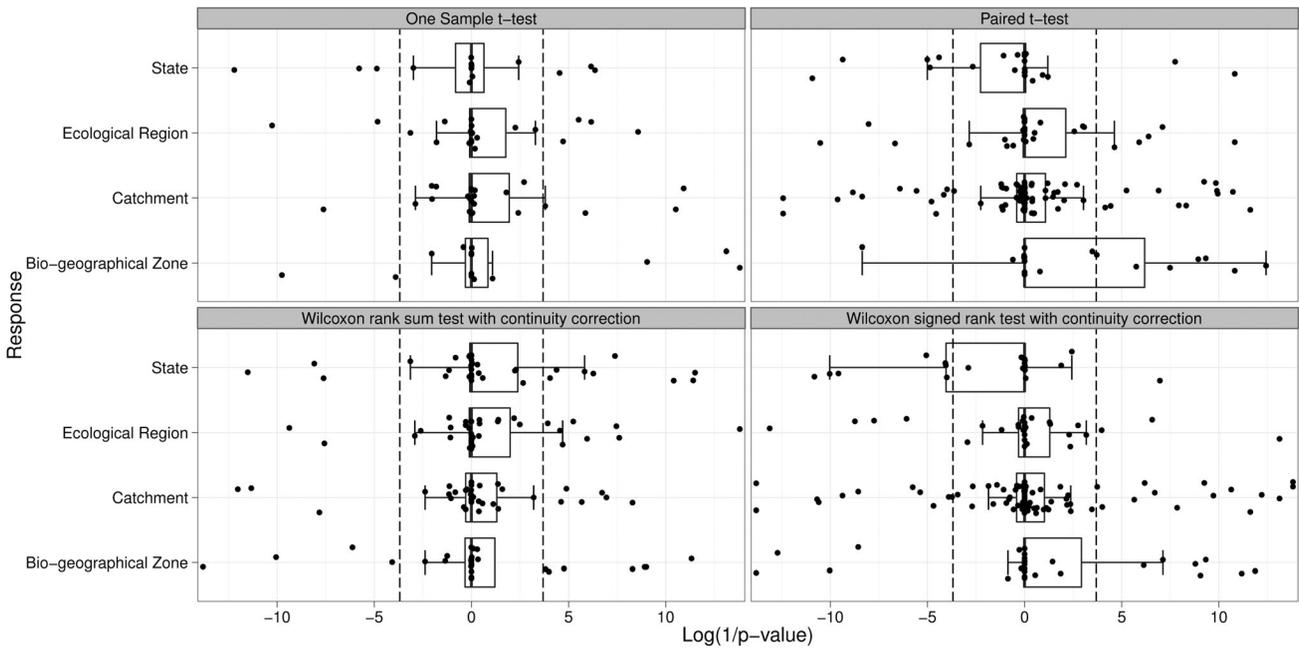
**Figure 9.** Box plots of *P* values for pairwise and unpaired tests using the less alternative on the negative and greater alternative on the positive *x* axis. Regions outside the dashed lines are significant at $P = 0.05$. Hypothesis 3a, $NDVI_{ctrl(pre)} \sim NDVI_{ctrl(post)}$ on NDVI values. Results show that a similar number of points are significant as are nonsignificant. Also these points are equally spread out on the positive and negative *x* axis showing that the number of microwatersheds with significantly higher NDVI values in control areas were similar in 2006 and 2011.
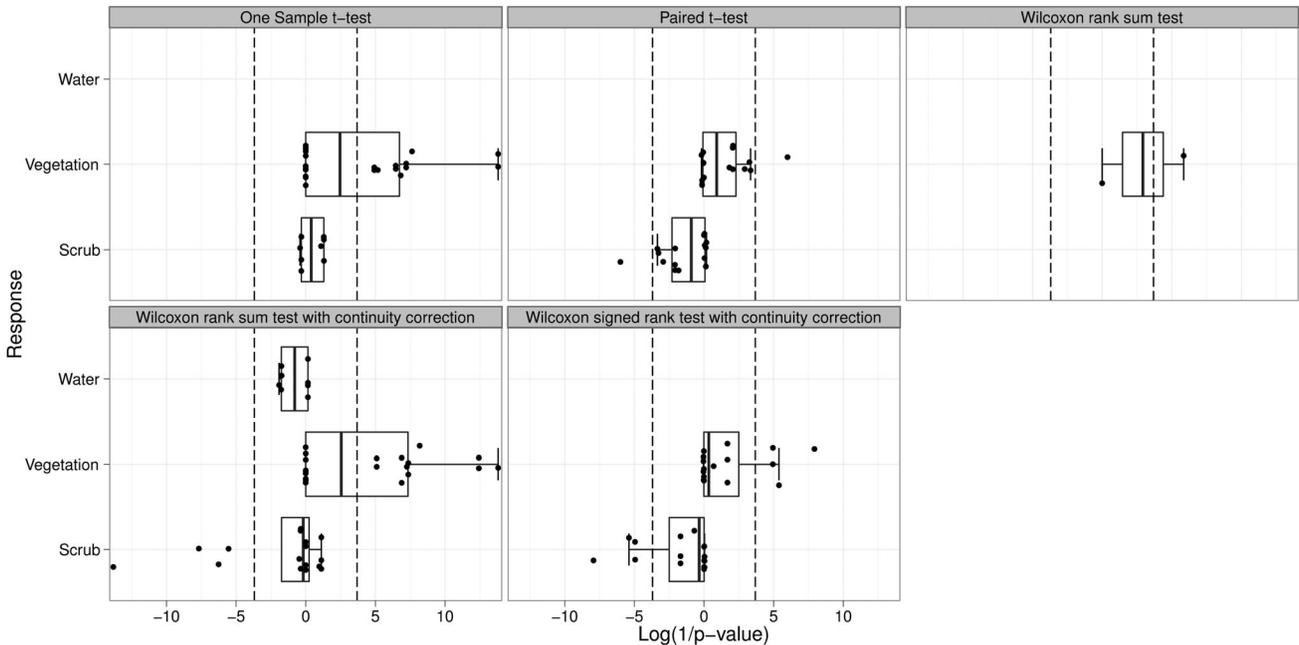


**Figure 10.** Box plots of *P* values for pairwise and unpaired tests using the less alternative on the negative and greater alternative on the positive *x* axis. Regions outside the dashed lines are significant at $P = 0.05$. Hypothesis 3a, $NDVI_{ctrl(pre)} \sim NDVI_{ctrl(post)}$ on responses. While most of the responses are nonsignificant, some control microwatersheds showed higher amounts of vegetation and less scrub in 2011 than in 2006.
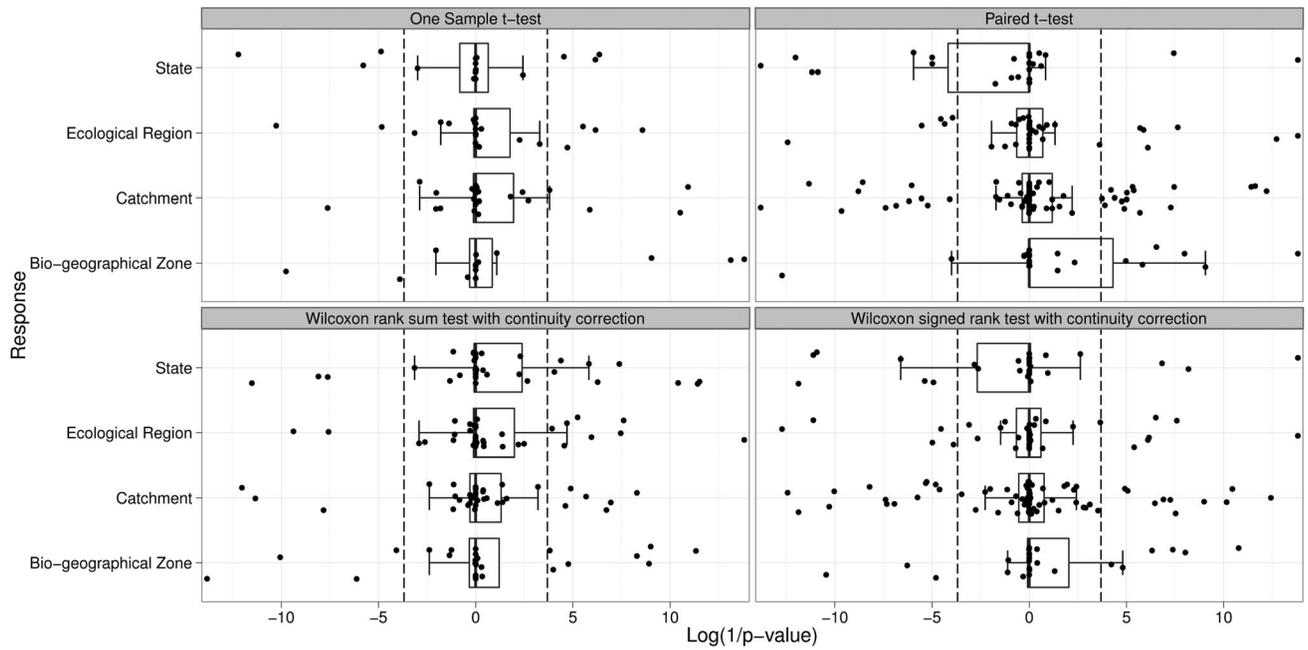
**Figure 11.** Box plots of $P$ values for pairwise and unpaired tests using the less alternative on the negative and greater alternative on the positive x axis. Regions outside the dashed lines are significant at $P = 0.05$. Hypothesis 3b, $\text{NDVI}_{\text{treatment(pre)}} < \text{NDVI}_{\text{treatment(post)}}$ on NDVI values. Results are very similar to Figure 9. A similar number of treated microwatershed showed a significant increase in NDVI after treatment as the numbers show a significant decrease. Also a large proportion of microwatersheds showed no significant difference in NDVI before or after treatment.
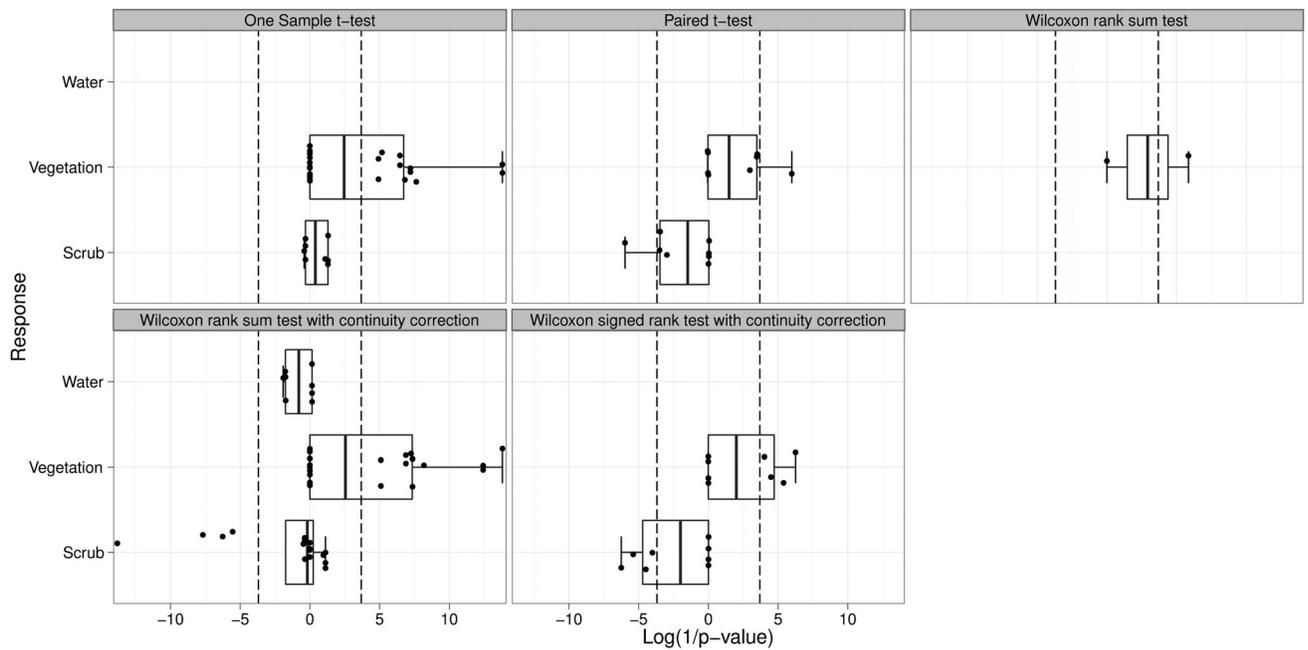


**Figure 12.** Box plots of $P$ values for pairwise and unpaired tests using the less alternative on the negative and greater alternative on the positive $x$ axis. Regions outside the dashed lines are significant at $P = 0.05$. Hypothesis 3b, $\text{NDVI}_{\text{treatment(pre)}} < \text{NDVI}_{\text{treatment(post)}}$ on responses. Results were very similar to Figure 10. Most treated microwatersheds showed no significant difference before or after restoration had taken place. Some however showed significant higher amounts of vegetation but less scrub.

services. Measurements of NDVI values is an inexpensive and robust method. However, this too is limited by the resolution of the satellite imagery [*Lunetta et al.*, 2006]. Further, the NDVI does not inform the user about causal factors behind increased productivities that would be revealed by finer grained data on a range of parameters.

[31] The period of the second set of images was selected so that there were two to five years for the treated areas to respond in terms of increased vegetation. Furthermore, we also compared treated and neighboring, untreated (control) watersheds in both 2006 and 2011. Therefore, cases where local conditions, such as poor rains, prevented or delayed a vegetative response to the treatment were accounted for. Comparisons between the cumulative NDVIs of before-after pairs or neighboring treated-untreated (control) pairs were not statistically significant. Paucity of data on completed watershed projects as well as imagery of sufficient resolution did not allow us to test over longer time periods.

[32] Our findings do however show that in terms of productivities, microwatersheds treated through these programs are indistinguishable from those that are not. This holds true across state boundaries, catchment areas, biogeographical zones, and ecological regions, ruling out the possibility of differential performance of the program across state policy, landscapes, and climatic conditions. Our analysis spans seasons and also accounts for local variations by comparing productivities of adjacent untreated microwatersheds. Thus, we conclude that watershed guidelines in India fail to deliver a mechanism to improve local productivities.

[33] In the present arrangement, areas selected for treatment are not watershed units but development units. The program is run more as a rural development initiative rather than a watershed restoration effort. Present institutional structures cater to local requirements, yet restoration work is required at watershed scales, with emphasis on restoration of watershed function. Lack of trained manpower coupled with high technical requirements, very low per hectare outlay, limited time frames for implementation coupled with long gestation periods for project outcomes are other major drawbacks of the program. Further, watershed services are typically low value and highly dispersed. The highest value service, water, is only available to land owners, making these programs inherently iniquitous.

[34] The preparation of watershed restoration plans requires a judicious mix of rural development goals that build upon hydrological and ecologically sound project design. This would change some of the major elements in the guidelines including selection of sites, training and capacity building of implementing agencies as well as the community-based organizations for planning, monitoring, and evaluation of project outcomes. Furthermore, improved hydrologic function will lead to increased ecological goods and services, better access to irrigation water, and increases in livelihoods leading to poverty alleviation. Poverty alleviation schemes are not as likely to lead to increased hydrological function however. There are at least four preconditions to such an approach:

[35] 1. Data accessibility and availability—this refers to hydrological, meteorological, geomorphological, and land-cover data at high spatial resolutions.

[36] 2. Standardized methods and techniques for measuring physical and socioeconomic parameters necessary to design and monitor restoration and management.

[37] 3. Analytical techniques to interpret field measurements for adaptive management. This would necessarily include the ability to set up and utilize hydraulic models and landscape tools as well as stakeholder analysis to ensure equity concerns are addressed.

[38] 4. Design of monitoring strategies, including setting up of measurement stations that track changes, both biophysical as well as socioeconomic.

[39] Ecological goods and services provided by watershed restoration are independent of the local dynamics that determine levels of participation and equity concerns. Pinning watershed restoration funding to local capacity for collaborative activities or governance predisposes the project success to being a function of luck rather than planning. Both collaborative management and watershed restoration have a black eye at the end of the process.

[40] WHD is largely about maximizing ecosystem services from watersheds in a fair, transparent, and sustainable manner. Restoring watersheds to perform these services is therefore bound to underlying hydrological and ecological processes, which, in turn, are governed by a host of environmental parameters including climate and geomorphology. This holds true even if the objective is not to restore natural flows, but to harvest or recharge ground water for agriculture and other uses. We need to identify strategies for physical and ecological restoration of a given watershed before defining institutional frameworks for their management. Trying to fit this reality to social needs is getting the proverbial cart before the horse.

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