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Citizen monitoring of waterways decreases pollution in China by supporting government action and oversight

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Water pollution is a persistent problem in China, in part, because local governments fail to implement water quality standards set by national and provincial authorities. These higher authorities often lack regular information about the immediate and long-term achievement of remediation targets. Accordingly, central authorities have encouraged nongovernmental organizations to monitor local governments' remediation efforts. This study examines whether nongovernmental monitoring of urban waterways improves water quality by facilitating oversight of local governments or instigating public action for remediation. We randomly assigned urban waterways in Jiangsu province previously identified for remediation to be monitored by a partner nongovernmental organization for 15 mo. We further randomized whether the resulting information was disseminated to local and provincial governments, the public, or both. Disseminating results from monitoring to local and provincial governments improved water quality, but disseminating results to the public did not have detectable effects on water quality or residents' pursuit of remediation through official and volunteer channels. Monitoring can improve resource management when it provides information that makes local resource managers accountable to higher authorities.

water pollution | monitoring | China | nongovernmental organizations

Recent estimates suggest that water pollution causes more than 100,000 deaths and USD 1.46 trillion in economic losses each year in China (1). Water pollution has been regularly featured in the nationwide Five-Year Plan, the central government's policy document that establishes priorities for all government units. Local officials have been mandated to reduce water pollution (2), and have been granted authority and resources to enforce environmental standards (3). A key policy created by the central government has been the "black and smelly" rivers program, which requires local governments to remediate severely polluted waterways.

Reducing water pollution and then maintaining water quality has proven difficult, in part, because local governments do not always have strong incentives to achieve remediation targets when monitoring is incomplete. Among the waterways identified as "black and smelly" and slated for remediation, the achievement of water quality targets has often been partial or temporary. For example, a special campaign of on-ground inspections in 2018 by the central government, corresponding to the start of this study, found that, of the 458 water bodies reported as remediated by local governments across several provinces, 37 no longer met remediation targets.* Independent baseline data on "black and smelly" waterways in this study showed that 91% were not in compliance with standards.

These shortfalls may result from a lack of regular, central monitoring of remediation efforts. Central and provincial inspections of remediation efforts are infrequent and haphazard, especially for small waterways that are the focus of this study. Since local officials are most interested in achieving targets that can be observed by higher authorities, incomplete monitoring creates oversight problems. Indeed, most improvements to water quality in China are located upstream of monitoring stations that allow central authorities to observe water quality continuously, rather than downstream (4). Because of the vast number of polluted water bodies, central authorities in China have encouraged monitoring by nongovernmental organizations (NGOs) as a supplement to official efforts (5, 6).

Nongovernmental groups that provide information about the progress of remediation efforts to local and provincial governments might improve water quality. Oversight is a challenge for higher-level governments, due to the dependence on local governments for information, both generally (7, 8) and with respect to pollution (2, 9). By monitoring water quality and sharing the information with multiple levels of government, nongovernmental groups may signal to local governments that resource status is observable and oversight is likely (5, 6, 10, 11). With

Significance

Approximately 70% of China's rivers and lakes are unsafe for human use. Effective implementation of existing pollution standards can improve the health and well-being of people across China. In this randomized trial, pollution decreased when a nongovernmental organization enlisted volunteers to monitor the quality of urban waterways slated for remediation and disseminated that information to local and provincial authorities. Disseminating information to the public through posters did not have detectable effects on water quality. Nongovernmental organizations can support the efforts of authorities to remediate pollution by providing monitoring that guides action and facilitates oversight between different levels of government, particularly when authorities that set remediation targets have an active interest in responding to public complaints and using monitoring for oversight.

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more regular information about water quality, higher-level governments may enforce standards more stringently, or local officials might speed and maintain remediation efforts to advance their careers or avoid penalties. Ultimately, increased monitoring might help close the "implementation gap" in China that emerges when local governments do not achieve environmental standards (12–14).

NGOs might also increase public demand for remediation by disseminating information from monitoring to the public. Norms against littering might be strengthened by increasing residents' knowledge of poor water quality or their awareness that fellow citizens are monitoring nearby water quality. Petitions to local governments for remediation might increase with public knowledge of poor water quality. Governments at all levels in China prioritize social and political stability, but lack information on public preferences because citizens do not regularly go to the polls (15–17). Authorities are interested in addressing discontent about pollution through remediation (18), so public attention and petitioning might prompt stronger remediation efforts.

In a large-scale field experiment, we test whether monitoring by volunteers leads to improvements in water quality. We assigned half of 160 urban waterways previously identified for remediation as part of the "black and smelly" rivers program to semimonthly monitoring by volunteer teams for 15 mo. We worked with a partner NGO to disseminate information from the monitoring program to multiple levels of government, the public, or both in randomly assigned treatments. We investigate the consequences of this monitoring program on water quality using independent, laboratory-grade measurements over 2 y. We surveyed local officials responsible for remediation efforts, to document the oversight pressures and public demands that they experienced. Additionally, we conducted baseline and endline surveys with residents near all of the waterways, to understand whether monitoring affected norms, knowledge, or demand for remediation. Finally, we tracked whether improvements in water quality are associated with increased housing prices, offering preliminary evidence about cost effectiveness.

This study is part of a larger Evidence in Governance and Politics (EGAP) Metaketa initiative of six coordinated, preregistered field experiments that test how external support for monitoring affects the use of resources (19). We committed, in advance, to report all preregistered results regardless of findings. We contribute evidence about how monitoring of resource status can address the challenges of authorities who set policies and have an interest in effectively overseeing lower-level authorities who implement them (20). A common challenge with the management of pollution worldwide is that local authorities responsible for enforcing rules shirk when higher-level, rule-making authorities have limited ability to oversee and sanction poor performance (21). This challenge also arises for fisheries (22), forests (23), and water bodies (24).

Disseminating monitoring to the public using posters did not have detectable effects on residents' attention to pollution, attitudes, or behaviors, nor on littering or water quality. Improving water quality in the short term by stimulating public attention is likely challenging in contexts where residents do not have collective authority for resource management. Volunteer monitoring may not have spurred detectable public action because many people believe that addressing water quality is a problem for government. Public signs may have been interpreted to indicate that an organization was already attending to the issue. Alternatively, the communication strategy may need refinement, or the public may be unwilling to engage with an NGO that criticizes government performance.

Disseminating monitoring in quarterly reports to local and provincial governments reduced pollutant concentrations by 19%, on average (95% CI: −0.01, −0.37). This result provides encouraging evidence to NGOs worldwide that seek greater accountability for environmental management through monitoring (6, 25, 26). National authorities in China have encouraged decentralized monitoring, by both the public and nongovernmental groups, to harness these kinds of benefits. Speaking to the importance of solving information problems in multilevel resource governance (21, 27), this study demonstrates how volunteer monitors can enhance oversight of authorities who implement resource rules.

Research Design

Setting. Jiangsu is one of the most industrialized provinces in China and has experienced severe water pollution, with 458 waterways having been designated as "black and smelly" by 2020 and slated for remediation. In 2018, the central-level Ministry of Housing and Urban-Rural Development and the Ministry of Ecology and Environment issued the "Implementation Plan for Tackling Black and Smelly Waterways in Cities" (Document No. [2018]106), which required Jiangsu Province to remediate all "black and smelly" waterways by 2020.[†] This mandate accelerated remediation plans that the Jiangsu provincial government had been developing since 2013.[‡] *SI Appendix*, section 1 describes the policy context.

While remediation targets come from central and provincial authorities, city and county mayors and secretaries are responsible for establishing waterway recovery plans and instructing relevant departments to implement them. Central and provincial agencies oversee city and county agencies in a hierarchical setup (*SI Appendix*, Fig. S4). Consequences for local officials who fail to meet remediation targets are noted in central policies. Local governments can take a number of actions to improve water quality in urban waterways, including upgrades to storm water and sewage systems, sediment dredging, installing floating microorganism panels, planting hydrophytes or riparian plants, and installing aeration systems (*SI Appendix*, Fig. S10). Residents have no direct roles or collective associations that deal with the management of nearby waterways, although they can decrease littering behaviors or petition local governments to address water quality.

Central authorities have encouraged nonofficial monitoring to improve the oversight of remediation, which depends mostly on haphazard data from local governments (*SI Appendix*, section 1). The central government has created platforms to collect information from the public about violations of pollution standards (6). Remediation efforts are associated with the timing of public complaints to official channels (28), but causal evidence about the effects of regular, systematic monitoring of pollution by NGOs is lacking, despite an increasing number of such programs.

Study Units. We obtained a list of all 206 small, urban waterways identified by the Jiangsu provincial Environmental Protection Bureau for remediation under the "black and smelly" policy in 2017. Unlike major rivers, these waterways were not subject to high-frequency monitoring during the study period. We used elevation and watercourse maps to remove from the sample waterways that are hydrologically connected, to avoid spillover. Prior to assigning treatment, we removed 6 waterways where the laboratory measurements of water quality that we use for analysis and survey enumeration did not align spatially, leaving a sample of 160 waterways (Fig. 1).

[†]Available at https://web.archive.org/web/20210308164426/http://www.mohurd.gov.cn/wjfb/201810/t20181015_237912.html (archived March 2021).

[‡]Jiangsu Government, Opinions on the Comprehensive Improvement of Urban River Environment in the Province, Doc No.[2013]60. Available at https://perma.cc/VJJ6-FT2X (archived March 2021).

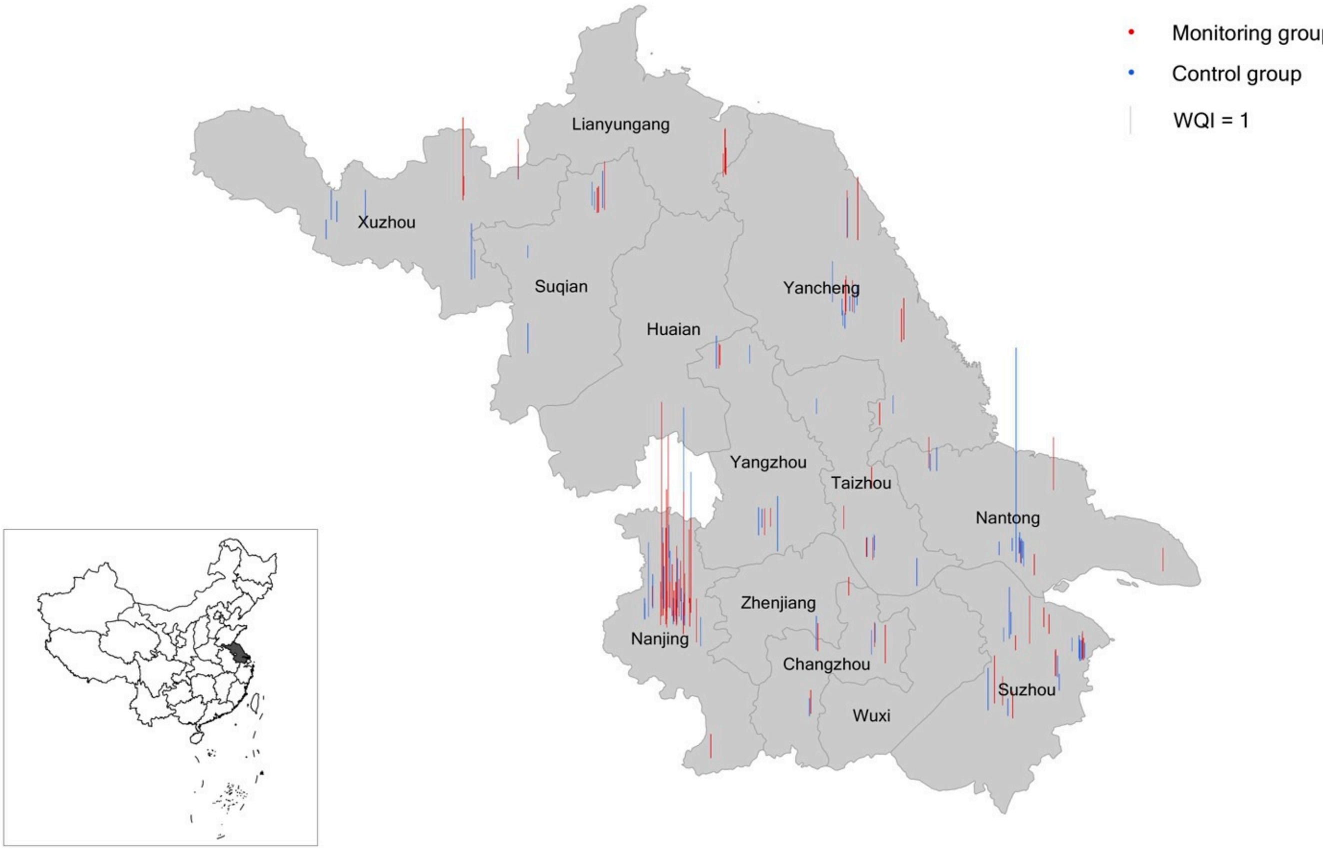

Fig. 1. Waterways included in the sample and baseline water pollution levels relative to target standard (water quality index [WQI] = 1).

Experimental Treatments. We assigned half of the waterways to semimonthly monitoring of water quality by volunteers. We partnered with an independent NGO, the Mochou Ecological and Environmental Protection Association (MEEPA; see *SI Appendix*, section 4), to organize volunteer teams of residents who lived near sample waterways to measure water quality using inexpensive field kits. The volunteers recorded observations about the clarity and odor of water, and completed chemical tests for pH, dissolved oxygen, chemical oxygen demand (COD), nitrogen, and phosphorous (see *SI Appendix*, section 6). MEEPA generally trained three volunteers to act as monitors for each waterway. Twice a month, these monitors filled out a water quality report and sent it to MEEPA via the WeChat app. Our research team worked with MEEPA to compile the results into quarterly scores and rankings for all waterways. Compliance with the monitoring protocol was high, and data were available each quarter for every waterway (*SI Appendix*, Fig. S3).

We assigned monitored waterways to two cross-randomized treatment arms: 1) dissemination of monitoring results to the county- and city-level Housing and Urban-Rural Development Bureau, Ecology and Environment Bureau, and Water Resources Bureau, as well as provincial-level authorities through quarterly reports (*SI Appendix*, Fig. S5). We disseminated reports to three levels of government to create common knowledge about water quality; and 2) dissemination to the public living near waterways. Monitors put up 8 to 10 posters where they would be most noticeable to residents (*SI Appendix*, Fig. S7).

We assigned treatment within blocks of 8 waterways formed by similarity in baseline water quality, resulting in 80 control waterways, 20 government dissemination waterways, 20 public dissemination waterways, and 40 waterways with both government and public dissemination. *SI Appendix*, Fig. S11 tracks the study design, and *SI Appendix*, Fig. S12 shows the study timeline.

Outcomes. To measure water quality for analysis, we contracted two professional laboratories to record at baseline, and twice at endline, the chemical measures of water quality that the Chinese Ministry of Housing and Urban-Rural Development uses to assess waterways: transparency, dissolved oxygen, oxidized reduction potential, ammonia, COD, phosphorous, and total nitrogen. We form a water quality index based on the relative achievement of industrial water standards for each component (see *SI Appendix*, section 12). The final index excludes dissolved oxygen, due to significant anomalies in measurement (see *SI Appendix*, section 13). The minimum detectable effect of each of the treatment arms on the water quality index is approximately 0.2 standardized effect sizes (see *SI Appendix*, section 21). Both at baseline and endline, we scored the amount of floating litter in each waterway based on visual inspection and also conducted a list experiment to estimate the prevalence of littering by nearby residents.

To measure resident attitudes and behaviors related to pollution and waterway management, we surveyed a rotating cross-section of 50 residents living within 2 km of waterways, at both baseline and endline. The survey also elicited behaviors consistent with motivation to address pollution, such as signing up for training as a volunteer monitor (see *SI Appendix*, section 15).

Findings

Government Dissemination Treatment. Waterways assigned to the government dissemination treatment experienced at least a 19%

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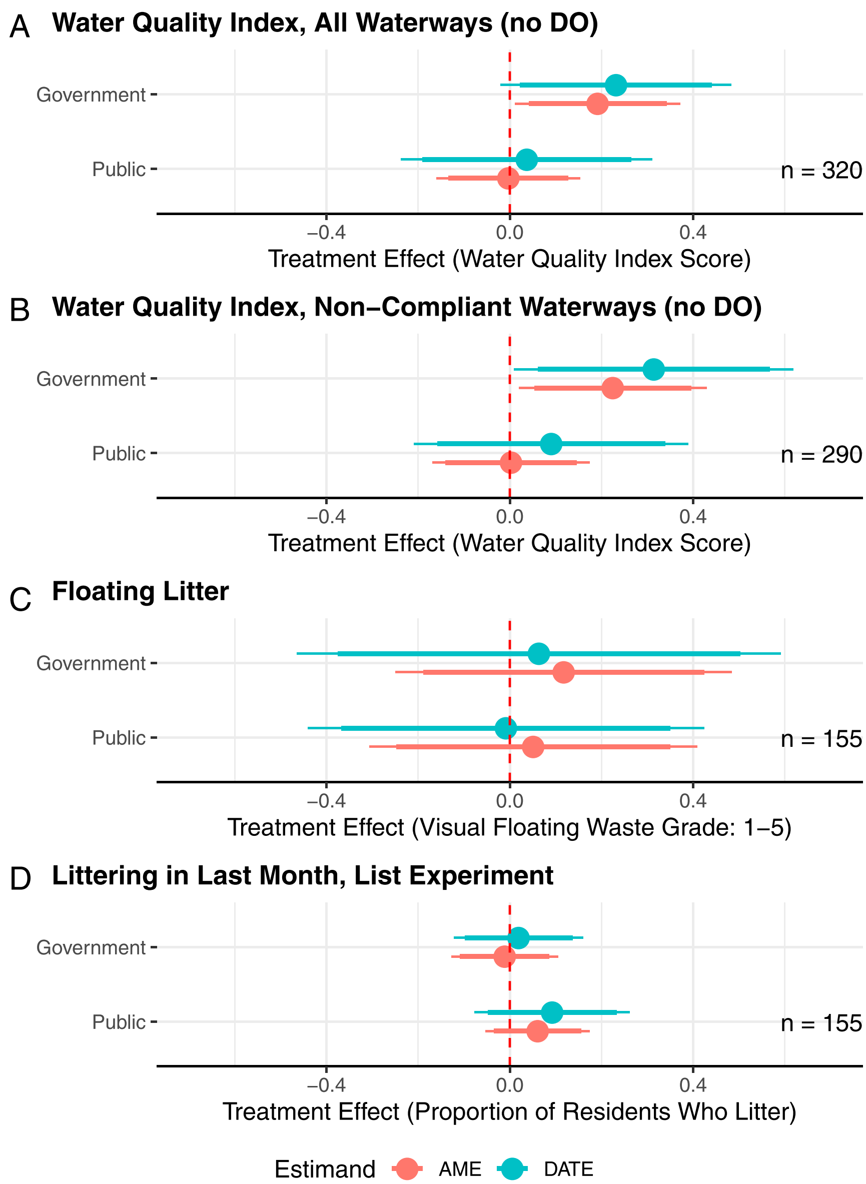

Fig. 2. Effect of monitoring on water quality outcomes (*A–D*). Thick and thin bars are 90% and 95% CIs, respectively. Preregistered analysis, modified to exclude unreliable DO measures from water quality index.

improvement in water quality, on average (Fig. 2 *A* and *B*).[§] This effect is approximately equivalent to a 0.17 standardized effect size (*SI Appendix*, Table S17).

The estimated improvement to water quality is not sensitive to the cooccurrence of the public dissemination treatment (*SI Appendix*, Table S8). Unlike chemical water quality, which local governments could control with a variety of remediation activities (*SI Appendix*, Fig. S10), the government dissemination treatment did not have detectable effects on the amount of floating litter or littering behavior by residents (*SI Appendix*, Table S9). Pollution remediation may have come about because of infrastructure investments, rather than behavior change by the public. We collected anecdotal evidence of infrastructure investments in treated waterways (*SI Appendix*, section 8).

As hypothesized in advance, the effect is slightly larger in waterways that were out of compliance with standards at baseline (Fig. 2*B*). Consistent with this finding, the positive effect of the government dissemination treatment is most apparent in pollutants with the highest levels of noncompliance at baseline (*SI Appendix*, Figs. S23 and S24) and in waterways with the most severe aggregate pollution at baseline (*SI Appendix*, Table S7). Robustness checks added after preregistration show that the positive effect of the government dissemination treatment on water quality persists across alternative specifications of the dependent variable and different sample restrictions (see *SI Appendix*, Figs. S22 and S23). We do not find evidence of a reallocation of effort between control and treatment waterways within cities or spillover between proximate waterways (*SI Appendix*, section 20).

We expected the government dissemination treatment would improve water quality by enhancing the provincial government's oversight of city- and county-level governments. However,

[§] All estimates are transformed so that higher values indicate better water quality or attitudes, norms, or behaviors in favor of improving water quality.

we could not systematically document how quarterly reports changed intergovernmental relations. To provide qualitative evidence, we surveyed city-level bureaucrats responsible for managing waterways in the sample and completed interviews with officials responsible for 82 of the 160 waterways. Recognizing the limitations of a questionnaire with a low response rate and clustering, 40% of officials who we reached reported experiencing pressure to respond to citizen complaints from higher levels of government and generally perceived the public to be attentive to actions taken to remediate water pollution (*SI Appendix*, section 17). The quarterly reports could have been interpreted as a complaint that was subject to oversight.

Public Dissemination Treatment. The public dissemination treatment did not have a detectable effect on chemical water quality, among either the full sample of waterways or the waterways out of compliance at baseline (Fig. 2 *A* and *B*). It did not have a detectable effect on the amount of littering (Fig. 2 *C* and *D*). The effect does not vary based on baseline water quality (*SI Appendix*, Table S7) or for pollutants more often out of compliance (*SI Appendix*, Figs. S23 and S24).

We expected the public dissemination treatment to improve water quality by informing residents about pollution, reinforcing norms against pollution, and increasing public demands for the remediation of pollution. To measure whether the public dissemination treatment improved access to information, enumerators asked respondents how they received information on local waterways, including community postings, which could capture the use of MEEPA posters. Approximately 11% of respondents located near waterways assigned to the public dissemination treatment reported using community postings to learn about local water quality, compared to about 12% of respondents located near waterways assigned to pure control. The similar use of community posting across conditions suggests that the public dissemination treatment did not gain attention. In addition, the number of QR code scans from the posters was very low, averaging just 9.3 scans per waterway during the study. This low attention occurred despite high rates of successful implementation (*SI Appendix*, Fig. S9).

As might be expected given low attention, the results do not consistently indicate that the public dissemination treatment increased residents' knowledge about water pollution or norms against pollution. *SI Appendix*, Table S3 provides descriptions of each survey item used to measure knowledge, attitudes, and norms. We find detectable effects on three outcomes (*SI Appendix*, Tables S11–S13). Compared to respondents in the control group, respondents residing near waterways with public dissemination reported marginally higher levels of environmentalism (*SI Appendix*, Table S11) and marginally better access to information about local water quality (*SI Appendix*, Table S12). However, we also find suggestive evidence that residents in the public dissemination treatment provided less accurate assessments of local water quality than did residents in the control group (*SI Appendix*, Table S12). At best, there is a weak effect of the public dissemination treatment on knowledge and attitudes about pollution.

We assess whether the residents assigned to the public dissemination treatment are more likely to become attentive to pollution or demand remediation. We use survey measures that include whether respondents had conversations outside of their households about pollution, whether they contacted officials about pollution, and whether they volunteered to join community groups working to manage pollution. Fig. 3 shows no detectable effects on these self-reported and revealed behaviors, which we expected to be the intermediate steps to improved water quality.

Property Values and Cost Effectiveness. Provided either of the treatments increased water quality, we hypothesized that it would also increase property values within 500 m of the treated waterways. The volunteer monitoring program cost a total of USD 103,500, and there are hundreds of thousands of households within 500 m of waterways in our sample. Even a modest treatment effect on housing prices would indicate a high level of cost effectiveness.

We measure the average price per square meter of housing sold during a prespecified 3-mo period prior to treatment and again 2 y later. Of the 160 waterways in the sample, only 83 had posttreatment data on the real estate transactions in the outcome period. The estimate of the effect of the government dissemination treatment on water quality is more imprecise in this subset than in the full sample, although consistent with the main estimate (see *SI Appendix*, section 16).

Nonetheless, there is suggestive evidence that property values increased in communities within 500 m of waterways assigned to the government dissemination treatment (Fig. 4). We explore the robustness of the treatment effect on property values by analyzing outcomes at the transaction, neighborhood, and waterway level and with different analysis procedures (*SI Appendix*, Fig. S17). The consistency of the estimates indicates the monitoring program and dissemination to multiple levels of government was highly cost effective.

We also hypothesized that the treatments would decrease perceptions that pollution has a negative effect on residents' lives and increase how often residents walked along waterways (*SI Appendix*, Fig. S17 *B* and *C* and Table S10). We find no detectable effect of the treatments on these outcomes, perhaps because the study period was too short.

Discussion

Disseminating results from monitoring to multiple levels of government improved water quality, but disseminating results to the public did not have detectable effects on water quality. Neither treatment had detectable effects on the actions or attitudes of residents living near waterways. These results indicate that the citizen monitoring addressed challenges with oversight, but, as deployed, did not increase public attention and action, consistent with related findings (5). The results are consistent with evidence that NGOs in China gain influence by acting in ways that are complementary to the interests of higher-level authorities (29).

The public dissemination arm did not have detectable effects on attitudes, behaviors, and intentions of residents, likely because it failed to generate attention or petitioning among residents. Consequently, public dissemination did not have detectable effects on water quality and did not reduce littering by residents. While 90% of the authorities that we interviewed at the conclusion of the experiment stated that they were concerned about public complaints, they could not take action if they did not receive them.

There are several plausible explanations for why the public did not respond to the posters, including the design or placement of the posters, the technical rather than action-oriented nature of the information, perceptions that addressing water quality is the responsibility of the government or MEEPA, or the public's beliefs about the risks of responding to a notice that is tacitly critical of government performance. While there is evidence that mass communication about pollution affects private avoidance and mitigation behaviors in China (30), our results suggest that information is not the primary limit on volunteerism and petitioning related to pollution.

Several aspects of the setting and intervention inform the transportability of the main results to other settings that face challenges related to pollution and multilevel governance. First, the authority to set resource rules rests with central government

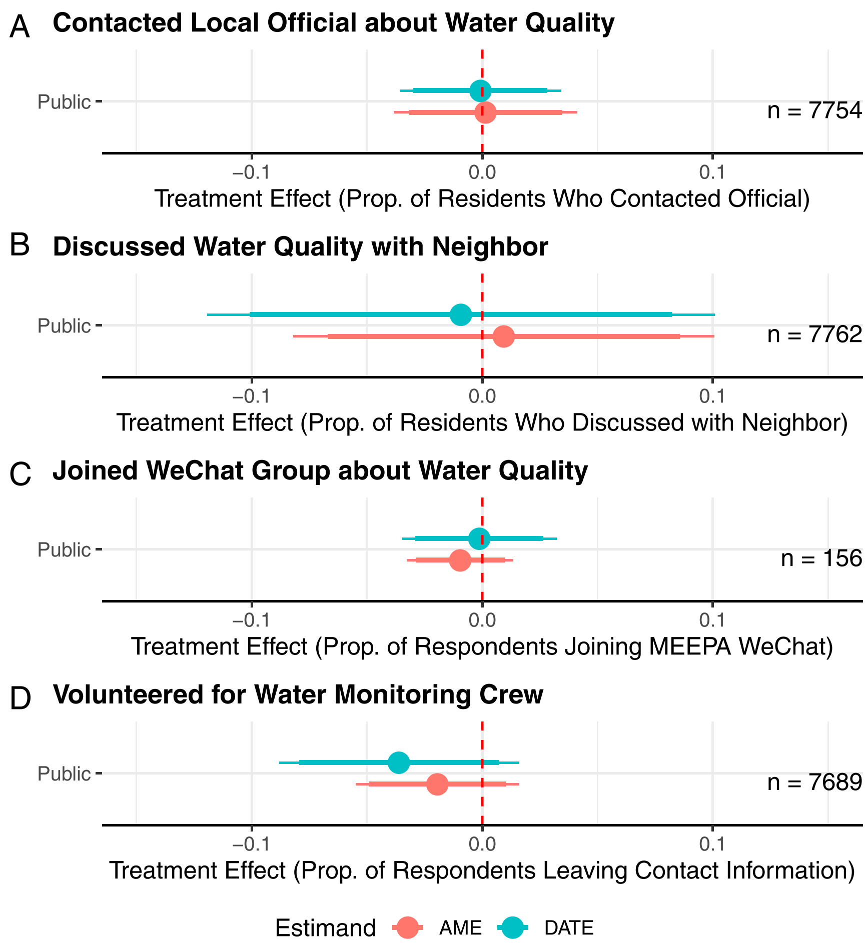

Fig. 3. Effect of monitoring on public participation (*A*–*D*). Thick and thin bars are 90% and 95% CIs, respectively. Preregistered analysis, unmodified.

agencies in China, rather than residents who directly experience resource degradation. Our results are most relevant to settings where rule making and implementation authority are at different levels of government, which gives rise to oversight challenges (21).

Second, higher-level authorities in China have encouraged nongovernmental monitoring and have an active interest in the remediation of pollution (6, 28, 31). They also have significant capacity to enforce rules and respond to technical information, boosting the likelihood of oversight based on new information. Monitoring is unlikely to have effects unless the authorities that establish resource rules have a strong interest in oversight and effective implementation.

Finally, local governments in China, which implement remediation targets, are not directly accountable to the people who experience resource degradation. They instead seek to meet targets set by provincial and central authorities. The public might be more likely to get involved in pressing for effective implementation and oversight in nonauthoritarian settings, opening new ways for monitoring to improve resource management. Even if the public dissemination treatment had been successful at driving public petitioning, local governments would have to respond to these appeals. Evidence is mixed about when governments in China are responsive to public petitions (32, 33).

The results nevertheless provide encouraging evidence to the many organizations worldwide seeking to improve environmental management by providing information that enhances oversight. Even more encouragingly, 78% of volunteers persisted with monitoring without pay for 15 mo, and those that dropped out were readily replaced. In China and elsewhere, official channels have been created to take advantage of nongovernmental monitoring (6, 26), offering the potential to harness the motivations of volunteers for the effective governance of resources.

Materials and Methods

Measurement. Two accredited environmental laboratories measured seven water quality indicators from each waterway at three points in time. They measured the indicators that the Ministry of Housing and Urban-Rural Development of China uses to assess water quality: transparency, dissolved

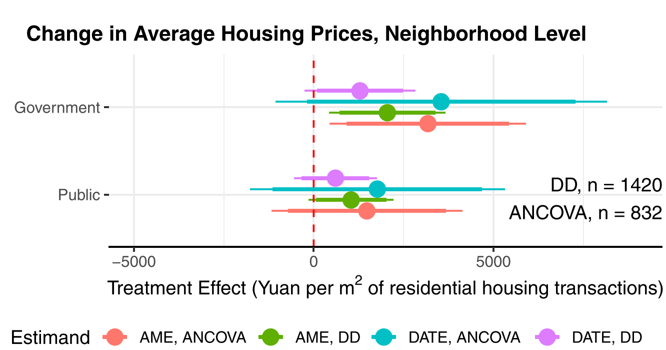

Fig. 4. Effect of monitoring on residential housing values. Thick and thin bars are 90% and 95% CIs, respectively. Preregistered analysis, modified to use the subwaterway neighborhood as the unit.

oxygen, oxygen reduction potential, ammonia, COD, phosphorous, and total nitrogen.

For the main analysis, we created a water quality index by calculating a standardized ratio for each indicator relative to the target grade IV water quality standard. Ratio values exceeding one indicate that the waterway was out of compliance with the standard. We took a weighted average of these normalized values, using weights corresponding to the importance of each indicator for management.

To measure littering, enumerators blinded to treatment assignment coded photographs of the trash floating on waterways on a five-point scale using reference photographs. We also use a list experiment to estimate the prevalence of littering behavior among survey respondents (see *SI Appendix*, section 15).

We collected outcomes measuring residents' attitudes about pollution and knowledge about how waterways are managed from surveys administered near waterways to different cross-sections of respondents at baseline and at endline. To recruit survey respondents, student enumerators walked near sample waterways and approached every fourth person with a request to provide a survey.

Estimation. We estimate treatment effects using ordinary least squares regression with standard errors clustered at the waterway. The estimating equations for waterway-level outcomes are

$$y_{j,t_x} = \alpha + \gamma_1 D_j^G + \gamma_2 D_j^P + \kappa y_{j,t_0} + \beta \boldsymbol{X}_{j|i} + \theta WQI_b + \nu t_x + \epsilon_j \quad [1]$$

$$y_{j,t_x} = \alpha + \tau_1 D_j^G + \tau_2 D_j^P + \tau_3 D_j^G D_j^P + \kappa y_{j,t_0} + \beta \boldsymbol{X}_{j|i} + \theta WQI_b + \nu t_x + \epsilon_j, \quad [2]$$

where γ_1, γ_2 are the average marginal effects (AME) of treatment arms; τ_1, τ_2 are the direct average treatment effects (DATE) of treatment arms; D_j^G is the treatment indicator for monitoring and dissemination to government assigned at the waterway level j; D_j^P is the treatment indicator for monitoring and dissemination to the public assigned at the waterway level j; κ is the estimated parameter value for $y_{i,t=0}$, the pretreatment value of the outcome variable; $\beta \boldsymbol{X}_{j|i}$ are parameter estimates for prespecified covariates at either the waterway or individual level; θWQI_b is the baseline water quality index used to form blocks; νt_x is a time period fixed effect used for outcomes measured twice (water quality index); and ϵ_j is the error term clustered at the waterway level j.¶

For the difference-in-difference (DD) analysis of housing values, the estimating equation is

$$y_{c,t_x} = \alpha + \gamma_1 D_j^G + \gamma_2 D_j^P + \gamma_3 T_{post} + \gamma_4 D_j^G T_{post} + \gamma_5 D_j^P T_{post} + C + \epsilon_j, \quad [3]$$

where γ_4, γ_5 are the AME of treatment arms, T_{post} is a posttreatment indicator, and C are community or city-level fixed effects. As above, the DATE is estimated by adding an interaction between treatment arms. Sample sizes are reported separately for analysis of covariance (ANCOVA) specifications given by Eqs. **1** and **2** and the DD specifications given by Eq. **3** in Fig. 4.

Preanalysis Plan. We preregistered the study at https://osf.io/vz9g2, and *SI Appendix*, section 23 explains modifications. Robustness checks were added after preregistration (*SI Appendix*, section 22). Both University of California, Santa Barbara (UCSB) and Nanjing University determined this study was exempt from human subjects oversight (UCSB Protocol 10-17-0275).

Data Availability. Anonymized replication data and scripts to reproduce all analyses have been deposited in Open Science Framework (https://osf.io/8fzmq/) (34).

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¶For water quality, the term θWQI_b is the same as $\kappa y_{j,t=0}$ and will only enter the regression one time.

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