



***Groundwater Sustainability : A Common Pool Resource  
Approach Towards its Management***

**ABSTRACT OF THESIS**

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## **Abstract**

Economic development requires sufficient human and natural capital. Classical, neo-classical and ecological economists all have cited the importance of environmental assets in the development process. However, with rapid population rise, changing consumption patterns and technological advancement the natural resources have come under threat. Unsustainable behaviour of humankind clubbed with lack of adequate regulations for natural resources has taken a toll on environmental health. Considering this, most of the natural resources which are treated as common pool resource tend to be overused or exploited. Public goods and common pool resources viz. fisheries, forests, groundwater basins, lakes, oceans, and the Earth's atmosphere etc. are under immense stress. Scholars have assumed that all common-pool resources suffer from the same deficient incentive structure which leads to widespread 'free-riding'.

Water resources in particular play an important role by virtue of their functions for human development, health, food security, industrial production, balance of the ecosystem and overall economic development. Water available for use is present in rivers, lakes or oceans and also lies underground which is termed as Groundwater. This research work is entirely focused on groundwater as it is one of the most important water sources in the world, more than two billion people depend directly upon aquifers for drinking water, and 40 per cent of the world's food is produced by irrigated agriculture that relies largely on it (UN-Water,2016,p.1-6). Moreover, groundwater, due to its common-pool resource nature and certain other socio-economic, behavioral, institutional, physical factors groundwater exhibit a tendency of depletion and degradation all over the world. Continuous fall in water tables is resulting in several socio-economic and health implications eventually affecting overall economic development. Considering this and taking into account the importance of groundwater and its massive use in India's agriculture sector this research study has attempted to fulfill the following objectives:

- To understand groundwater resources with reference to depletion, pollution and the linkage between resource use and their socio-economic impacts with particular reference to agriculture.
- To analyse the socio-economic factors that influence agriculture groundwater use and management.

- To suggest possible solutions for sustainable use of groundwater in agriculture.

## **Research Methodology**

During the research work, relevant data from both primary and secondary sources have been collected. A good volume of statistical data is involved in this research, especially information related to groundwater availability, use and depletion trends from Groundwater Year Books, brochures published by Central Ground Water Board, State Ground Water Board, Ministry of Jal Shakti has been obtained. In order to ascertain the inequity in groundwater use, data on landholding wise use of dugwells, shallow wells and deep tubewells published in Minor Irrigation Census reports has been utilised. Considering the factors which influence groundwater use and management state wise secondary data, documents, reports have been collected mainly for the variables viz. on landholding pattern, poverty levels, state domestic product, electricity consumption by agriculture sector, power tariff of agriculture consumers, environment performance. Regarding the impact of groundwater stress on agriculture, socio-economic condition of farmers, health hazards faced by them and farmer's willingness to pay for groundwater sustainability, primary level data of 300 farmer households from four villages of Baghpat district is collected through an interview schedule.

For the purpose of data analysis, the secondary as well as raw data obtained from the interview schedules are statistically processed using STATA 13 version. Means, Standard Deviations, coefficient of variation, Correlation coefficients has been calculated. Student's-test and chi-square test was applied to know the significant differences population and sample. Further, gini coefficients, growth rate (GR), simple OLS, multiple regression, dummy regression model and Logistic regression are used to reach a definite conclusion. In dummy variable regression, each category of independent variable is represented in ordinal terms by 1 or 0. In the logistic regression models, the dependent variable is the log of the odds ratio. The estimation of logit model is based on the cumulative logistic distribution function and is interpreted using odds ratios. Moreover, socio-economic vulnerability index and groundwater stress index have been estimated.

## **Outline of the Study**

Chapter *one* of the study titled “**Economic Development and Groundwater: Theoretical and Conceptual Framework**” is basically an attempt to highlight the importance of natural resources particularly groundwater in economic development. It focuses on the theoretical and conceptual understanding of common pool resources particularly groundwater.

Chapter *two* titled “**Groundwater: Stress, Governance and Implications**” is an attempt to analyse the set of drivers and impacts of groundwater depletion/degradation. Groundwater depletion and degradation has massive impacts on environment, economy and human beings. An elaborative review of literature has been done in this chapter and it suggests that groundwater degradation and scarcity have implications ranging from ecological effects such as salination and desertification, to social inequalities to political challenges, as well as economic tensions.

Chapter *three* titled “**Groundwater: Extent and Dynamics behind its Management**” presents the status, extent and dynamics affecting management of groundwater resources across states in India. It also highlights the relationship between land distribution and groundwater accessibility.

Chapter *four* titled “**Socio-Economic Profile of the Baghpat, Uttar Pradesh**” presents the social and economic status of sampled farmer households in different villages.

Chapter *five* titled “**The Various Dimensions of Agriculture in the Surveyed Area**” made an attempt to observe India’s agrarian crisis through the lens of primary data collected from different villages of Baghpat district, Uttar Pradesh.

Chapter *sixth* titled “**Groundwater Scenario and Perception in the Surveyed Area**” analyse the perception of farmer households about groundwater availability, accessibility, causes of water decline and response to depletion threats. It also assessed groundwater stress levels in different sampled villages and across land size groups.

Chapter *seventh* entitled “**Willingness to Pay for Managing Groundwater by Farmer Households**” presents an outline of contingent valuation approach, estimates the Willingness to Pay (WTP) of farmer households for managing groundwater resources in the region and also encapsulates its determinants.

Chapter *eighth* “**Major Findings and Policy Recommendations**” exhibits the key findings, suggestions and policy recommendations.

## **Major Findings**

- The study highlights the importance of natural resources particularly groundwater in economic development. It focuses on the theoretical and conceptual understanding of common pool resources particularly groundwater.
- It states that groundwater management in agriculture sector in India faces a set of challenges ranging from administrative, social, economic, and political. Institutional factors viz. common pool resource nature, land easement act<sup>1</sup>, lack of water pricing and tax mechanism pose a challenge towards effective groundwater management. Due to the characteristics of groundwater as a common property resource and ineffective regulations, large farmers with higher pumping capacity and deeper tube wells have a disproportionate claim over the resource than others and has lead to creation of ‘water markets’ and exacerbated social inequity. Low private cost of using groundwater due to subsidized electricity to agriculture sector has promoted sub-optimal use of this precious resource.
- Apart from this, supply side factors which include grants or low-cost loan finance for water well construction and irrigation hardware, support for the collection and dissemination of hydrogeological knowledge on groundwater occurrence and potential, technical evolution of waterwell pumps have made groundwater a likeable resource, thus, hampering its management. Intensive agriculture dominated by monoculture has led to overexploitation of natural resources particularly groundwater. In India, water-guzzling crops production viz. rice, wheat and sugarcane is extremely high and this cropping pattern has been followed since a long period which now demands a shift with rising water problems and climate change. In addition, groundwater depletion and degradation is affected by farmer ignorance, illiteracy and incomprehension towards its management and efficient use. Socio-economic condition of farmers affects groundwater management. Farmer’s behaviour towards environment conservation is highly affected by socio-economic variables viz. size of land holding, educational level, off-farm income, and environmental values etc.

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<sup>1</sup> The Easement Act, 1882 provides every landowner to collect, dispose all the water under and over the surface on his land.

- Taking into account the impacts or effects of groundwater depletion and degradation, the study present that they also range from environmental impacts to pecuniary, social and health. Environmental implications include soil salinization, salt water and sea water intrusion, land subsidence, and drying up of lakes and vegetation in different parts of the country. Various pecuniary impacts include increased pumping costs, decreased land values, loss of rural livelihoods, high input cost, migration, social conflicts and inequalities are also very prominent. Unsustainable groundwater use can have long term impacts on agricultural production and food security. Further, groundwater contamination is a serious issue for aquatic/ocean life and human health. Drinking water containing bacteria and viruses can result in illnesses such as hepatitis, cholera, typhoid and even major problem like Methemoglobinemia or ‘blue baby syndrome’.
- Considering the governance and management of groundwater resources, literature review reveals that there exist primarily two instrumental approaches i.e. assignment of regulations and water-use rights (including rules, permits, entitlements, licenses) which establish the privileges, restrictions, and obligations of groundwater users and second approach is use of pricing(includes taxation). A third and a relatively new approach is community management.
- Through secondary level data, the study attempted to assess the present scenario of groundwater stress in India. Data revealed that groundwater is the main source of irrigation and provider of drinking water in India. Regional analysis of Ground Water Resources of India reveals that North Western plain states and Western Arid region have highest groundwater development as well as have the highest share of over-exploited units. Among the states, Uttar Pradesh ranks first in terms of share of replenishable ground water resources and its stage of groundwater development is as high as 74 percent. Data evidences depict that groundwater stress has deepened over the years in Uttar Pradesh. Groundwater development is highest in Western region of Uttar Pradesh with an average of 84.76 percent, followed by Central region (72 percent), Eastern region (70.70 percent) and Bundelkhand (65.14 percent). District wise analysis of groundwater development show that Baghpat district in Western Uttar Pradesh is the only district wherein none of the block is in safe category and groundwater stress is serious. Therefore, the study selected it for primary survey.
- In order to decipher few major factors affecting groundwater use and management in agriculture sector, the study used certain statistical techniques. Correlation analysis reveals that groundwater development has a positive linear correlation with population growth rate, power subsidy, NSDP

growth rate, electricity consumption and Human Development scores on the contrary it possess a negative correlation with poverty, power tariff rate for agriculture sector and environmental performance score. Further, regression analysis show that a positive and statistically significant relationship exist between stage of groundwater development and population, economic growth, power subsidy and a negative relationship with poverty and power tariff.

- Using data from four consecutive agriculture census of India viz. 2000-01, 2005-06, 2010-11 and 2015-16 the study measured the inequalities (through gini coefficients) in land distribution. Data anatomisation suggested that land distribution is uneven in India and have remained so over time with 0.53 values in 2000-01, 0.54 in 2005-06, 0.53 in 2010-11 and 0.51 in 2015-16.
- The study tried to establish linkage between land distribution inequality and groundwater accessibility by using Minor Irrigation Census (MIC) and Agriculture Census data. An analysis of state wise percentage share of various groundwater schemes held by different farm size category from 2000-2014 found that its ownership across states is highest with medium landowners i.e. 40.53 percent on all India level, followed by small category farmers (29.49 percent) marginal farmers (26.62 percent) and large category (3.44 percent) during 2013-14. Assessing it state wise it is observed that such inequality in ownership of groundwater schemes is extremely high in Punjab, Rajasthan, Haryana and Uttar Pradesh. Setting up a linkage between land distribution and groundwater inequities i.e. of their gini coefficients, it is deciphered that majority of the states which have a high value of gini coefficient in land distribution viz. Haryana, Rajasthan, Madhya Pradesh, Uttar Pradesh and Punjab etc. also have it in case of groundwater accessibility pattern. Thus, confirming that landholding ownership inequality has an impact on access to groundwater accessibility.
- Assessing the various dimensions related to groundwater stress and to understand the socio-economic dynamics in the selected area, the study presents the social and economic status of sampled farmer households in different villages. Gurana and Vazidpur villages have households with relatively better off socio-economic condition than Pura Mahadev and Mawi Kalan. However, there are certain variables wherein no inter-villages differentials could be seen. All the villages have predominance of 'Jat' community and they are the ones who are better off with reference to all indicators. Overall, a trend of higher family size with increase in landholding ownership could be seen but majorly a nuclear family structure is witnessed across all villages.

Most of the people could afford to live in a pucca house and a small percentage resides in a katchha type of house structure.

- Considering education level, data analysis indicates that Gurana and Vazidpur are better in terms of education level as the percentage of illiterates is lower in these villages. Taking into account the employment and income pattern, it is found that unemployment is high in Pura Mahadev and Mawi Kalan while low in Gurana and Vazidpur. Households in Gurana, Vazidpur have lower proportion of people depending upon secondary source of income. The mean income of households in Gurana village is Rs. 6,57,017, highest in all four villages, followed by Mawi Kalan (Rs. 4, 57, 170), Vazidpur (Rs. 4, 46, 874) and Pura Mahadev (Rs. 4, 41, 615).
- An assessment of groundwater levels across the villages found that water depth is much lower in Pura Mahadev and Mawi Kalan, ranging from 100-140 feet than in Gurana and Vazidpur (70-90 feet). Due to extremely low levels of water table, a larger share of population in these villages depend upon submersibles/electric motors for abstracting water for domestic use while in Gurana and Vazidpur still a significant proportion of population thrives on water from other sources viz. hand pump and piped water supply.
- Further, the result of Socio-economic Vulnerability index show that Gurana village is relatively less vulnerable with a total score of 0.79 followed by Vazidpur (0.70), Pura Mahadev (0.27) and Mawi Kalan (0.19).
- The study attempts to observe India's agrarian crisis through the lens of primary data collected from different villages of Baghpat district, Uttar Pradesh. Primary data analysis data show that total production of wheat is highest for Mawi Kalan followed by Gurana, Vazidpur and Pura Mahadev. Small and marginal farmers together produce 65.08 percent of wheat in Gurana, 65.17 percent in Vazidpur, 74.45 percent in Pura Mahadev and 65.35 in Mawi Kalan. This confirms the general view that small farmers are necessary for food security and their contribution in production is the most significant. Analysing productivity levels of wheat village wise it is found that higher levels of productivity exist in Vazidpur and Gurana and small farmers are more productive. As far as sugarcane production is considered, data shows that it is highest in Gurana followed by Vazidpur, Pura Mahadev and Mawi Kalan. Average productivity trends show that sugarcane crop yields is higher in case of marginal and small farmers.
- We have calculated the cost of cultivation under sugarcane and wheat cropping system among different farm size categories in all sampled villages. Inter village comparison explains that the

total cost of cultivation in marginal category is highest in Mawi Kalan i.e. Rs. 84959.33 per acre followed by Pura Mahadev (Rs.79720.4/acre), Vazidpur (Rs.79635.3/acre) and Gurana (Rs.77308/acre). A similar trend is observed in all land size categories. Considering the net returns, data reveals that across all land size, farmers in Gurana earn the maximum profit except in case of medium landholder wherein Mawi Kalan leads and is trailed by Gurana, Pura Mahadev and Vazidpur. Inter-farm size analysis suggests that marginal farmers in all villages bear the highest cost of cultivation followed by small, medium and large farmers. The highest share of their expenditure is incurred on imputed value of family labour (approx. 30 percent) followed by hired labour (ranging from 10-15 percent), electricity (10 percent), fertilizers (6-9 percent). The water charges command 5-6 percent of the total cost in case of marginal and small farmers whereas medium and large farmer expenditure is just 2-1 percent of the total cost on it.

- Further, an analysis of certain other factors responsible for groundwater overuse in the region has been done. Cropping pattern assessment shows that majority of the respondents in all the villages stated that their cropping pattern has changed in last ten years and they currently follow only wheat-sugarcane cropping system. Earlier they used to grow vegetables, maize etc. but as it was not yielding higher returns so they stopped growing those crops. A major problem witnessed by farmers in production of wheat and sugarcane is high cost of irrigation. As both wheat and sugarcane are water intensive crops, extensive irrigation is required which is now solely dependent on groundwater. Though, majority of the farmers have installed submersible pumpsets on their farms, few still purchase it. Water charges in Gurana and Vazidpur ranges from Rs.40-50 per hour in this which is relatively less than Pura Mahadev and Mawi Kalan. Considering the credit availability, it is found that credit facility is majorly availed by medium and large farmers with 85 percent and 100 percent respectively taking loans for agricultural purposes. This clearly indicates that still credit penetration is low among marginal and small farmers.
- In order to see the factors affecting agriculture output, multiple regression model with dummy variables has been used. The results of the model depict that total output would increase 0.35 units if the farm lies in Mawi Kalan (high groundwater stressed, socially economically backward village) while it would rise by 0.44 percent if it is in Gurana region and with 0.41 percent in case of Pura Mahadev. Such outcomes portray that Gurana village is more productive than Mawi Kalan as they are in better position-socially, economically and hydrogeologically. Considering land size group, the regression results show that output in marginal farm category would reduce

1.32 percent and in small category it will dip down by 0.75 percent. The total production is estimated to increase by 0.57 percent if it's a large farm, suggesting large farms are productive within the sampled region. As far as association of household income with agricultural production is concerned, the results depict that households with less income are able to produce less. The influence of caste and religion on total production is also evident. Within the sampled region OBC category households are in better position socially and economically, therefore when a household belongs to this category agriculture output is expected to rise by 0.37 units. Further, the regression result shows that farmers belonging to Hindu religion category are able to produce more. The agricultural output is expected to rise by 0.62 units if farmer is a Hindu. Considering education, the regression estimates depict that if the farmer is literate then production would increase by 0.13 units.

- An analysis of the perception of farmer households about groundwater availability, accessibility, causes of water decline and response to depletion threats has been done. Study also assessed groundwater stress levels in different sampled villages and across land size groups. Considering the inter-village groundwater depth levels, data revealed that groundwater level is relatively higher in Gurana and Vazidpur wherein the usual depth is 70 and 90 ft respectively, while it is lower in Pura Mahadev and Mawi Kalan where the groundwater is available at a depth of 120ft and 130 ft. respectively. The supreme reason for water decline is inadequate canal infrastructure followed by access to groundwater abstraction technology and easy and flexible property of groundwater to be the key drivers of increased groundwater depth. Majority of the farmers in all villages depend upon pumpsets for irrigation. Inter- village frequency distribution shows that ownership of pumpsets is relatively lower in Gurana and Vazidpur than in Pura Mahadev and Mawi Kalan. This scenario could be seen from two sides; a) higher percentage of pumpsets owners has promoted groundwater scarcity in Pura Mahadev and Mawi Kalan; b) as the groundwater level is lower in these villages so the viable option that the farmers have is to install a pumpset on farm. Large and medium category a higher percentage of famers have submersible and few lack it while in marginal and small category, 25.08 percent in total could not own it. This throws light on the fact that marginal and small farmers lag behind in accessing groundwater through pumpsets. As far as awareness about energy efficient pumps is considered, 18.67 percent in the sampled villages were aware about the availability of energy saving pumps while 81.33 percent had no idea.

- The study deciphered the linkage between groundwater accessibility and land inequities. Land rights are the major reason behind their water insecurity while 12.67 percent see economic backwardness and 10 percent consider caste to be the primary factor. As land and water rights are linked, land distributional inequities pave way for water stress especially among small and marginal farmers.
- Conceiving knowledge about the behavioural pattern of the farmers towards groundwater conservation it is seen that they literally compete with each other to obtain easy and larger share of groundwater. Out of the total 300 farmers, 48.33 percent stated that they will dig deeper if their neighbouring farmer drills deeper or installs a more powerful pumpset. This problem can be basically identified with a prisoner's dilemma because the presence of firms playing their dominant strategy which maximizes their own profit (disregarding competitors' profits) leads to severe depletion of the resource, and consequently to low profits for all. Deeper analysis shows that marginal farmers belonging to Pura Mahadev and Mawi Kalan showcase far more competitive behaviour.
- In order to ascertain the perceived groundwater stress levels across different villages and land-size groups, a groundwater stress index has been formulated. Its results show that groundwater stress is highest in Mawi Kalan followed by Pura Mahadev, Vazidpur and Gurana. Land-size group wise the results depict that the heat of groundwater depletion is least felt by large farmers, while all other categories suffer.
- The study further estimated the health impact of groundwater degradation across different sampled villages it is found that the cases of water related illness is highest in Pura Mahadev (69) followed by Mawi Kalan (65), Vazidpur (37) and Gurana (32). Results of Logistic model show that the likelihood of experiencing water related infections is higher in families which are socio-economically backward and live in village where water levels are low. The chances proportion affirm that the odds of having a patient with water related illnesses is higher if the family unit lives in land area where water table is beneath 100 ft. Thinking about the impact of education on occurrence of illness, the discoveries demonstrate that if the head of the household is educated, there are less chances of a family member experiencing such infections as the general dimension of mindfulness in the family would be high. To the extent social category is concerned, the odds ratio indicates that the likelihood of family units to have a patient with water related illness is

higher in different classes however not in OBC classification. Considering the effect of income level on occurrence of illness, it is seen that family units having a place with the lower 60 percent income group have higher chances to experience the ill effects of water related ailments. Family size has additionally been considered as a determinant of sickness so the calculated outcomes demonstrate that families with in excess of five individuals have higher odds of having people who experience the ill effects of water related ailment.

- The study estimates the Willingness to Pay (WTP) of farmer households for managing groundwater resources in the region and also encapsulates its determinants. Data analysis show that majority of the sampled population is willing to pay for groundwater management but a higher percent of people agreed in villages with high groundwater stress i.e. Pura Mahadev and Mawi Kalan. As groundwater problem is more precarious, so to solve the current crisis in these villages a higher proportion of people are willing to pay Rs.100 or above while it is not so in Gurana and Vazidpur.
- Coming to the answers behind unwillingness to pay, data tells that majority of the respondents in all the villages believed that managing groundwater resources is the responsibility of government so they will not pay for it and few also stated that until unless the present needs are met there is no need to worry about the future.
- Considering the determinants of willingness to pay (WTP), the results of logistic regression reveal that with reference to social factors, age and caste of the respondent have significant relationship with willingness to pay while the education level's association is statistically insignificant. The odd ratio shows that the probability of farmer household to pay a higher amount for managing groundwater problem is less if respondent belong to caste other than OBC. Considering age of the respondent, the results depict that WTP of the young person is less than an old/matured person. As far as effect of education is concerned, the regression output depicts a negative and statically insignificant relationship. Taking into account the economic factors, land size, income level and value of agriculture output all show a statistically significant association with WTP. Increase in farm size leads to rise in willingness to pay. Income of the household also has a positive relationship with WTP. Considering hydrogeological factors viz. location of the village and groundwater stress level, the results show that both these variables are positively and statistically related. If the household belong to Mawi Kalan village as there are more chances that ~~it will pay above Rs. 50 per month to solve the groundwater problem. The groundwater stress~~

level also highly affects the WTP. The odd ratio reveals that if the household's groundwater stress level is high then there are higher chances to pay more.

## **Conclusion**

Groundwater depletion and degradation is a serious matter of concern as it reduces food production, productivity, increases cost of cultivation, discourages farmers to invest more, leads to migration, social inequities and fall in income levels. Different global and national agencies have evaluated the degree and dimensions of groundwater scarcity/ stress in different parts of the world and have consistently conceded to the gravity of the situation and stated that management of the available resource is the only option.

Groundwater mismanagement in Indian agriculture sector is to great extent interplay of institutional, social, economic, political and ecological factors. Poor state of farmers, lack of canal infrastructure and ineffective rules/regulations could be very important reasons for groundwater stress in districts of Uttar Pradesh. The agrarian, socio-economic and hydrogeological analysis of farmer households in our study area corroborates that land size differences, education level, caste, income, water depth, awareness about environment, behavioural patterns all are significant factors affecting groundwater use and management. The study has been carried out in one of the most critical areas with reference to groundwater stress in Uttar Pradesh, therefore, the results help in highlighting that though groundwater scarcity is not acute in all the regions of Uttar Pradesh but districts like Baghpat are highly affected. The people are suffering to a large extent and there are multiple factors behind groundwater overexploitation. The estimated results clearly show the inter-village and inter-land size differentials that exist in agriculture production, productivity, cost of cultivation, income from agriculture and WTP within the dynamics of groundwater resources. The study findings suggest that the most vulnerable (marginal/small farmer residing in Pura Mahadev or Mawi Kalan village) is the ultimate sufferer and is the one who is ready to spend a higher amount to come out of the problem. Self-interested behavioural pattern towards groundwater use within the sampled population is despite having knowledge of rising groundwater stress is evident.

## **Policy Recommendations**

- It is not possible to meet the needs of the large farmer population in India only through surface water so states can facilitate groundwater trade, and reduce costs for water buyers, by introducing institutional mechanisms to curb unsustainable use and fixing a ceiling price as per the hydrogeological and socio-economic setting.
- Investment in improvising and innovating the canal infrastructure is necessary so as to distribute the burden between surface and groundwater resources.
- Separate electricity feeder system for agriculturists in Uttar Pradesh is an effective mechanism to curb over-extraction of groundwater.
- Precision agriculture is a kind of farm management approach in which taking into account the basic nature of the physical conditions of the area, the farm is managed with accuracy. Adoption of precision agriculture tools would enable farmer to undertake informed decisions as well as indulge in sustainable farm practices.
- Farmers are aware about rising water stress but are not worrisome about it in the regions where groundwater is available. It is necessitated that they are educated about the issues emerging out of groundwater over-misuse.
- Community management can prove to be a powerful tool in conservation of this valuable resource. There are several success stories of community management of water resources which can be replicated or modified as per the local setting and the participatory members can be provided financial incentive by the government.