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Impact of Watershed Management Projects on Agricultural Development: A Systematic Review

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Abstract

Population growth and *rapidly developing technologies have affected surface water resources and climate change has created a major stress. Water scarcity is one of the most serious problems in the world. Climate change has observed significant indicators like increasing degraded lands due to soil erosion, desertification, salinization, flooding, water logging, degradation of water qualities and imbalance between availability and demand of fresh water for agricultural, industrial and domestic use, degradation of forest and wild life. Effective watershed management can be helpful in the prevention of these environmental problems and Agricultural Development (AD). It is multi-functional sustainable activity performed to improve the crop productivity, minimize the risk of degradation of natural resource like soil, water. Watersheds are classified major watershed (50,000-2, 00,000 ha), sub-watershed (10,000-50,000 ha), mili-watershed (1000-10,000 ha), micro-watershed (100-1000 ha) and mini-watershed (10-100 ha). Watershed Management Projects (WMPs) are implemented for the development of degraded and drought prone areas and rainfed agriculture based on natural resource management and conservation. These WMPs have been used water harvesting structures including Water Absorption Trenches (WAT), Continuous Contour Trenches (CCT), check dams, gully, earthen plugs, etc. for the conservation of groundwater, soil, forest, etc. The watershed treatments like percolation ponds, farm ponds and field bunds are also suggested. The participatory WMPs are widely suggested for the conservation of natural resources like soil, water, forest, wild life etc. and also for increasing agricultural productivity, generating employment and raising income to the farmers. This study will discuss WMPs modeling (definition, classification of models and proceed) and a review of WMPs assessment models that are widely used in India.*

Keywords: *Climate change, Watershed management, Agricultural development, Water absorption trenches, Continuous contour trenches, Agricultural productivity.*

Introduction

Watershed can be defined as a unit of land contributes run-off at a common point i.e. outlet (Kumar et al., 2013,). The watershed boundaries follow at the highest ridgeline around the basin and meet at that lowest point of the land i.e. outlet. It is unique biophysical unit of land and therefore, it is a resource region and logical planning unit for sustainable agricultural development. There are some widely recognized environmental problems that impact from climate change : 1) The increasing degraded lands due to soil erosion, desertification, salinization, flooding, water logging, etc., 2) Degradation of water qualities and imbalance between availability and demand of fresh water for agricultural, industrial and domestic use, 3) Degradation of forest and wild life (Darghouth et al., 2008, Willett and Porter, 2001; Burrell, 2008), etc. Agriculture and human activities have key role in the degradation of land and water resources. Effective watershed management can be helpful in the prevention of these environmental problems (Jankar and Kulkarni, 2013). This approach provides logical framework for organizing activities involved in land and water conservation. Therefore, watershed approach has been adopted in many of the projects undertaken for environmental conservation.

Watersheds are classified as small size (< 250 km²), medium size (250-2500 km²) (Aher *et al.*, 2014) and large (> 2500 km²). Singh (1994), Pangare and Pradesh (2006), Aouragh and Essahlaoui (2014), Farhan and Al-Shaikh (2017), Gaikwad and Bhagat (2018) have reported the classifications of watersheds as major watershed (50,000-2, 00,000 ha), sub-watershed (10,000-50,000 ha), mili-watershed (1000-10,000 ha), micro-watershed (100-1000 ha) and mini-watershed (10-100 ha) are useful in the implementation of WMPs. The physiographic, hydrogeological and geomorphological parameters are responsible for various hydrological processes in the watershed (Kumar and Kumar, 2011; Rai *et al.*, 2014).

Therefore, the process of site selection for implementation of WMPs vary according to different characteristics of the region including geology (Yunus *et al*., 2014; Gebre *et al*., 2015), physiography (Gebre *et al*., 2015; Gaikwad and Bhagat, 2018) and hydrogeology (Kumar and Kumar, 2011; Warner *et al*., 2012, Gebre *et al*., 2015; Gaikwad and Bhagat, 2018). Many research reports conducted on the implementations and success assessments of WMPs have reported micro-watersheds as suitable size for its successful applications.

The eastern part of the selected study area has been classified as drought prone area by the Fact Finding Committee (FFC) appointed by the Government of Maharashtra in 1973. The drought prone areas are characterized with depleting level of groundwater (Jankar and Kulkarni, 2013), deforestation, decreasing productivity of crops (Zhao *et al*., 2012), declining number of livestock and quality of human resources (Nedumaran *et al*., 2014), high poverty (Kerr and Chung, 2001), hunger and malnutrition (Wani *et al*., 2008) and migration of human and cattle (Gumma *et al*., 2016) for their survival. Therefore, the emphasis over the past few years was on the management of micro-watersheds in *rainfed* areas for sustainable development in order to increase food and livelihood securities.

WMPs are implemented for the development of degraded and drought prone areas and *rainfed* agriculture based on natural resource management and conservation (Johnson *et al*., 2013). These WMPs have been used water harvesting structures (Patel *et al*., 2013) including Water Absorption Trenches (WAT) (Wani *et al*., 2011; Bisen and Kudnar, 2013), Continuous Contour Trenches (CCT) (Wani *et al*., 2011; Mondal *et al*., 2013; Bisen and Kudnar, 2013), check dams (Patel *et al*., 2013; Nedumaran *et al*., 2014), gully plugs (Wani *et al*., 2011; Bisen and Kudnar, 2013), earthen plugs (Wani *et al*., 2011; Bisen and Kudnar, 2013), etc. for the conservation of groundwater (Bisen and Kudnar, 2013), soil, forest, etc. The watershed treatments like percolation ponds (Gebre *et al*., 2015), farm ponds (Kumar *et al*., 2011; Bhattacharyya *et al*., 2015) and field bunds (Pangare and Pradesh, 2006) are also suggested.

Several benefits are reported including positive effects of WMPs as increase in groundwater levels (Zende *et al*., 2013; Ranjan *et al*., 2013), reduction in run-off (Gassman *et al*., 2007), reduction in sediment load (Aher and Pawar, 2013), increase in agricultural productivity (Aher and Pawar, 2013; Giordano and Shah, 2014), change in land use pattern (Johnson *et al*., 2013; Chen *et al*., 2014), cropping pattern and crop diversification (Bhatta and Doppler, 2010; Johnson *et al*., 2013), cropping intensity (Sundaram, 2012; Aher and Pawar, 2013), improved fodder production (Nedumaran *et al*., 2014; Bhattacharyya *et al*., 2015), livestock population (Bhattacharyya *et al*., 2015; Rathore *et al*., 2019), reduced migration (Pangare and Pradesh, 2006; Bisen and Kudnar, 2013; Aher and Pawar, 2013), women empowerment (Razak *et al*., 2013; Diiro *et al*., 2018), debt reduction (Aher and Pawar, 2013), improvement in the standard of living (Aher and Pawar, 2013; Bisen and Kudnar, 2013; Razak *et al*., 2013), capacity development of the community, etc. (Aher and Pawar, 2013).

Some of the scholars like Teka *et al.* (2020), Puno and Puno (2019) have reported lacunas and practical errors based on field observations and assessments in implementation of WMPs measures. These lacunas and errors are associated with site suitability (Gebre *et al*., 2015), selections of catchment area, suitability of design, rate of siltation, degradation of vegetation cover, etc. Kumar and Sharma (2013) have notified the issues in the implementation of WMPs like management, policy, poverty, upland-lowland, institutional, lack of basic knowledge of an ecosystem functions. Some scholars have reported combined parameters including geology (Patel *et al*., 2013), hydrology (Wani *et al*., 2008; Ruhoff *et al*., 2013), landforms (Singh and Singh, 2011), Land Use/Land Cover (LULC) (Price, 2011; Kaur *et al*., 2014), groundwater level (Moradi and Rezaei, 2014) and quality of soils for the detection of suitable sites for soil and water conservation structures (Farhan and Anaba, 2016) for enriching the natural resources. Further, Patel *et al.* (2013) have reported the usefulness of morphometric analysis for the selection of suitable sites in the implementation of WMPs by using RS and GIS approaches. Here, the prioritization of micro-watersheds based on the morphometric analysis was performed in the present study to analyse watershed suitability in the implementation of WMPs.

The scholars like Patel *et al.* (2013), Sellami *et al.* (2013), Aher *et al.* (2014), Rai *et al.* (2014) have used different approaches including traditional, pragmatic, quantitative, sampling, time series, numerous, graphical, historical, geospatial (Remote Sensing and GIS) (Patel *et al*., 2013; Kaur *et al*., 2014), generalized (Ames *et al*., 2005), hydro-physical (Strahler, 1957), planning (Ghanbarpour and Hipe, 2011), watershed, geomorphometric (Kinthada *et al*., 2013), participatory approaches, multi-criteria decision-making (Moradi and Rezaei, 2014), Participatory Rural Appraisal (PRA) (Chambers, 1994), fuzzy AHP (Rezaei *et al*., 2013), AHP and influence approaches (Gaikwad and Bhagat, 2018), etc. for analysis of WMPs for sustainable development and management of watersheds. The present study is based on the geospatial parametric approach for the analysis of selection priorities for implementation of WMPs and its impact on AD.

The scholars have used many indicators and techniques to assess the watershed suitability for implementation of WMPs (Gebre *et al*., 2015). The impacts of WMPs were analyzed on the basis of natural and socioeconomic parameters (Pangare and Pradesh, 2006). Gebre *et al.* (2015) have used the information about the geology, landforms, soils, groundwater level, LULC, etc. for the suitability analysis of watersheds for selection of sites for the implementation of soil and water conservation structures. Zolekar and Bhagat (2015) have used land suitability analysis for agricultural planning and management to increase production. Panhalkar (2011) has used GIS technique for site suitability analysis of watersheds. The geospatial techniques including RS and GIS techniques like Automated Geospatial Watershed Assessment tool (AGWA) are efficient tools for suitability analysis of watersheds (Miller *et al*., 2007). Therefore, the GIS based multi-criteria AHP and influence approaches were used for analyzing the selection priorities of watersheds in the implementation of WMPs.

Thus, the focus of the present study is on the analysis of selection priorities of micro-watersheds for the implementation of WMPs and its impact on AD in the region. The AD in different micro-watersheds has been spatially compared according to the status of implementation of WMPs in the region.

Methods

1. **Literature review**

Literature review strategies we set a clear path and a set of problems for the review using a proper methodology for conducting reviews in the implementation of WMPs and conservation of water and soil. Available sources included governmental and non-governmental databases and using google search engines that provided wide coverage of peer-reviewed publications. The search engine https://www.freefullpdf.com was also used to increase access to Download Free Scientific Publications like Life sciences, Health sciences, Physics sciences, Mathematics, Social sciences & Humanities has been a wide focus on assessment of WMPs. Databases were searched from 1980 through 2020.

2. **Literature selection criteria**

Literature were selected based on whether they contained significant key words in the article title, abstract and main contained of the text. Online or PDF articles selected for use in the review of the mention criteria: 1) the study addressed a process of water and soil conservation; 2) the study existing data on one or more of the assessable indicators for assessment of WMPs and 3) the study recognized changes in water and soil conservation during a period of working and complete processes of groundwater recharge in the watersheds with different land cover. Literature that used provided only qualitative assessment of WMPs.

3. **Literature and data organization**

To achieve our main objective of searching and organizing the quantitative literature data applicable to assessment of WMPs and their impact on AD, Papers searched online were entered into Mendeley Reference Manager Software and retrieved by key words. Organized qualitative characteristics through a "tag" processes. Every paper was organizing systematically different qualitative characteristics.

Results and Desiccations

1. **Watershed management programs**

Watershed Management Programs (WMPs) is one of significant activities in semi-arid and arid regions for rural development (Thapa, 2008; Bouma *et al*., 2011). It is multi-functional sustainable activity performed to improve the crop productivity, minimize the risk of degradation of natural resource like soil, water (Meshesha and Birhanu, 2015), vegetation (Bhattacharyya *et al*., 2015), etc. to improve the soil moisture, soil fertility and rural economy (Wani *et al*., 2011). Watershed management technique is the most effective as an operational development model for rainwater harvesting and groundwater recharge, increasing agricultural productivity in *rainfed* regions and effective use of natural and socioeconomic assets (Addisu *et al*., 2013). Sustainable watershed management practises are for upgrading the environmental aspects, human health and wellbeing, economic improvements, etc. (Singh *et al*., 2015).

The Government of Maharashtra has adopted watershed approach from early 1970s of 20th century as a spatial unit for resource based planning and management for development (Gosain and Rao, 2004). 'Indo-German watershed management program' have implemented the projects through NGOs like WATER, Panipanchyat (Pune), Nisargyan (Sangamner), Social centre (Ahemdnagar) and sugar factories like BST Sangamner Sahakari Sakhar Karakhana, Sangamner, etc. in drought prone areas of Maharashtra. Therefore, the present study has analyzed the WMPs undertaken in upper Mula basin in Maharashtra to understand the success and problems in implementation.

2. **Implementation of watershed management programs**

Water is useful for different purpose like domestic needs, industrial use, agricultural requirements, power generation (hydro-power and thermal power), and navigation and recreation purposes. Agriculture is the greatest user of water claiming about 80% of all composition. Therefore, the need of water conservation arises in the soil profiles, aquifer (Sellami *et al*., 2013), ponds (Mondal *et al*., 2013), lakes (Yeole *et al*., 2012), reservoirs (Safriel *et al*., 2011), streams (Sellami *et al*., 2013), etc. The water demand is increasing but supply is limited. The basic source of water for both surface and groundwater is precipitation which varies from region to region. Therefore, WMPs have been implemented in different water scarcity regions across the world. The main objectives of implementation of WMPs in drought prone areas are land improvements, soil and water conservation, forest management (Tiwari *et al*., 2008), water harvesting for better crop production (Nedumaran *et al*., 2014), agricultural productivity improvements through improved soil moisture protections and caring irrigation facilities (Pangare and Pradesh, 2006), livelihood improvements, farmer security, etc. In India, integrated watershed development programs were highlighted in 1980s with participatory approach (Wani *et al*., 2008). The watershed management and planning is one of the significant skills for implementation of WMPs to control soil loss in the watershed. Surface run-off and soil losses are the two major hydrological impacts from the heavy rainfall (Gajbhiye *et al*., 2015). Therefore, the implementation authorities are focusing on soil and water conservation activities applying technical measures including terracing, contour bunding on gully and rills for controlling the land degradation on hilly region (Nedumaran *et al*., 2014; Tiwari *et al*., 2008). Water conservation decline in the wasteful water losses like run-off (Petkovsek and Mikos, 2004; Dhawale, 2013; Gajbhiye *et al*., 2015), evaporation (Antonopoulos *et al*., 2013; Stagge *et al*., 2014), transportation losses (Bouma *et al*., 2011) and deep percolation (Antonopoulos *et al*., 2013; Savvas *et al*., 2013). These conservation measures include physical and vegetation management. The plantation activities of

WMPs also have impact on control on losses through evaporation, surface run-off and improvement in groundwater recharges, etc.

a. **Agricultural development**

Agriculture is important activity in India. Indian economy depends upon the agriculture sector. After independence, major focus of India government was on AD through improvement in irrigation facilities, seeds, fertilizers, technology, financial support, education, etc. Different organizations have provided financial assistance to the farmers for the development of irrigation facilities. However, excessive irrigation has exploited groundwater and water scarcity appeared in the summer season especially in drought regions, the irrigated agriculture and orchards began run out of water. Therefore, WMPs were undertaken by various governmental agencies, NGOs and local authorities in India. The main focus of implementing the WMPs was AD. Therefore, AD is one of the significant components of WMPs (Winnegge, 2005). The assessment of implemented WMPs is essential for understanding the success of these projects in AD.

Further, Zolekar and Bhagat (2015) have identified affecting factors of agricultural production like slope, soil depth, erosion, moisture, water holding capacities, texture and availability of nutrients. The drought prone regions show availability of some natural resources along with social problems like deforestation, soil erosion, lack of agricultural land, less agricultural productivity, high population density, etc. (Addisu *et al*., 2013).

b. **Impact assessments**

Assessment of AD in micro-watersheds is useful tool for impact assessment of WMPs. The assessment of AD can consider the increase in cultivable land, conservation of soils, recharge in groundwater, increase in agricultural productivity, income to the farmers, etc. (Smith *et al*., 1999). Many researchers have outlined the methodology useful in organizing and performing a sustainability impact assessment (Reidsma *et al*., 2011) of AD in watersheds. Gassman *et al*. (2007) have used SWAT for hydrological analysis. Vu *et al*. (2014) have used statistical methods of assessment for land degradation in Vietnam (pixel-based data and NDVI for each 64 km^2 pixel). Here, AHP based multi-criteria analysis and influence technique was used for assessment AD in micro-watersheds in Mula River basin to understand the impact of WMPs on agriculture (Rambabu, 2014).

Miller *et al*. (2002), Lockwood *et al*. (2015) have used LULC, landscape and types of soils for assessment of AD. Economic influence of crop excesses (Tomer and Locke, 2011), agricultural production (Dolak *et al*., 2013), greenhouse practices, agro-hydrological monitoring (Capodici *et al*., 2013), adoption of new technology, participation of community (Pangare and Pradesh, 2006), ecological stability (Palanisami *et al*., 2009), suitable agricultural land (Kapalanga, 2008; Rezaei *et al*., 2013; Gupta and Uniyal, 2013; Gaikwad and Bhagat, 2018), etc. are significant components used for assessment of WMPs for AD. However, many of WMPs have been assessed using cropping pattern, available irrigation facilities, area under irrigation, improved economic conditions, etc. Therefore, cropping pattern has been used for impact assessment of WMPs for AD.

Review of literature

Watershed is an integral natural unit of geological, landform, climatic and biological characteristics as well as socioeconomic characteristics. The degradation of these natural and socioeconomic elements adversely affects the biodiversity, natural resources and human life. The present study focused on the impact assessment of upper Mula River watershed to understand the impact of WMPs. Therefore, the literature was reviewed to understand the watershed, WMPs, watershed development projects, assessment techniques, impact assessment, agricultural development, etc.

c. **Watershed**

The watersheds are characterized by physical characteristics: 1) Geology (Chitra *et al*., 2011), lithology (Larouche *et al*., 2015), 2) Topographic and morphometric characteristics including (Gray, 1961; Ali *et al*., 2014), geomorphology (Price, 2011; Johnson *et al*., 2013; Ali *et al*., 2014; Larouche *et al*., 2015), elevation (Price, 2011; Ali *et al*., 2014), land slope (Panhalkar and Pawar, 2011), 3) Hydrological characteristics (Garg *et al*., 2003; Panhalkar and Pawar, 2011), 4) Soils (Garg *et al*., 2003; Price, 2011), 5) Climatic characteristics (Ali *et al*., 2014), 6) Glacial (Larouche *et al*., 2015), 7) Vegetation type (Larouche *et al*., 2015), and 8) Human characteristics like land use (Garg *et al*., 2003; Singh *et al*., 2015), etc. Iqbal *et al*. (2013), Ali *et al*. (2014), Gumma *et al*. (2016), Gaikwad and Bhagat (2018) have used morphometric characteristics of watershed for assessment of different basins for planning, monitoring and management of resources.

Willett and Porter (2001), Addisu *et al*. (2013) have defined the term watershed as topographically (Singh *et al*., 2015) demarcated catchment area or unique hydrological division which collect the water through stream network (Kumar and Kumar, 2011) at a common point (Kumar *et al*., 2013; Kaur *et al*., 2014; Singh *et al*., 2015). Ali *et al*. (2014) have referred watershed as a physically arising hydrological units (Tiwari *et al*., 2008; Gupta and Uniyal, 2013). Further, some scholars have defined it as natural boundaries of unique topography (Addisu *et al*., 2013; Smyle *et al*., 2014; Singh *et al*., 2015), physical features (Gray, 1961; Singh *et al*., 2015) and climatic conditions (Singh *et al*., 2015). Tiwari *et al*. (2008), Gupta and Uniyal (2013), Singh *et al*. (2015),have used human and natural terms to define the watershed. The watershed boundaries are following at the highest ridgeline around the basin and meet at the lowest point of the land i.e. water flow (Kurian and Ton, 2005). It is unique biophysical unit of land (Asbjornsen *et al*., 2015) and therefore, it is a resource region and logical planning unit for sustainable AD.

d. **Watershed management programs**

In 1980, Government of India started WMPs to achieve dry land development, reducing poverty, restoring ecosystems and enlightening food security (Smyle *et al*., 2014; Gray *et al*., 2016) on the basis of micro-watershed with traditional approaches of water resource management (Government of India, 2011). The focus of WMPs in India was the conservation of degraded natural resources (Bouma *et al.*, 2011; Nedumaran *et al.*, 2014) and AD in *rainfed* region (Johnson *et al.*, 2013) with not only improved crop productivity but also minimizing the degradation of natural resource (Wani *et al.*, 2011). Rainwater harvesting is significant in watershed management with the process of planning and execution of the projects for sustenance and development of watershed functions (Mangrule and Kahalekar, 2013) including plants, animals and human communities. The watershed management models identify the inter-relationships between the uplands (Nikolaus, 1977), lowlands, land use, geomorphology, slopes and soils (Mishra and Nagarajan, 2010). Watershed development refers to the conservation, renewal (Sundaram, 2012) and the sensible use of all resources including natural (land, water, plants, and animals) and human resources (Bisen and Kudnar, 2013). In India, WMPs was funded by several governmental and non-government agencies like Central Government (National Watershed Development Program (NWDP) for *rainfed* areas, Indian Council of Agricultural Research and Drought Prone Areas Program (ICARDPAP), State Government (Jal Sandharan and Adarsh Gaon Yojana, Government of Maharashtra Watershed Programs), joint agencies (World Bank) and contributors Indo-German Watershed Development Program (IGWDP) (Pangare and Souza, 1998). Further, environmentally integral approach has been adopted by the different agencies at global (Swami *et al.*, 2012), regional and local level for education of WMPs. The present study performs analysis of micro-watershed and impact of WMPs on agriculture (Mondal *et al.*, 2013).

Field verification and accuracy assessment

Field verification is one of the significant parameters of the research carried out in understanding to produce supplementary data to assess the quality or accurateness of the arrangement (Ejaro and Abdullahi, 2013). These methodologies entail field authentication and method based analysis of differences between predicted values and observed values (Buffington and Montgomery, 2013). Data collection can be conducted by using three main types of survey methods: census, sample surveys, and administrative data.

Field verification was undertaken in selected categories to check the priority assigned to each class using a random sampling method. Watershed boundaries were prepared at 1000 ha scale and overlaid on the priority map to identify watersheds that were in a very high priority zone (Gumma *et al.*, 2016). The socioeconomic data was linked with geographic locations of the sampled households using Global Positioning System (GPS) (Bhatta and Doppler, 2010). In the ex-post evaluation, the percentage of families are actively involved in both maintenance and replications of soil and water conservation practices was assessed by means of a field survey (Kessler, 2007). Therefore, the data was collected through conducting fieldwork and circulating questionnaires within farmers in selected micro-watersheds in the study area for understanding the executed watershed development programs and its impact on agriculture.

Accuracy assessment is the ending phase of the analysis, which validates the final results. Accuracy assessment confirms the reliability, self-evaluation and errors in the classification methods. Many scholars have used primary data collected from GPS based ground authentication (Zhao *et al.*, 2013; Miller and Doyle, 2014) communications with stakeholders (Tomer and Locke, 2011; Mangrule and Kahalekar, 2013), remotely sensed data (Iqbal and Sajjad, 2014; Su *et al.*, 2014; Feizizadeh *et al.*, 2014), etc. for accuracy assessment.

An error matrix comprises (Bhagat and More, 2013; Chakravarty, 2015) of an $n \times n$ display where n is the class of classes in the secondary data calculating of analysis. The columns represent the reference data (Zolekar and Bhagat, 2015) or field survey data and rows show classes in the classified map produced from secondary data collected from various agencies. Sampling strategy (Sellami *et al.*, 2013; Alkire *et al.*, 2013; Alganci *et al.*, 2018), response plan (Wulder *et al.*, 2006) and analysis (Montroull *et al.*, 2013; Asbjornsen *et al.*, 2015) are the major components of an accuracy assessment.

The concluding section of the accuracy assessment is the application of analysis and assessment proprieties to the reference data (Santillana and Makinano, 2016; Alganci *et al.*, 2018). Judgments of the map and reference data are prepared using a data cross arrangement, the product of which is recognized as a confusion matrix (Zhao *et al.*, 2013). Some scholars have suggested that the error matrix (Chakravarty, 2015) must be described in terms of sizes and an error matrix is never normalized (Chu *et al.*, 2009; Bhagat and More, 2013). However, the present study has used error matrix for an accuracy assessment to analyze the AD.

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Conflicts of interest

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