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REVIEW ARTICLE

Assessing the disparities in impact assessment methodologies: A multidimensional context

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Abstract

To assess the efficacy and performance of an intervention or policy, impact assessment plays a crucial role. This article aims to systematically combine the existing literatures published on impact assessment methodologies using a narrative approach. Databases such as Springer, Google Scholar and Science Direct are used to identify the literature sources on different impact assessment methodologies such as Difference in Difference (DID), Propensity Score Matching, Instrumental Variable Analysis, Randomized Controlled Trial, Regression Discontinuity Design and Synthetic Control Method. Although these techniques have always been significant, their implementation varies across scientific domains due to challenges such as resource constraints and methodological complexities. To address current global issues and enhance the precision of methodologies across field, recognizing the contextual relevance of each method is essential. Each methodology offers unique characteristic uses and is characterized to solve various research issues. This helps in decision making strategies for future-oriented programs. The study emphasizes the portability and wider interdisciplinary uses of these approaches by investigating their practical application in several domains such as health, education and the environment. The limitations, challenges and intrinsic biases associated with different methodologies are analyzed and discussed. The article evaluates various approaches in assessing the impact, thereby aiding the reader to understand the appropriate methodologies for different conditions.

Keywords: difference in difference; instrumental variable; propensity score matching; randomized controlled trial; regression discontinuity design; synthetic control method

Introduction

The concept of impact assessment has gained significant attention among the environmental and developmental agencies (1). The United States Nations Environmental Policy Act (NEPA) of 1969 laid the foundation for impact assessment (2). Impact assessment is a basic tool to determine the change and it helps to identify how the beneficiaries been impacted. It supports community development and informs necessary policy measures (3). Measuring the beneficial effects of research is a very personal procedure, yet, advantages derived by one group in a specific area, period and society might be interpreted as weakening the desires of other groups (4). The output of the assessment will yield significant data regarding the interactions among various parties in the perspective of innovation. It will establish the necessary institutional prerequisites to achieve greater impact on technology (5). The impact studies involve four major rationales such as i) responsibility and reliability ii) precision and significance iii) program implementation iv) future oriented planning and priority determination (6).

The uniqueness of each disciplinary branch has led to increased specialization within each subfield (2). Environmental Impact Assessments (EIAs) in wealthier nations have led to significant progress in conservation and environmental improvement; but, when applied internationally, these developments may not be effective or could even pose risks. This is because a comparable level of focus is not provided in low income countries (7). Enhancing the lives of deprived communities without diminishing the supply of natural resources is the aim of the researcher. On the contrary, R&D managers are subjected to obligations in selecting their investment portfolios for the purpose of effectively managing the social consequences of constrained resources because of the constant loss in funding (8). There is a need for an effective implementation of IA in terms of its thematic demand to analyse the potential implications while considering the overall effects of planned measures (9). This review acts as a guide to suggest an extensive research plan which will allow the impact assessment to change in response to the requirements. This article aims to guide the researcher through the overall

structure of an impact assessment personalised to the objective of the evaluation. The most suitable assessment plan for the consequences can be chosen appropriately.

Current scenario analysis

The inappropriate ecological and social governance of developing techniques' eventual use creates significant hazards such as rising inequality, depletion of resources, increased emission of green-house gases and subsequent damage to the ecosystem. For discovering the unexplored possibilities for modern environmental management, impact assessment is being digitized (10). The continuous revolution of technologies provides us with both possibilities and hazards. It is ultimately up to society to determine which outcomes and impacts will materialize (9). Since there is an increased recognition for critical nature of the social aspects of projects, the new methods of impact assessment have evolved to address a holistic approach that gives equal attention to environmental and social factors (2, 11, 12). Though millions of dollars are spent on environmental impact assessment, it appears like enough effort is not directed towards integrating the current methodologies for meaningful examination (13).

Materials and Methods

Data sources and search strategy

Google Scholar and Science Direct were used as the primary databases for the literature review. The reason behind selecting these databases was their comprehensive collection of academic literatures involving various disciplines. The major keywords used in the search engine were "impact assessment" and "impact assessment methodologies". Fig. 1 shows an overview of the methodology used for the search purpose.

Comprehensiveness of database

The data comprehensiveness defines the number of articles used for the evaluation of the study. A total of 145 articles were downloaded based on the relevance to the topic. Out of 145, 46 articles were excluded due to scanty discussions. After filtering, 99 articles were chosen for in-depth review. Sample articles analysed on various impact assessment methodologies for the review are tabulated in Fig. 2.

Distributive analysis

Geographical distribution: The geographic diversity of authors whose works were reviewed is shown in Fig. 3. United States is found to be the pioneer in the subject of impact assessment (14). This is followed by the United Kingdom and Australia in terms of articles published. The major developing countries such as India, China, etc., accounts for minor contribution in the academic publications on impact assessment (15).

Distribution of articles by research domain: By the analysis of various articles related to impact assessment it is found that the impact evaluation is carried out more frequently to assess the environmental effects (EIA) (16). It has been asserted that the major cause is based on the fact that the scientific exploration in the field of environmental science has greater conceptual foundations (17). Followed by impact assessment on policy initiatives paves a major contribution. This is followed by climate change, sustainability and social impact assessment (16).

Year wise distribution of article: Fig. 4 represents the growth of article publications on the title impact assessment in the recent years. This trend line shows a progressive increase in the publications and emerging scope of impact assessment. It is noted that the recent years the research topic has taken more relevance in the academic contribution.

Evolution of impact assessment tools

Table 1 provides an over-view of the evolution and objectives of various impact assessment methodologies.

Descriptive analysis

Description based on respondent selection

It is always important to assess the progress of the program achieved in the field (29). DID methodology focuses on comparing the treated and controlled group of the intervention over a period of time (30). Propensity score matching calculates

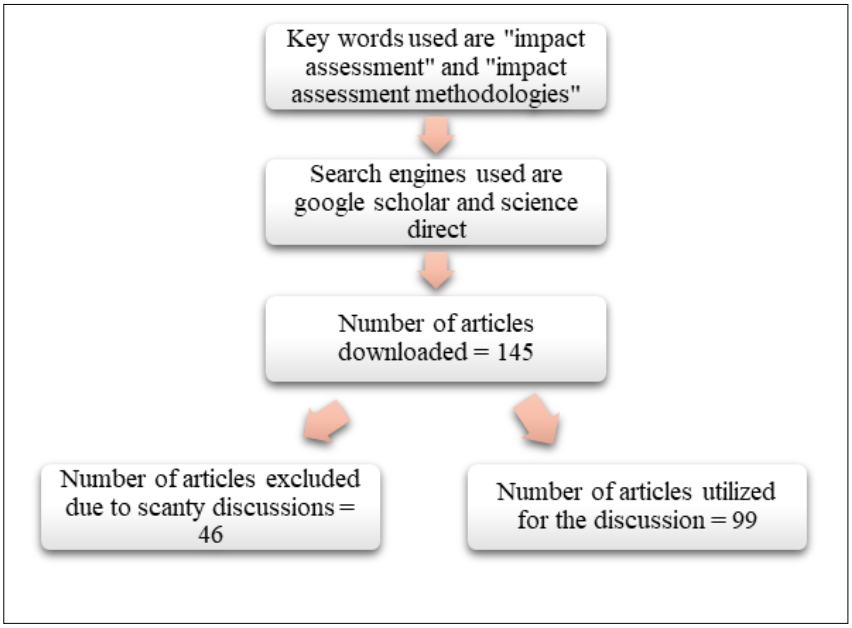

Fig. 1. An overview of methodology used for review.

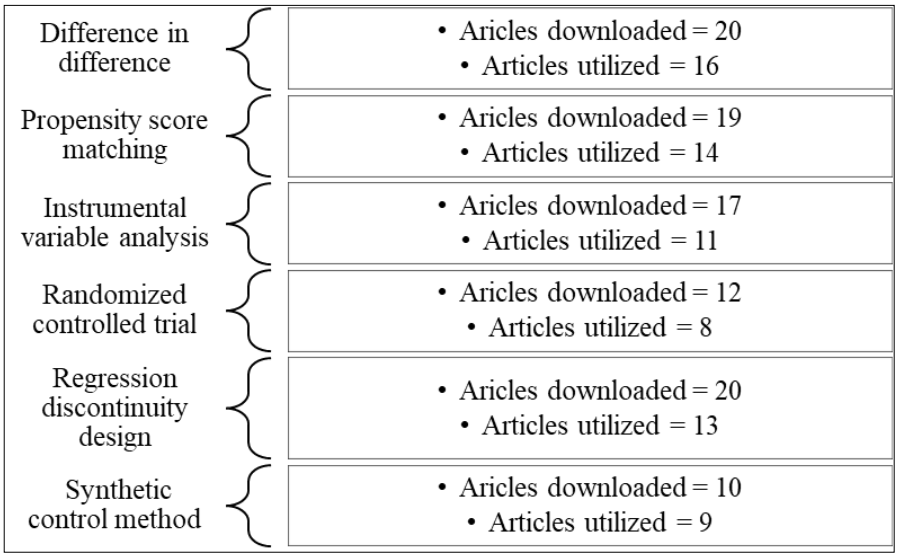

Fig. 2. Comprehensiveness of database.

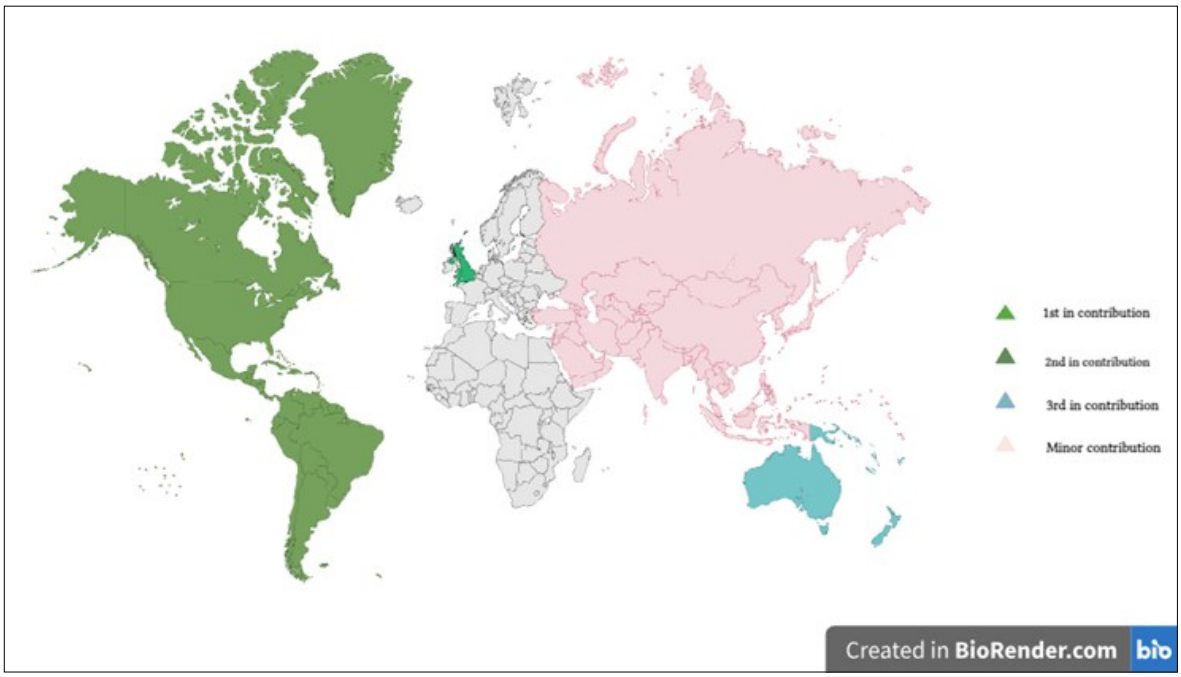

Fig. 3. Geographical distribution of publications on impact assessment (14, 15).

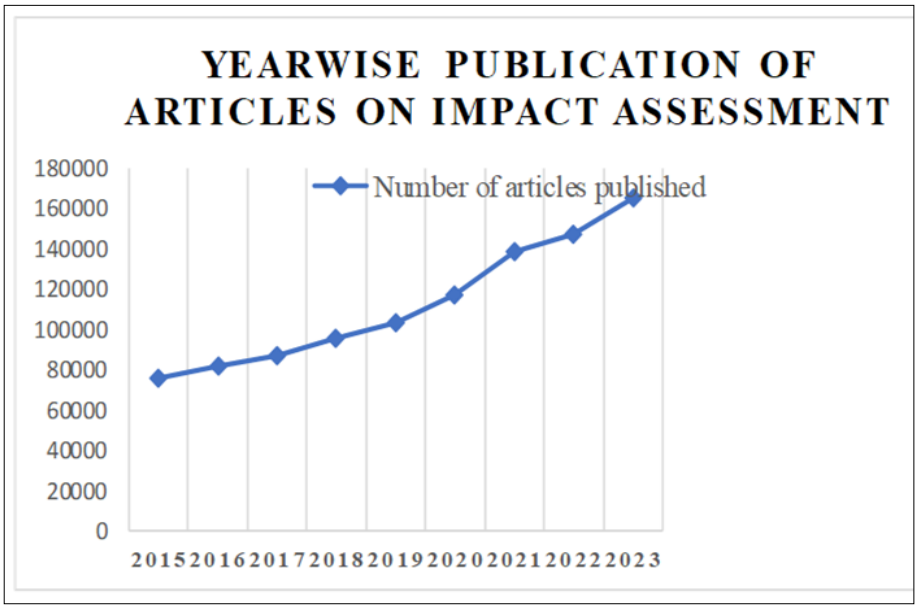

Fig. 4. Year wise distribution of articles on impact assessment.

Source: ScienceDirect

Table 1. Evolution of impact assessment methodologies

Methodology	Year	Objective	References
DID	1855	To estimate the impact of an intervention based on the controlling variable	(18, 19)
PSM	1983	To observe the likelihood of an intervention of the treated with observed variables	(20, 21)
Instrumental Variable	1981	Used in the assessment of impact where endogeneity bias plays a major role	(22, 23)
Randomized controlled trial	1948	To assess the efficiency by randomly allocating the treated and control group	(24, 25)
Regression discontinuity design	1960	To evaluate the impact by selecting the treatment groups based on predetermined threshold level	(26, 27)
Synthetic control method	2010	To assess the impact by creating a weighted synthetic control unit	(28)

the effectiveness of the intervention by the comparison of a treated group with matched variables (31). Instrumental variable analysis uses an instrumental variable in order to address the issue of avoidance of variable bias (32). In randomized controlled trial the treatments are allocated in a random manner to avoid the differences among the population served (33). Regression discontinuity design employs selection of individuals according to the predetermined threshold level (34). Creation of synthetic control units is part of the synthetic control method.

Description based on application

DID methodology: DID approach is a method used to evaluate the changes and the output driven by a policy. This is a research design that is used to compare the effects of the project or an intervention over a period of time (35). This design is addressed by the comparison of a group that is exposed to the policy with the group that is not exposed to the policy change (36). This methodology is applied when there is an availability of panel data for the following intervention (37-39). The difference measured is calculated in terms of efficiency (40). It is employed when the randomized controlled trials are impractical (41). The major components of DID are the treatment group, control group and the intervention period. Let us consider two groups A and B where A is exposed to the policy change and B is not exposed. Since the effects of a treatment changes with time there occurs bias with variation in time estimates (42). Then the difference in outcome before and after the change in both the groups are compared to calculate the impact of the policy. It has become a powerful approach to address the cofounding in the observational studies (43).

$$DID=(\Delta Y_1post-\Delta Y_1pre) - (\Delta Y_0post-\Delta Y_0pre) \quad \text{Eqn.1}$$

Where, ΔY_1post is the difference in output of treatment group after the intervention, ΔY_1pre is the difference in output of treatment group before the intervention, ΔY_0post is the difference in output of control group after the intervention and ΔY_0pre is the difference in output of control group before the intervention. This is arithmetically written as A2-A1 - B2-B1 (35). By regression analysis, DID estimates can be written as, $Y = \beta_0+\beta_1 A_1 +\beta_2 A_2 +\beta_3 A_1A_2 +\mu$ (44). The DID is formulated based on the fact that when one part of population is exposed to an intervention, the comparison with the part not exposed can be used to evaluate the effects created (37). In case of non-linear model, the treatment effect is calculated by difference between the cross differences (45). The method of DID can also be used to measure the effect of the following intervention in its related areas. The use of DID approach predicts the range that is apart from the allowed range (46).

Propensity Score Matching (PSM): The PSM methodology is widely utilized in various observations to mitigate the treatment selection bias (47). Propensity scores replicates the attributes of randomized controlled trial (48). The method of propensity score matching was first used by Heckman. The PSM is used where the study data lacks randomization. Two steps are followed in conducting PSM, 1) conduct of probit regression and 2) calculation of average treatment effect (49). Propensity scores are the probability of the samples in receiving the treatment in the pre and post intervention period (50). It estimates the individuals' propensity to get the binary treatment by the usage of probit or logit as a function of observed and matched variables (51). The average effect on the treated (ATT) measures the average difference between the treated and their matched counterparts. The steps to implement the propensity score matching as shown in the Fig. 5. It depends upon the assumption that the quality of matching depends upon the quality of the data used for propensity scores. The main objective of PSM is decreasing the selection bias (53). There are four different approaches for propensity scores, i) matching - pairing similar treated and untreated units; ii) stratification - dividing sample into score-based blocks or strata; iii) weighting - assigning units with weights based on the probability of receiving treatment; iv) regression - Including propensity scores as covariates. It is found that PSM always performs well in larger samples (54).

Instrumental variable analysis: To address the issue of omitting the variable bias the methodology of instrumental variable analysis is used. It controls the use of latent variables. An instrumental - variable is correlated with the explanatory variable but not with the error term in the outcome equation. This method is widely applied in the treatment effect studies, particularly in health sciences (55). Fig. 6 provides a diagrammatic representation illustrating the role of latent variables in IV analysis.

The application of instrumental variables reduces the selection bias. It can be appropriately used for polycentric samples (independent units or regions) (56). The application of IV was initially done by Permutt and Hebel to evaluate the smoking effect of pregnant women on the weight of the child born. The simple linear equation of an instrument variable can be written as,

$$Y = \alpha + \beta Z + U_i \quad \text{Eqn. 2}$$

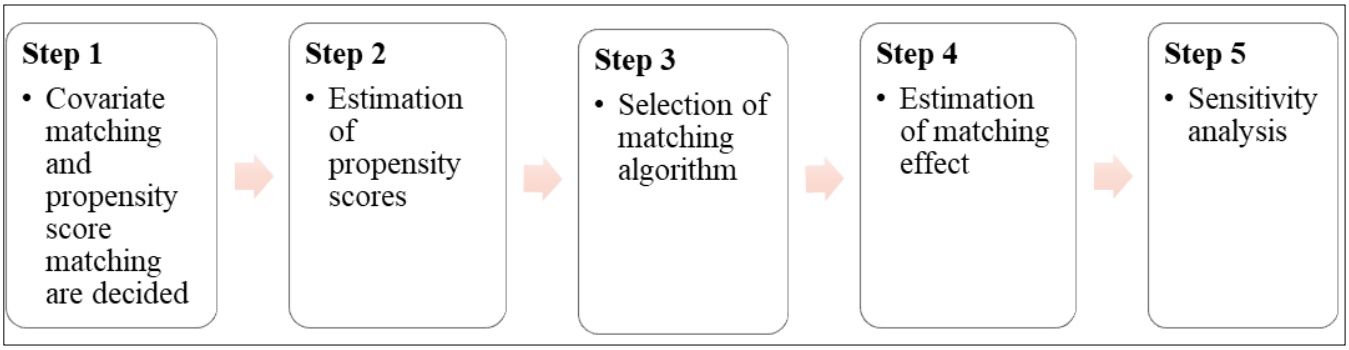

Fig. 5. Steps to implement the propensity score matching.

Source: (52)

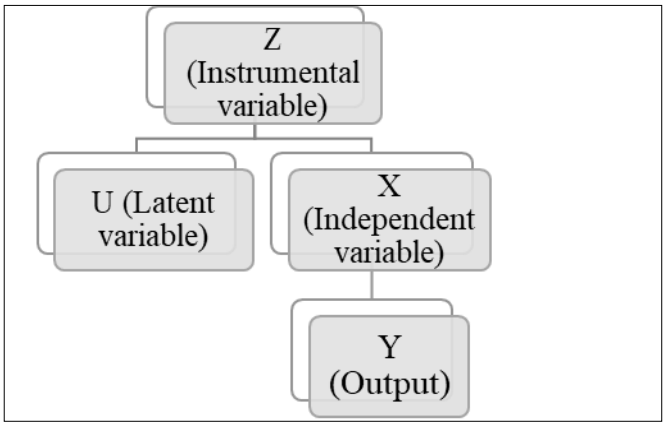

Fig. 6. Role of latent variables.

Source: modified from (55)

Where, Y is the endogenous dependent variable that is dependent on Z, the instrumental variable and U is the stochastic error term (57). Here IV should satisfy the following conditions such as Z should be related to Y but not related to U_i. One of the major applications of IV is simultaneous equation model.

$$y = \alpha + B y + \beta x + €_y \qquad \text{Eqn. 3}$$

Where, y is the endogenous variable, α is the intercept of y, B represents how variables in y affects each other, β represents the effect of x and $€_y$ error or disturbance (58). The estimates of IV can be highly biased, if there is minimal endogeneity (59). This causes a condition named exclusion restriction where the dependent variables are influenced to be independent (60).

Randomized controlled trial: It is predominantly used to assess the impact of any experiment intervened in the field of medical science and social science. It is a trial conducted under standardized conditions where the treatments are allocated randomly to the reference group. It is one of the precise techniques to determine whether a causal relationship exists between the treatment and the outcome. When more than two existing groups are compared for an observation, systematic differences may occur which can only be eliminated by allocating the treatment at random by randomized controlled trials (61). The history of randomized controlled trial sets back to 600 BC when Daniel conducted the clinical trial by comparing the health effects of vegetarian population with the population following Babylonian diet. For the reduction in the imbalance between the population, randomization is carried out in a precise manner (62). The classification of randomized controlled trial is presented in Table 2.

The major limitation while using RCT is lesser duration for study (63). In a nutshell it is clear that the randomized controlled trials helps in formulating a research trial into practise (64).

Regression discontinuity design: In regression discontinuity of design, the sample individuals are selected based on the predetermined threshold level (65). This method is better utilized for fair allocation of resources. The provision of scholarship to the students based on their income level and family standards explains this clearly. The concept of regression discontinuity was first formulated by Thistlethwaite and Campbell (66). It is better utilized when there occurs non possibility of assigning the samples before and after the effect (67). In regression Discontinuity Design the relationship between the outcome and the threshold level is more important (68). For research of determined cutoff score *c* the participants receive training if X ≥C; T=1 and those of X<C; T=0 is deprived of training. This is illustrated by the given equation below,

$$Y = \beta_0 + \beta_1 X + \beta_2 T + R \qquad \text{Eqn. 4}$$

The regression discontinuity designs can be classified into sharp and fuzzy designs.

Sharp designs: If no misallocation occurs based on the cutoff score.

Fuzzy designs: If there is any misallocation or crossover among the treated.

The basic assumptions of the design are i) specified cutoff scoring for the allocation of interventions ii) single regression mode over the entire score value iii) no other factors can cause disintegration of the score iv) principle of interference and v) conditional average treatment effect (68). This methodology is more accurately employed in application of economic sciences (69).

Synthetic Control Method (SCM): In the absence of a suitable control, the SCM creates a synthetic control unit using a weighted average that closely resembles the treated unit than any of the individual control units (70). The application of SCM helps in the reduction of problems occurring due to endogeneity. The method of synthetic control was initiated by Abadie and Gardeazabal in their study of assessing the impact of economic growth of violent conflicts in the Spanish country. This method is done by comparing the performance of synthetic unit with that of treated units which gives dynamic treatment effect (71). The synthetic

Table 2. Classification of Randomized controlled trial

Based on the interventions	Explanatory trial Efficacy Phase 1, 2, 3 and 4
Based on participant exposure and response	Parallel Crossover Factorial
Based on the number of participants	N of one trial Sequential trial Fixed trial
Based on the level of blinding	Single blinded trial Double blinded trial Quadruple blinded trial
Based on non-randomized participant preferences	Preference trial

control must closely resemble the treated unit in the pre-intervention period (72). SCM has gained significant traction in policy evaluation literature over the past 15 years. In case of standard approach of SCM, the selection of control unit is from a collection of units collectively known as donor pool. The equation based SCM can be written as,

Where,

Y_{1t} = $\mathbf{Y_{1t}} = \sum_{j=2}^{j+1} w_j \mathbf{Y_{jt}}$ Eqn.5 outcome variable of unit 1 at time t

W_j = vector for weighted control units

T = duration of the treatment happening

Source: (73)

It is used to estimate the counterfactual scenario in the absence of change by analysing the outcome trend (74). It does not assign equal weights to the compared untreated units as assigned in DID method (75).

Description based on predominant sectors

Social welfare: The impact of employment policies on wages and employment was measured using propensity score matching. Variables such as wages and employability were taken as outcome variables (76). The minimum wage's effect on employment in a low income country was evaluated using DID approach (77). The conduct of logit model followed by propensity score matching was performed to analyse the impact of air pollution on the selection of employment location (78). The impact of adopting agricultural technology on poverty reduction of farmers in rural Bangladesh was assessed by propensity score matching. This pursued the positive impact on poverty and income increment (79). The impact on farmers income by agro-industrial development was carried out by PSM. The impact assessment resulted in the increase in the outcome and household income of the farmer practising contract farming (80). The impact on household income by contract farming was measured using Instrumental Variable analysis. The assessment indicated that with the 1% increment of possibility in adopting contract farming there occurs 0.5 increment in the household income of the farmer (81).

Public welfare: DID was made use to analyse the effect of personal income tax levied by China on consumption of residents' (82). To assess the effect of taxes on distribution of income methodologies such as double difference and propensity score matching was taken into consideration. Here the propensity scores are considered as the possibility of an individual selected for the treatment. The study was conducted by focussing on factors such as income, access to education and employment (83). The approach of PSM was used for impact assessment study of agricultural adaptations on the economic performance of farmers. The assessment came out with the identification of greater yield and productivity among the adaptor-farmers (84). The approach of propensity score matching was adopted to measure the impact of soil and water conservation practices on food security. The study showed that the method of adopting soil and water conservation practices increased food production frequency compared to the control group (85). The food security because of irrigation of smallholders is measured by employing propensity score matching. It was found that the irrigation caused a positive impact on the productivity of crop (86). The investigation of the impact of inflation by propensity score matching showed a positive result in countries involved in oil exports (87).

Health economics: The impact of health reforms in the reduction of childhood infections was assessed by propensity scoring and DID analysis. The results indicated positive impacts (88). The major and reliable technique to evaluate the public health intervention was synthetic control method. The article suggested the use of the synthetic control method where the randomization is impossible (89). The effect of air quality on human health in Canada was studied by using regression discontinuity design (90). To assess the effect of health reforms on managing childhood infections in Ghana was evaluated using propensity score matching and difference in difference methodology. The entire analysis was performed using STATA (88). Randomized controlled trial was taken as a methodology in assessing the impact of user charges on health outcomes in the countries of low and middle income. It was found that reduced charges improved the access for healthcare (91).

Environmental economics: To evaluate the impact of major events on carbon emissions in the hosting provinces in Beijing DID and propensity score matching was employed. It was concluded that there occurs more pollution in the presence of an event and decline in the pollution level after the completion of an event (92). To assess the impact of interprovincial events on carbon emissions, the DID approach was used. For the purpose of eliminating the differences of characteristics among selected cities for the assessment on carbon emissions propensity score matching was employed

(92). The assessment of impact created by highspeed railway on pollution was measured by adopting the methodologies like DID and propensity score matching (93).

Finance: The impact of microfinance programs was studied using DID. This paves the way to control non randomization that arises due to variables that change over time. The suggested alternative was the usage of instrumental variable analysis and randomized controlled trial (94). The upliftment in the women empowerment by MGNREGA was studied by difference in difference approach and found that the policy improved the living standards of women (95).

Marketing: The impact assessment of agricultural development in strengthening technical skills and fostering the market linkages was done by DID methodology. The performance with the adoption was found better and beneficial (96). The assessment of impact of market building interventions in capital market was measured using the regression discontinuity design, the randomized controlled trial, the instrumental variable analysis, the DID and the PSM. These methods also assisted in measuring the spillover effects in the presence of macro-economic data (97).

Farm management: To assess the impact of integrated aqua-agriculture on farm income, PSM was used. It was estimated that the adopting farmers attained higher productivity than the non-adopters (98). Conducting impact assessments requires donors to exert more effort and have adequate knowledge of resource use (99).

Discussion and Analysis

The analysis of the case studies taken for the review of impact assessment is tabulated below in Table 3. The table provide a summarized outlook on application of various impact assessment methodologies across different sectors. It is made clear that there is more prevalent use of DID and PSM in impact assessment according to the total count of 13 each. This is followed by instrumental variable analysis and randomized controlled trials, each with the frequency of six. By the usage of suitable techniques, the precision and the

Table 3. The analysis of the case studies taken for the review of impact assessment methodologies

Objectives	Case studies					
	DID	PSM	IV	RCT	RDD	SCM
Social welfare						
Employment ↑		✓	✓			
Poverty ↓	✓	✓		✓		✓
Household income ↑		✓	✓			
Public welfare						
Tax		✓				
Economic performance	✓					✓
Food security		✓		✓		
Inflation		✓				
Health Economics						
Healthcare access ↑	✓			✓		✓
Public health	✓	✓				✓
Environmental Economics						
Carbon emission ↓	✓	✓	✓			
Pollution control	✓	✓			✓	
Finance						
Microfinance	✓		✓			
Empowerment	✓	✓		✓		
Marketing						
Market linkages	✓				✓	
Technical skills	✓					✓
Capital market	✓	✓	✓	✓	✓	
Farm Management						
Productivity ↑	✓	✓				
Farm income ↑	✓					
Resource use efficiency ↑		✓	✓	✓	✓	
Total	13	13	6	6	4	5

Increment is denoted using ↑

Decline is denoted using ↓

Objectives taken into account is denoted by ✓

efficiency of the programmes can be improved in various fields. This helps to put forth the suggestions on policies that supports development in the areas of social, economic and environmental domains.

Conclusion

In summary the method of selection and the employment of these techniques are necessary to provide a thoughtful insight into various domains. This detailed analysis of impact assessment methodologies provides a comprehensive glance into their origin, application and domain specific implementation. The review we conducted depicts the way impact assessment techniques have advanced and become more complex. This study highlights how the sophisticated methods like DID, propensity score matching, instrumental variable analysis, randomized controlled trial, regression discontinuity design and synthetic control method have evolved over time. These advanced techniques have drastically improved the accuracy of the evaluation. The impact assessment in future will be beneficial in directing the decision-making procedure and improving the outcomes among various domains. It will mark widespread usage in various disciplinary research such as environmental science, public health, etc. Artificial intelligence and machine learning can enhance precision and uncover patterns that conventional techniques overlook.

Authors' contributions

YF drafted the manuscript. NK oversaw the review and editing of the manuscript. SS, CV and GV provided advisory insights for the framework. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The Authors do not have any conflicts of interest to declare.

Ethical issues: None

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