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Web page: www.itegam-jetia.org
Email: editor@itegam-jetia.org
Galileo Institute of Technology and Education of the Amazon (ITEGAM).

Joaquim Nabuco Avenue, No. 1950. Center. Manaus, Amazonas. Brazil.
Zip Code: 69020-031. Phone: (92) 3584-6145.

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RESEARCH ARTICLE OPEN ACCESS

ASSESSMENT OF THE MAJOR CONTRACTORS' SELECTION CRITERIA AND THEIR IMPACTS IN CIVIL ENGINEERING CONSTRUCTION PROJECTS

Reuben A. Okereke[1], Dennis Isaac Pepple*[2] and Nneka Mercyjane Ihekweme[3]

[1] Department of Quantity Surveying, Imo State University, Owerri, Nigeria.
[2] Department of Surveying and Geo-Informatics, Federal Polytechnic of Oil and Gas Bonny Island, River State, Nigeria.
[3] Quantity Surveying Department, Federal University of Technology, Owerri, Imo State, Nigeria.

[1] http://orcid.org/0000-0003-1337-8179, [2] http://orcid.org/0000-0003-0071-4807, [3] http://orcid.org/0000-0002-1549-6307

Email: raphica2013@gmail.com, *dennispepple2@gmail.com, nnekamercyjane@gmail.com

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ABSTRACT

Construction projects in especially developing countries are characterised by failure to meet project baselines (time, cost, quality). This is worsened by the inefficiencies in the application of contractors' selection criteria during the bidding processes of both civil and building construction projects. The application of contactor section criteria and their benefits in civil engineering projects is an area that is underexplored in construction management literature in the Nigerian context. This study aims to assess the major criteria influencing the selection of contractors on civil engineering construction projects and to determine the impacts of the contractor selection criteria. A well-structured quantitative research questionnaire was purposively administered to experienced construction experts in both clients and consultants organisations to gather data. The gathered data were analysed using frequency, percentage, relative Importance index (RII), Severity index (RI) and Mann-Whitney Test. It was found that the major criteria that are considered during contractors' selection in civil engineering construction projects are; managerial capability and competent supervisory staff, technical ability, financial soundness, competitive tender/bid price, and health and safety policy/performance. Also, the major benefits of contractors selection criteria in civil engineering construction projects are; enable the client or project owner to select contractors who are performers for the project, facilitate the achievement of project success and the objectives within the scheduled time and cost, to minimise project risks, maximize overall value to the project owner or client, and selection of contractor with sound financial management capabilities. The study recommended that clients and consultants should adopt the major criteria in the selection of suitable contractors for civil engineering construction projects.

I. INTRODUCTION

The construction industry globally is critical to the economic growth and development of a nation. According to [1], "the construction sector is the economic prime mover and the bedrock of survival of nations". The provision of buildings, roads, bridges, among other structures, job creation, contribution to gross domestic product (GDP) and national income; are all evidence of the contributions to economic growth and development of the economics of the world [2, 3]. Despite the economic contribution and being an agent that drives economic development [4], construction projects executed in the sector is known to be characterised by not meeting project baselines targets. Poor time, cost, quality and safety performance have been the order of the day [5]. These situations have been blamed on poor contractors' selection systems driven by inefficient section criteria implementation during the bidding process of construction projects [6, 7], especially in developing construction markets of the world. In addition, the poor performance of construction contractors has also been linked to qualification and resources related problems [8, 9].

Contractor evaluation and selection is a vital process in construction projects (whether public or privately owned), it is aimed at choosing an experienced and suitable contractor that can deliver the project in line with the clients' requirement and project objectives [10, 6]. Contractor selection is a major decision process that impacts the success and progress of construction projects. This implies that if a contractor is improperly selected, the consequences will be poor quality, schedule overrun and cost performances of the project [6, 11, 12]. The selection of the best bidder is a difficult task whose success relies oftentimes on the appropriateness of tender requirements, the knowledge and experiences of the client and project managers [13, 14]. The essential set of indicators that influence the decision of the client towards the selection of a capable contractor for a project is known as 'contractor selection criteria' [15, 11]. Contractor Selection Criteria is an amalgam of prequalification and tender evaluation criteria that is related to time, cost and quality performance [16, 17]. Project clients' and consultants' decisions are shaped by factors such as contractors' track record, previous experiences in a similar job, clients' knowledge and experience of the contractors, finical capability, and the reputation of the contractors, among others. These factors influence contractor selection for the job at hand and future patronage [18].

These section criteria help to reduce to the barest minimum the risks associated with project delivery, ensure value maximisation for the client and build a long-term relationship between project members [19]. Accidents are reduced on construction sites where the selection criteria are effectively followed [20]. The tradition of using the lowest bid criterion has not yielded the best results in project performance; multiple criteria have been advocated for effective contractor section [6]. Focusing on bid price alone in the selection of contractors has been the main cause of the problems in the delivery of projects [21]. [22] reported that in the UK, the tradition of the lowest tenderer section is still in practice. Research has shown that the lowest tenderer is most likely to put the project in a situation where the planned duration and cost are overshot, and Quality might be compromised.

In Nigeria, [17] reported that the contractors' selection criteria impact significantly the project time and quality performance. This is because of the lowest cost mentality that has been found to cause problems that affect the project baselines and contractors' profit and revenue. Studies regarding contractors' pre-qualification and section are enormous, especially at the international scene [e.g. 18, 23, 19, 24, 11], while it is scanty in the Nigerian context. Furthermore, the benefits of contractors' selection criteria on the project clients and construction performance have not been given detailed attention by researchers in the Nigerian context. Again, the few existing studies on contractors' selection and prequalification [e.g. 19, 25, 26, 27] focused on building construction projects. Contractors' section criteria and their benefits on the project clients and civil engineering projects have been underexplored in the Nigerian context. Furthermore, such studies are grossly lacking in the study area of this present study. It is based on this knowledge that this study assessed the major criteria influencing the selection of contractors on civil engineering construction projects, with a few to determine the benefits of contractors' selection criteria. The working objectives of this study are; i) To assess the major criteria influencing contractors selection in civil engineering construction projects, and ii) to determine the benefits of contractors selection criteria.

It is the understanding of this study that clients and project managers within the study area will be better informed on the key and most critical factors that need to be considered before contractor selection. Knowing the importance of investment is a major driver of an innovative approach, effective implementation of the outcome of this study could help improve project performance and contractor's profitability as uncertainties regarding performances are minimised or even eliminated early in the project life cycle. It will also add to the existing body of knowledge in the subject matter.

II. LITERATURE REVIEW

II.1 CONTRACTORS' SELECTION CRITERIA ON CIVIL ENGINEERING CONSTRUCTION PROJECTS

Contractors' selection is dependent on certain criteria that are used as a basis for assessing, evaluating a bid and the suitability of the contractor. Studies abound that have identified a series of factors and criteria for appropriate contractor's assessment and selection on construction projects [28]. The use of the lowest bid price is common but is counter-productive in the industry. [29] emphasized value for money in contractors' selection and the practice of the automatic selection of the lowest bidder instead of the most optimum (responsive) tender should be avoided. Selecting the lowest bidder by clients often leads to awards of construction contracts to incompetent, unqualified, inexperienced and inadequately financed contractors [30]. In a similar vein, an inappropriate selection of contractors could lead to severe extra costs that result from rework which evolves from poor quality work, claims, disputes, abandonment, bankruptcy, among others [31]. [32] states that researchers do agree that the major selection criteria for contractor are; past experienced and capability and performance of employees, financial reliability and soundness, safety, firm's reputation, quality, capability of equipment,, technology, local information available, current workload and backlog, contractors accessibility, time and cost performance in previous projects, and among others.

According to [23] in Egypt after a survey of 29 construction experts, found that the top twelve significant factors that influence sub-contractors selection in construction projects are; flexibility and cooperation when resolving delays, reputation, delay, failure to comply with the quality specifications, quality, suppliers incompetency to deliver materials on time, failure to complete the contract, physical resources, tender price, contractor's difficulty in reimbursement, flexibility in critical activities and safety consciousness on the job site. Similarly, in Egypt, [33] state that the main criteria for the pre-qualification and bid evaluation of contractor's submissions are; financial soundness, technical ability, management capability, health and safety, and reputation.

According to [18] in the Jordanian construction industry sampled clients on the factors that could increase a contractor's chances of being pre-qualified and reported that the top ten factors are contractor's; willingness to offer a reasonable and competitive price to do the job after being qualified, strength and financial arrangements, previous track record and experience in similar projects, ability to provide a high-quality recommendation from satisfied clients, competence and knowledge to do the job, managerial capability and supervisory staff competence for the project, ability to select competent sub-contractors from a list provided by the client, ability to provide a detailed programme to execute the project, effectiveness and attitude to work with the client as a team, and size in relation to project size. A specialised pre-qualification requirement is suggested to be good manufacturing practices that are required in the Jordanian construction industry. Five critical factors were established to influence the selection of contractors in Ghana according to the report of [34]. These factors are managerial capabilities, quality standards, resource availability, duration, project cost and project location. These factors should be prioritised when selecting the 'best' contractors for a construction project for clients to achieve social and economic value for money. The familiar considerations in the Ghanian construction sector is the criteria of selecting contractors based on the evaluations of their management and technical ability, experience, past performance, health and safety, and environmental measures [11].

In the Pakistani construction industry, [7] reported that the most vital influencing factors for the selection of contractors as perceived by the clients and consultants are; proper planning, creditworthiness, transition plans, plant and equipment holding, financial stability, past performance, and quality. It was further stated that there is a high level of possibility for project success if a multi-criteria approach is used to select a contractor. In Turkey, [6] found that the top twelve criteria that influence contractors selection in public construction projects are; termination of construction work, the experience of technical staff, financial strength, financial credibility, lowest bid, safety plan and safety record, construction work quality reference, length of time in the construction sector, similar work experience, number of technical staff, materials and equipment, and work experience document.

Through a systematic review, [35] found that the most important contractors' selections criteria for construction projects are; price, health and safety, past project performance, duration, experience in similar jobs and quality. By virtue of putting these factors into consideration during contractors' selection, critical aspects of the project such as time, cost and quality are observed. The role of management capability, technical ability, past performance records, financial capability, and health and safety performance has been highlighted as critical factors for contractors' selection [36, 37]. Through a comprehensive review of the criteria for the section of contractors and bid evaluation, [24] found that the most important criteria for selecting suitable contractors for construction projects are; management capability, financial capability, Experience, Resources, technical capability, Environment, health and safety, time of completion, and political consideration. In selecting an appropriate and suitable contractor for construction projects, it is a good practice to consider and evaluate the contractor's safety performance records, how workers are compensated, the rate of injuries recorded, periodic safety programme conducted and personnel safety competency level [20].

Six selection criteria were identified by [38], and they are turnover, manpower resources, equipment resources, post-experience, past performance, and affordable relatable projects. The study of [39] recommended that recommended bid price (amount), financial soundness, technical ability, management capability, safety and health records, and reputation should form the basis for selecting suitable contractors on construction projects. An extensive list of criteria was developed by [40] which comprise majorly financial performance, technical performance, safety and health policy, and public work past performance. The common contractors' selection criteria in literature are; management capability, technical ability, financial capacity, and occupational health and safety [41]. Emphasize was however laid on the management capability as it has a major impact on the performance of the contractors in terms of time and cost.

Sixteen contractors' selection criteria have been selected from the literature and summarized in Table 1 below.

Table 1: Major contractors selection criteria on Civil engineering construction projects.

S/nr	Contractors selection criteria	Source(s)
1	Financial soundness	[33, 40, 39, 23, 41, 11, 34, 7, 6, 24]
2	Technical ability	[33, 40, 39, 41, 11, 7, 6, 24]
3	Managerial capability and competent supervisory staff	[33, 18, 39, 11, 34, 6, 24, 41]
4	Health and safety policy/performance	[33, 40, 39, 23, 41,11,6, 20, 24]
5	The reputation of the contractor	[33, 23, 39]
6	Competitive tender/bid price	[18, 23, 34, 6, 39]
7	Quality compliance records	[18, 23, 34, 7, 6]
8	Size in relation to project size	[18]
9	Previous track record and experience in similar projects	[18, 40, 11, 7, 38, 6, 24]
10	Competence and knowledge to do the job	[18, 11, 6]
11	Project duration/time of completion	[18, 34, 24]
12	Resource availability	[34, 23, 24, 38]
13	Project location	[34]
14	Proper planning	[7, 6]
15	Environment measures	[24, 6]
16	Political consideration	[24]

Source: Authors, (2022).

II.2 BENEFITS OF CONTRACTORS SECTION CRITERIA IN PROJECT PERFORMANCE

Literature has highlighted poor project performance as a consequence of wrong contractor's choice during evaluation and section of contractors for a project [12, 42]. The major ideas behind contractors as well as sub-contractors selection process are to minimise project risks, achieve better project quality, maximise value and maintain reliable and strong relationships between the parties to the projects [23, 19]. The selection of an appropriate contractor is an important tool for minimising accidents in the workplace. This is because safety consideration is important in choosing suitable contractors that will be compatible with the safety management systems of the client [20]. Fong and Choi [43] submitted that elements that can be problematic during the project development are eliminated during contractor selection by the clients.

Contractors' selection criteria help to speed up bid evaluation and contract awards. This is true as the number of tenderers is limited only to those with the necessary financial capability and project experiences. Furthermore, unprepared contractors are weeded out, bidders are protected from being given jobs that are above their capability and competencies, and project risks are reduced [44]. Thorough evaluations of the potentials of the contractors are made before employing them for the job. This makes it possible for optimum performance to be attained with regards to time, cost and quality [45]. Selecting a competent contractor will help to guarantee success and the efficient use of scarce financial resources, projects are completed on time and within budget [46, 47].

Serious considerations should be given to other attributes of contractors in addition to the submission of the lowest prices. The use of prequalification criteria was reported to help reduce subjectivity in the selection of contractors by the project owner [48]. Prequalification criteria lead to huge project success [49], thus, helping clients to select the most qualified contractor that will not delay the project, cause failures, abuse and misuse of project funds, and whose actions or inaction will not lead to project abandonment [21]. Contractors' selection is useful in evaluating experiences, determining capable and qualified contractors, eliminating those contractors who do not have the required experience, competent, as well as those with poor financial status [6]. The contractor's prequalifying criteria is important in project planning as they have a huge impact on what the outcome of the project will be [41].

The number of bidders who might default is minimised by the client through selection criteria. This is achieved through the streamlining of the number of eligible bidders involves in the bidding process [50]. According to the findings of [11], the major benefits of the criteria used by clients for selecting contractors in construction projects are; "enabling the client or project owner to select contractors who are performers for the project, saving the project owner a lot of time, minimising the possibility of contractor default, and facilitating the achievement of project success and the objectives within the scheduled time". The overall aim of the contractor selection criteria is to ensure that the employed contractor has the capability and the know-how to deliver the project with the clients' requirements. A suitable selection of a contractor is equivalent to a successful performance [35, 6].

Thirteen selected benefits of contractors' selection criteria on civil engineering construction projects are summarized in Table 2 below.

Table 2: Benefits of contractors section criteria in civil engineering projects.

S/n	Benefits of contractors section criteria	Source(s)
1	To minimise project risks	[21, 43, 44, 23, 19, 6]
2	achieve better project quality	[23, 45, 19]
3	maintain strong relationships between the parties to the projects	[23,19]
4	minimising accidents and better health and safety performance in the workplace	[20]
5	Facilitate the achievement of project success and the objectives within the scheduled time and cos	[46, 44, 47, 45, 11]
6	helps in project planning towards the outcome of the project	[41]
7	Maximize overall value to the project owner or client	[6]
8	Enable the client or project owner to select contractors who are performers for the project	[21, 44, 49, 6, 11, 51, 52]
9	Minimize the possibility of contractor default	[11, 50]
10	help to speed up bid evaluation and contract awards, thus saving the client time	[44, 6]
11	Weeding out unprepared, incompetent and unsuitable contractors	[44, 50, 53, 11]
12	Selection of contractor with sound financial management capabilities	[21, 46, 47, 6]
13	reduced subjectivity in the selection of contractors by the project owner	[48]

Source: Authors, (2022).

III. MATERIALS AND METHODS

This study utilised a survey research questionnaire to meet the purpose of the study. Data on the major criteria influencing contractors section in civil engineering projects, and the benefits of contractors selection criteria, were obtained from construction experts such as (Architect, Builders, Engineers and Quantity Surveyors) engaged by clients and consultants organisations in Owerri, Imo State, Nigeria. These experts were chosen because they are key employees of construction-based organisations in the construction industry of any nation [54]. The questionnaire is widely used and it covers large samples at a shorter time [55]. The government as well as private investors and clients are embarking on numerous construction and developmental projects within the study area.

The construction experts sampled are those with an appreciable level of experience in construction contracts procurements, especially civil engineering construction projects such as road projects. Owing to the quality of responses expected and respondents' availability, purposive sampling techniques was adopted in the administration of the questionnaire to the experts. The researcher administered the research instrument using both manual and electronic means. The idea was to improve the response rate and ensure an eco-friendly sustainable survey. [54] posit that the electronic means of the survey is an environmentally friendly means of a survey, as the number of hardcopy paper questionnaires is minimised or even eliminated. The questionnaire used was developed from variables obtained from the literature review and was designed into three divisions. This first division gathered data on the respondents' demographic information. Information gathered on the first part was used to do a quality check on the other parts. The second division gathered data on the major criteria influencing contractors section in civil engineering projects, and the third division gathered data on the benefits of contractors' selection criteria. A 5-point Likert scale served as the basis for the questions in the research instrument. A scale of 1 mean 1 is the lowest rank while a scale of 5 is the highest rank.

The sampling period lasted for about 3 months, during which usable responses of 132 were collected and used for the analyse that followed. Descriptive analytical tools such as Frequency, percentage and relative Importance index (RII), Severity index (RI), Mann-Whitney U-Test were used to analyse the gathered data. Frequency and percentage were used to analyse data gathered on the respondents' demographic information.

Relative Importance Index (RII) and Severity index (RI) were used to analyse data collected on the major criteria influencing contractors section in civil engineering projects, and the Relative Importance Index (RII) was used to analyse data on the benefits of contractors' selection criteria. Mann-Whitney U-Test was used to compare the views of the participants regarding the ranking pattern of the assessed variables. The Cronbach's alpha test was used to verify the reliability of the research instrument. A Cronbach's alpha values of 0.884 and 0.825 were obtained (see Table 3), these values are above the 0.70 cut-off points proposed by [56]. It is premised on this that the data were adjudged reliable and of good quality. The entire research methodological flow as been summarised in figure 1 below.

Table 3: Reliability Statistics.

Variables	Cronbach's Alpha	N of Items
Contractors' selection criteria on Civil engineering construction projects	0.884	16
Benefits of contractors section criteria	0.825	13

Source: Authors' Analysis, (2022).

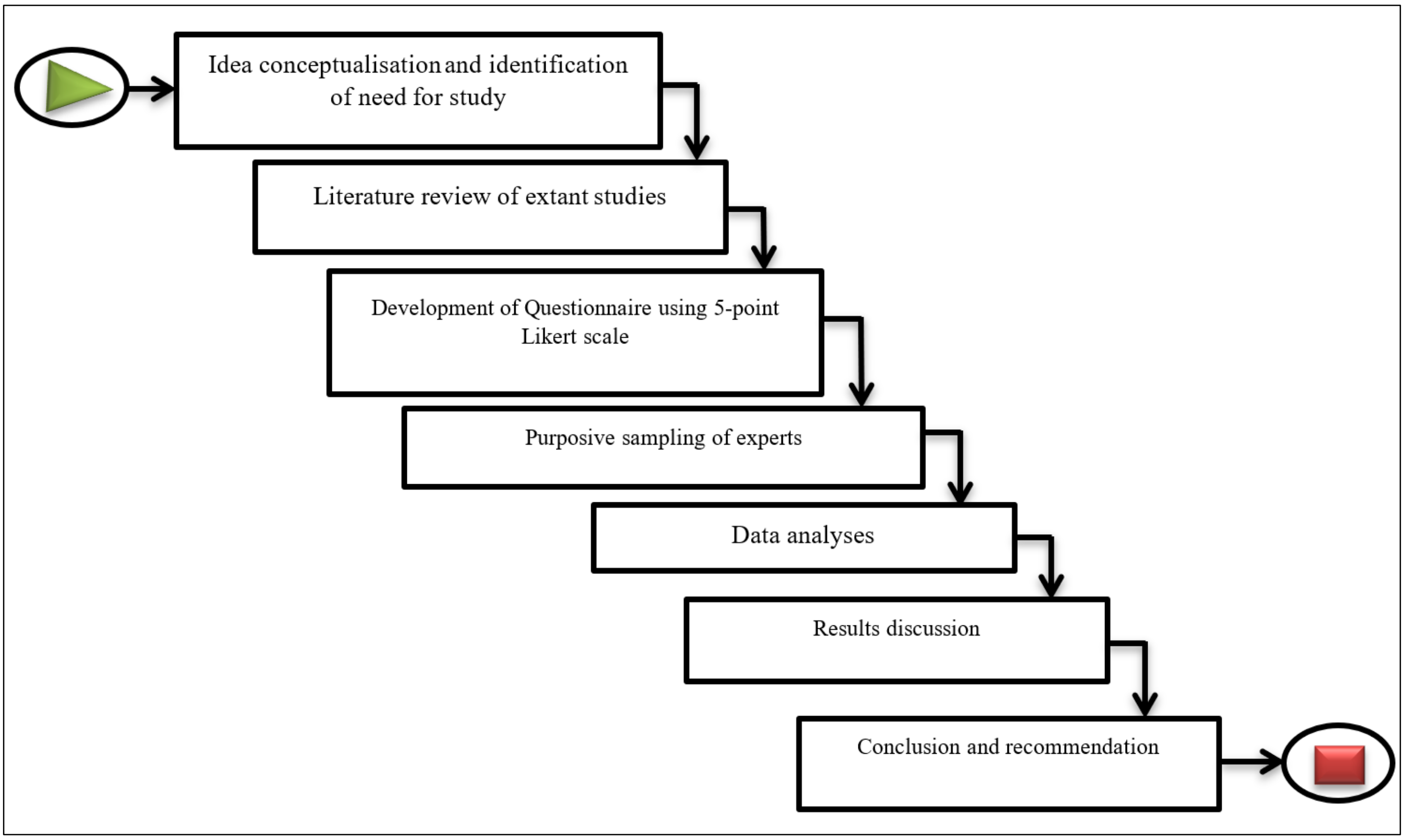

Figure 1: Study methodological flow chart.
Source: Authors, (2022).

IV. RESULTS AND DISCUSSIONS

IV.1 RESPONDENTS' BACKGROUND CHARACTERISTICS

Table 4 shows that 38.64% of the respondents are from client organisations and 61.36% are from consultants organisations. In terms of the respondents' profession, 17.42% are Architects, Builders are 9.09%, Engineers are 44.70%, and Quantity Surveyors are 28.79%. With regards to the respondents' years of experience; the average years of experience is 11.63%. However going by the grouping, 9.09% have between 1-5years of experience, 32.58% have between 6-10years of experience, 38.64% have spent between 11-15years, 13.64% have spent between 16-20years, and 6.06% have over 21 years of industry experience. This shows adequate experiences in the industry and the subject of this study. The educational qualification of the respondents shows that those with BSc/B.Tech is more with 44.70%, followed by M.Sc/M.Tech (30.30%), then HND and PGD with 10.61% each, and last PhD holders are 3.79%. This indicates that they are educated enough to understand the content of the questionnaire towards meeting the study objectives. The respondents who are majorly built environment professionals are majorly chartered members of their different professional bodies. This show they have the requisite professional qualification that would aid this study.

Table 4: Respondents' demographic information.

Variables	Classification	Freq.	Per cent	Cum. %
Organisational Type	Client organisation	51	38.64	38.64
	Consultants organisation	81	61.36	100.00
	TOTAL	**132**	**100.00**	
Profession	Architects	23	17.42	17.42
	Builders	12	9.09	26.52
	Engineers	59	44.70	71.21
	Quantity Surveyors	38	28.79	100.00
	TOTAL	**132**	**100.00**	
Years of experience	1-5years	12	9.09	9.09
	6-10years	43	32.58	41.67
	11-15 years	51	38.64	80.30
	16-20 years	18	13.64	93.94
	21-above	8	6.06	100.00
	TOTAL	**132**	**100.00**	
Education qualification	HND	14	10.61	10.61
	PGD	14	10.61	21.21
	BSc/B.Tech	59	44.70	65.91
	M.Sc/M.Tech	40	30.30	96.21
	PhD	5	3.79	100.00
	TOTAL	**132**	**100.00**	
Professional status	Corporate member	117	88.64	88.64
	Probationer member	15	11.36	100.00
	TOTAL	**132**	**100.00**	

Source: Authors’ Analysis, (2022).

IV.2 CONTRACTORS SELECTION CRITERIA ON CIVIL ENGINEERING CONSTRUCTION PROJECTS

Results in Table 5 shows that the top five major criteria that are considered during contractors selection in Civil engineering construction projects are; managerial capability and competent supervisory staff (RII=0.867; S.I=86.67%; ranked 1st), technical ability (RII=0.861; S.I=86.06%; ranked 2nd), financial soundness (RII=0.853; S.I=85.30%; ranked 3rd), competitive tender/bid price (RI=0.838; S.I=83.79%; ranked 4th), and health and safety policy/performance (RII=0.826; S.I.=82.58%; ranked 5th). While the least ranked contractor section criteria are; resource availability (RII=0.745; S.I=74.55%; ranked 12th), Environment measures (RII=0.744; S.I=74.39%; ranked 13th), political consideration (RII=0.729; S.I=72.88%; ranked 14th), project location (RII=0.702; S.I=70.15%; ranked 14th), and proper planning (RII=0.698; S.I=69.85%; ranked 16th).

Overall, the assessed criteria are all significant in the selection of suitable contractors for civil engineering construction projects. This is premised on the maximum RII (0.867) and S.I (86.67%) values, minimum RII (0.698) and S.I (69.85%) values, with an average value of RII (0.702) and S.I (79.24%). It follows that these criteria are given adequate attention and consideration by way of evaluations of every contractor's bid submission against these criteria to come up with the best contractors that can sufficiently execute the project to completion and within baselines.

Furthermore, the Mann-Whitney U-Test (see Table 5; columns 6 & 7) performed to compare the views of the client and consultant respondents groups on the relative ranking of the assessed variables showed that; the participants' ranking styles are the same 14(87.50%) of the assessed variables. That is, their views converge in 87.5% of the criteria for selection contractors. The significant p-value of these variables is greater than a 5% level of significance. This further means that there is no statistically significant difference in the way the participants ranked these criteria. However, divergent opinion was observed in 2(12.50%) of the variables as the p-value is less than 5% level of significance. This shows that a statistically significant difference exists in the way the participants ranked these criteria. These variables are project location (Z=-2.513; p-value=0.012) and political consideration (Z=-2.447; p-value=0.014). There is thereof the need for a further reflection on this criteria.

However, with a mean rank of 59.24 for the Client organisations group and 71.07 for the Consultants organisations group, the overall Mann-Whitney U-Test showed that there is no significant statistical difference in the ranking of the variables by the two groups of participants. These imply that these variables are given adequate consideration in the section of contractors for civil engineering construction projects.

The major contractors' selection criteria reported in this study is in support of the findings from previous studies such as [40, 39, 41, 24, 6, 34]. The managerial capability of the contractor team is very critical to ensuring that the works will be performed in accordance with the specifications and project requirements. The competence of the supervisor engineers and other senior trades heads are an indication of the management capacity to deliver. The managerial strength and capability of the contractors have been highlighted in construction management literature to be top criteria for the selection of a suitable contractor for construction projects [18, 34, 11]. The technical capability and financial soundness of a contractor is a pointer to experience, maturity and performance ability. The quality of tools and equipment, technical and production team experiences, creditworthiness, ability to manage clients' scarce financial resources; are evident in the technical and financial capability records of the contractors. This is in line with the reports of [33, 36-37,6-7].

Bid price is another vital selection criterion for contractors in civil engineering projects. While the practice of basing contract awards or contractor selection of bid price along, particularly the lowest bid price, is still on in some construction markets of nations. The practice has not yielded the needed result in terms of guaranteeing that such a contractor can perform. Bid price or tender price was highlighted as one of the factors influencing contractors section [39, 23, 35]. A Contractor with sound health and safety policies, a good compensation system, a better motivation system for workers, good records on health and safety; is a careful and experienced candidate that value risk management. High accident rates show inexperienced supervisory teams and a lack of health and safety policies and regulations. The consequences of the high accidents rates are; stoppage of work, high expenses, death, schedule slippage, quality issues, among others. Health and safety performance records were highlighted by [20, 36-37] as being a critical selection criterion for contractors.

Table 5:Major contractors selection criteria on Civil engineering construction projects.

S/N	contractors selection criteria	RII	S.I	Rank	Z	Sig.
1	financial soundness	0.853	85.30	3rd	-0.961	0.322
2	technical ability	0.861	86.06	2nd	-0.413	0.679
3	managerial capability and competent supervisory staff	0.867	86.67	1st	-1.032	0.302
4	competitive tender/bid price	0.838	83.79	4th	-0.308	0.758
5	health and safety policy/performance	0.826	82.58	5th	-0.993	0.321
6	the reputation of the contractor	0.823	82.27	6th	-0.905	0.365
7	Quality compliance records	0.823	82.27	6th	-0.311	0.716
8	size in relation to project size	0.794	79.39	10th	-0.308	0.758
9	previous track record and past experience in similar projects	0.818	81.82	8th	-0.173	0.852
10	competence and knowledge to do the job	0.794	79.39	10th	-0.888	0.375
11	Project duration/time of completion	0.814	81.36	9th	-0.838	0.402
12	resource availability	0.745	74.55	12th	-0.464	0.589
13	project location	0.702	70.15	15th	-2.513	0.012*
14	proper planning	0.698	69.85	16th	-1.022	0.305
15	Environment measures	0.744	74.39	13th	-0.833	0.403
16	political consideration	0.729	72.88	14th	-2.447	0.014*

Source: Authors, (2022).

Table 6: Mann-Whitney U test for Contractors selection criteria.

Variables	Respondents Groups	N	Mean Rank	Sum of Ranks	Z	Sig.
Contractors selection criteria	Client organisations	51	59.24	3021.00	-1.733	0.083
	Consultants organisations	81	71.07	5757.00		
	Total	**132**				

Source: Authors' Anaysis, (2022).

IV.3 BENEFITS OF CONTRACTORS SECTION CRITERIA

Results in Table 7 shows that the top five benefits of contractors selection criteria in Civil engineering construction projects are; enable the client or project owner to select contractors who are performers for the project (RII=0.9106; ranked 1st), facilitate the achievement of project success and the objectives within the scheduled time and cost (RII=0.897; ranked 2nd), to minimise project risks (RII=0.865; ranked 3rd), maximize overall value to the project owner or client (RII=0.861; ranked 4th), and selection of contractor with sound financial management capabilities (RII=0.844; ranked 5th). While the least benefits of contractors section criteria in Civil engineering construction projects are achieving better project quality (RII=0.820), maintaining strong relationships between the parties to the projects (RII=0.794), help to speed up bid evaluation and contract awards, thus saving client time (RII=0.783), minimising accidents and better health and safety performance in the workplace (RII=0.782), and helps in project planning towards the final outcome of the project (RII=0.768).

Notwithstanding the relative ranking of these variables, they are all the benefits of contractors' section criteria in Civil engineering construction projects. This is based on the maximum RII of 0.911(91.1%), minimum RII of 0.768 (76.8%) and an average RII value of 0.832 (83.2). It follows that criteria for contractors section in civil engineering projects are very vital for achieving the needed clients and project requirements. These assessed contractor section criteria are therefore justified in civil engineering construction projects as the benefits are numerous and impact positively on the project and the clients.

A 100% convergence was observed in the ranking of these Benefits of contractors' selection criteria by the two groups of participants. All the assessed variables have a p-value of more than 0.05. Therefore, there is no significant statistical difference in the ranking of the variables by the various professions in the client and consultant organisations. This is based on the result of the Mann-Whitney U-Test (see Table 7; columns 5 & 6).

In addition, with a mean rank of 57.75 for the Client organisations group and 72.01 for the Consultants organisations group, the overall Mann-Whitney U-Test supports what was reported in Table 7. There is no significant statistical difference in the ranking of the variables by the two groups of participants (see Table 8). This implies that the participants are in agreement that the application of contractor selection criteria would yield numerous benefits to the clients and the projects.

The findings in this section regarding the benefits of contractors selection criteria in civil engineering construction projects, support what has been reported in previous related studies [23, 19, 11, 6, 44-47]. Selecting the most suitable contractor that will deliver a construction project within cost, time, quality and other project constraints is the major benefit of the selection criteria for contractors. By this, clients can achieve maximum value for their monies are risks are minimised or even eliminated via the contractor's selection. Problems at the construction stage will be minimised and work will progress smoothly.

Table 7: Benefits of contractors section criteria in civil engineering projects.

S/N	Benefits of contractors section criteria	RII	Rank	Z	Sig.
1	To minimise project risks	0.865	3rd	-1.738	0.082
2	Achieve better project quality	0.820	9th	-1.144	0.253
3	Maintain strong relationships between the parties to the projects	0.794	10th	-0.928	0.354
4	Minimising accidents and better health and safety performance in the workplace	0.782	12th	-0.237	0.814
5	Facilitate the achievement of project success and the objectives within the scheduled time and cost	0.897	2nd	-1.844	0.064
6	Helps in project planning towards the final outcome of the project	0.768	13th	-0.015	0.988
7	Maximize overall value to the project owner or client	0.861	4th	-0.971	0.332
8	Enable the client or project owner to select contractors who are performers for the project	0.911	1st	-0.177	0.858
9	Minimize the possibility of contractor default	0.821	8th	-0.878	0.383
10	Help to speed up bid evaluation and contract awards, thus saving the client time	0.783	11th	-0.326	0.744
11	Weeding out unprepared, incompetent and unsuitable contractors	0.838	6th	-1.308	0.232
12	Selection of contractor with sound financial management capabilities	0.844	5th	-0.701	0.483
13	Reduced subjectivity in the selection of contractors by the project owner	0.833	7th	-0.353	0.726

Source: Authors' Anaysis, (2022).

Table 8: Mann-Whitney U test for benefits of contractors section criteria.

Variables	Respondents Groups	N	Mean Rank	Sum of Ranks	Z	Sig.
Benefits of contractors section criteria	Client organisations	51	57.75	2945.50	-1.494	0.158
	Consultants organisations	81	72.01	5832.50		
	Total	**132**				

Source: Authors' Anaysis, (2022).

V. CONCLUSIONS

This study used a quantitative research questionnaire to assess the major criteria influencing the selection of contractors on civil engineering construction projects and to determine the benefits of the contractor selection criteria. Experienced construction experts engaged in clients and consultants organisations were sampled using the purposive sampling technique in the study are. The data gathered were analysed using named analytical tools and findings made and conclusion drawn.

The study found that the top five major criteria that are considered during contractors' selection in civil engineering construction projects are; managerial capability and competent supervisory staff, technical ability, financial soundness, competitive tender/bid price, and health and safety policy/performance. It was also found that the top benefits of contractors selection criteria in civil engineering construction projects are; enable the client or project owner to select contractors who are performers for the project, facilitate the achievement of project success and the objectives within the scheduled time and cost, to minimise project risks, maximize overall value to the project owner or client, and selection of contractor with sound financial management capabilities. There was no significant statistical difference were observed in the views of the participants' groups regarding the contractor selection criteria in civil engineering construction projects and the benefits of the contractor selection criteria to the clients and the projects.

It is recommended that the critical contactors selection criteria reported in this study should be adopted in the selection of suitable contractors for civil engineering construction projects. In addition, the selection criteria are very beneficial to achieving better project performance and success as well as the clients. The major aim of contractor selection criteria which is to meet project baselines is evident in the benefits found in this present study.

The various construction experts that are charged with the responsibility of selecting suitable contractors in their organisations will benefit from the outcome of this study in making informed decisions and guiding project owners to employ the best contractors for civil engineering projects. Awareness of the benefits of a technique, process or idea triggers interest in the adoption and application of such process, idea or techniques. This study will make it possible for clients/consultants organisations to use and base their choices of contractor selection/contract awards on the reported criteria. The study also adds to the few existing studies of contactors section criteria and benefits of the criteria on civil engineering projects in Nigeria and other developing counties of Africa and beyond. This study is limited by the number of variables (criteria and benefits) assessed, sample size, study area, sampling technique, and data analysis methods. Therefore, generalisation of the study outcome should be made with caution. Based on these, a similar study should be carried out in other states in Nigeria or other African countries with similar construction market conditions as Nigeria. This could lead to more variables identification and results for comparison purposes will be available. An empirical study to ascertain the drawback in the application of contractor selection criteria in the delivery of construction projects can be embarked upon.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Dr. Reuben A. OKEREKE**,** Dennis Isaac PEPPLE.

Methodology: Dr. Reuben A. OKEREKE**,** Dennis Isaac PEPPLE**,** Nneka Mercyjane IHEKWEME.

Investigation: Dr. Reuben A. OKEREKE**,** Dennis Isaac PEPPLE**,** Nneka Mercyjane IHEKWEME.
Discussion of results: Dr. Reuben A. OKEREKE**,** Dennis Isaac PEPPLE**,** Nneka Mercyjane IHEKWEME.
Writing – Original Draft: Dr. Reuben A. OKEREKE**,** Dennis Isaac PEPPLE**,** Nneka Mercyjane IHEKWEME.
Writing – Review and Editing: Dr. Reuben A. OKEREKE**,** Dennis Isaac PEPPLE**,** Nneka Mercyjane IHEKWEME.
Resources: Dr. Reuben A. OKEREKE**,** Dennis Isaac PEPPLE**,** Nneka Mercyjane IHEKWEME.
Supervision: Dr. Reuben A. OKEREKE**,** Dennis Isaac PEPPLE**,** Nneka Mercyjane IHEKWEME.
Approval of the final text Dr. Reuben A. OKEREKE**,** Dennis Isaac PEPPLE**,** Nneka Mercyjane IHEKWEME.

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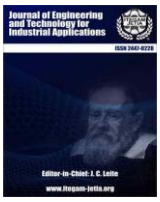

RESEARCH ARTICLE OPEN ACCESS

COST OF RAISING SOIL ORGANIC CARBON FOR A QUARTER-CENTURY IN A SEMI-ARID TURKISH PLAIN: HARRAN PLAIN

Erhan Akça[1], Mehmet Ali Çullu[2], Mustafa Hakkı Aydoğdu[3], Günay Erpul[4], Gönül Aydın[5], Pınar Pamukçu Albers[6], Fatih Tufaner[7], Ahmet Çelik[8], Kamil Varınca[9], Uğur Zeydanlı[10], Melike Kuş[11], Mustafa Talha Gönüllü[12], Mehmet Reşit Sevinç*[13], Hatice Parlakçı Doğan[14] and Nihat Küçük[15]

[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 ,13, 14, 15] Department of Bozova Vocational School, Harran University. Sanlıurfa, Turkey.

[1] http://orcid.org/0000-0001-8988-4196, [2] http://orcid.org/0000-0002-9641-3867, [3] http://orcid.org/0000-0002-4945-5239
[4] http://orcid.org/0000-0002-3797-6969, [5] http://orcid.org/0000-0002-4492-1982, [6] http://orcid.org/0000-0003-1935-1815
[7] http://orcid.org/0000-0002-1286-7846, [8] http://orcid.org/0000-0001-8958-4978, [9] http://orcid.org/0000-0002-7932-2146
[10] http://orcid.org/0000-0001-7599-3615, [11] http://orcid.org/0000-0002-7336-365X, [12] http://orcid.org/0000-0001-7951-8125
[13] http://orcid.org/0000-0002-0617-7822, [14] http://orcid.org/0000-0002-2186-3505, [15] http://orcid.org/0000-0002-1483-0422

Email: erakca@gmail.com, macullu@harran.edu.tr, mhaydogdu@hotmail.com, gunayerpul@gmail.com, gonaydin@gmail.com, pinarpamukcu@hotmail.com, ftufaner@adiyaman.edu.tr, ahmetcelik@adiyaman.edu.tr, kvarinca@gmail.com, ugur.zeydanli@dkm.org.tr, melike.kus@dkm.org.tr, talha.gonullu@gmail.com, *rsevinc@harran.edu.tr, hparlakcidogan@yahoo.com, nihatk@harran.edu.tr.

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Turkey.

ABSTRACT

For decades, scientists have been studying the role of soil organic carbon (SOC) in the environment. SOC in agricultural lands may rise if conditions such as adequate soil water retention, balanced nutrition, minimal tillage, crop rotation, added organic residues, and fertilizers are met. However, implementing all of these measures takes a long time, large expenditures, and enormous effort, particularly in semi-arid and arid lands where organic matter accumulation is difficult; such depletion can be attributed to oxidizing soil conditions. As a result, the long-term cost of increasing organic carbon is uncharted territory for policymakers and land users. In this context, the Harran Plain of SE Turkey, which borders the arid lands of Northern Syria, provides an opportunity to calculate the cost of a unit increase in organic carbon as a result of a drastic change in cultivation over 30 years of irrigation. We attempted to reveal the price of organic carbon increase in a semi-arid region that is far from sustainable agricultural practices after irrigation in this study. The organic carbon in the plain increased by 14,93 t. C/ha i.e., 0.28% on average which is well-below COP 21 initiative of 0.4% annual increase. When the irrigation network investment expenses, annual fertilizer use, and labor need for agricultural production were calculated for the entire Harran Plain from 1995 to 2018, it was calculated that one-ton C/ha in the Harran Plain costs US$491,19. We can estimate that the total SOC increase over 167.400 ha cost around $1,047,029,777. This revealed that increasing SOC in semi-arid climates is an expensive goal.

I. INTRODUCTION

Climate change, desertification/land degradation, and biodiversity loss in the ecosystem are posing serious risks to the planet, which humanity have never seen at such extreme levels [1], [2]. As of November 2019 (https://www.co2.earth), atmospheric CO_2 levels are above 417 ppm. Land degradation/desertification of the Earth's surface affects about half of the world's population (3.2 billion) [3], and more than one million living species are currently threatened with extinction [4]. Although the total impact of these problems will be felt more acutely in developing and low-income countries, migration from affected regions/countries to developed countries will magnify the problem's global impact. As a result, enhancing SOC is seen as the most important instrument in combating the aforementioned issues. Several successful strategies, including as crop rotation, raising soil moisture content, mulching, and green manuring, have been demonstrated to improve SOC; nevertheless, the precise computation of SOC increase cost as a result of these treatments is not well-defined, as this study attempts to demonstrate. However, financial cost of land degradation, in contrast to soil organic carbon loss, is well-studied, despite the fact that they are strongly linked.

Nkonya et al. (2016) reviewed 12 research on the costs of land degradation and found that values had risen from $17.58 billion in 2007 to $9.4 trillion in 2007. Due to reduced ecosystem functioning, land degradation alone costs $6.3 trillion per year in ecosystem service value [5]. The social cost of an additional ton of carbon resulting from CO2 emissions or its equivalent carbon was assessed by Nordhaus (2017) at $31. Since worldwide CO2 emissions hit 36 billion tons in 2018, this equates to $36 billion [6]. Tol (2018) analyzed 27 studies from various parts of the world and concluded that a 2.5°C increase in global temperature would result in a 1.3 percent drop in global per capita income [7]. According to the Global Soil Partnership (2017), the erosion of the 75 billion tons (Pg) of arable soils around the world costs $400 billion each year. If this volume of loss were spread as a 15-cm thick soil layer, it could cover 34 million ha of land, which is close to Germany's 37 million ha land size. Increasing harvest frequency to compensate for yield losses in degraded soils resulted in higher pesticide use, contributing to pollution [8]. In China, it is estimated that $859 million will be required to clean the country's polluted soils [9]. Turkey is not an outlier in a globe beset by climate change, desertification, and loss of biodiversityr [10]. According to Akça and Çullu (2015), soil sealing is the major hazard to arable soils in all of the country's geographic regions, which is also corroborated by Kapur et al. (2019)'s study, which mentions soil sealing as a statewide land degradation driver [11], [12]. Turkey was rated 15th in the world in terms of CO^2 emissions, with 428 Mt. [6]. Using an analytical hierarchy process model, Türkeş et al. (2019) created a desertification vulnerability and risk assessment for Turkey, estimating that areas under moderate and high desertification risk account for well over 75% of the country's entire territory [13].

The global thresholds for preventing desertification, land degradation, drought, climate change, and biodiversity loss appear to have already been exceeded, and mitigation and adaptation appear to be the only options for securing humanity's future [14], [15]. Researchers proposed several techniques decades ago for mitigating and adapting to climate change, desertification, and land degradation. Researchers proposed several techniques decades ago for mitigating and adapting to climate change, desertification, and land degradation, such as water harvesting, water retention in a soil profile, conservation tillage, nutrient management, green manuring, crop residue management, afforestation, and terracing, when the threats were not extreme as today [16]–[19]. It is not surprising that organic carbon, due to its unique dynamics in soil ecosystems, is the main asset in the success and evaluation of many of these methods [20]. Orr et al. (2017) defined the scientific conceptual framework of the UN's land degradation neutrality (LDN) approach and recognized soil organic carbon (SOC) as one of the main indicators of LDN monitoring. Several SOC maps are produced at the local, regional, national, and global levels to assess the effects of land use, climate, and vegetation on soil carbon [21], [22].

Researchers are attempting to establish a SOC threshold level, such as Hiederer and Köchy (2012), who established 3 percent organic carbon as a baseline for calculating the bulk density of fertile soils. While Lal (2015) suggested increasing the SOC pool to above 10 to 15 g/kg to stimulate soil restoration activities, Johannes et al. (2017) suggest a SOC/clay ratio of 1:10 other than the mass of carbon for obtaining a good structure independent of soil management. Although a 0.4 percent/year increase in SOC was set as a global goal at the Paris COP21 meeting, there is still no fixed target value for SOC because numerous factors such as climate, soil properties, and land use practices control SOC dynamics [21], [23], [24].

Aside from these, the increase/sequestration of soil carbon is calculated as the gains from emissions reduction [8], and studies on the cost of raising/sequestering organic carbon in the soil are relatively few [25] because monitoring soil carbon, particularly in semi-arid regions, requires decades because increasing SOC requires long-term irrigation and nutrient inputs [26].

In this study, we attempted to assess each unit of carbon increase in the 167.400 ha Harran Plain (Şanlurfa, SE Turkey) from 1995 to 2018 by assessing infrastructure and ultrastructure investments, fertilizer, and labor costs, which we believe will improve current knowledge on the economics of land degradation rehabilitation even current land use in the Plain is unsustainable as a result of a yield-oriented production approach that ignores natural resource quality enhancement.

II. MATERIALS AND METHODS

The study relied on two data sources. The first is the organic matter values of 25 soil series defined in a soil survey conducted in 1998 before to the initiation of irrigation. The second set of data includes organic carbon data from 406 soil samples that will represent the entire plain in 2018, comprising resamples of 28 locations of the 1988 soil survey.

II.1 MATERIALS

The Harran Plain, located in SE Anatolia at (38°47′–39°15′ E and 36°40′–37°21′N), is one of Turkey's largest irrigated plains, with an average temperature of 18.8°C and an annual rainfall of about 442 mm. Rainfall is irregular and mostly falls in the winter, with almost no rain falling between June and September (DM, 2011). It has a slope of 530 meters in the north and 358 meters in the south (Figure 1).

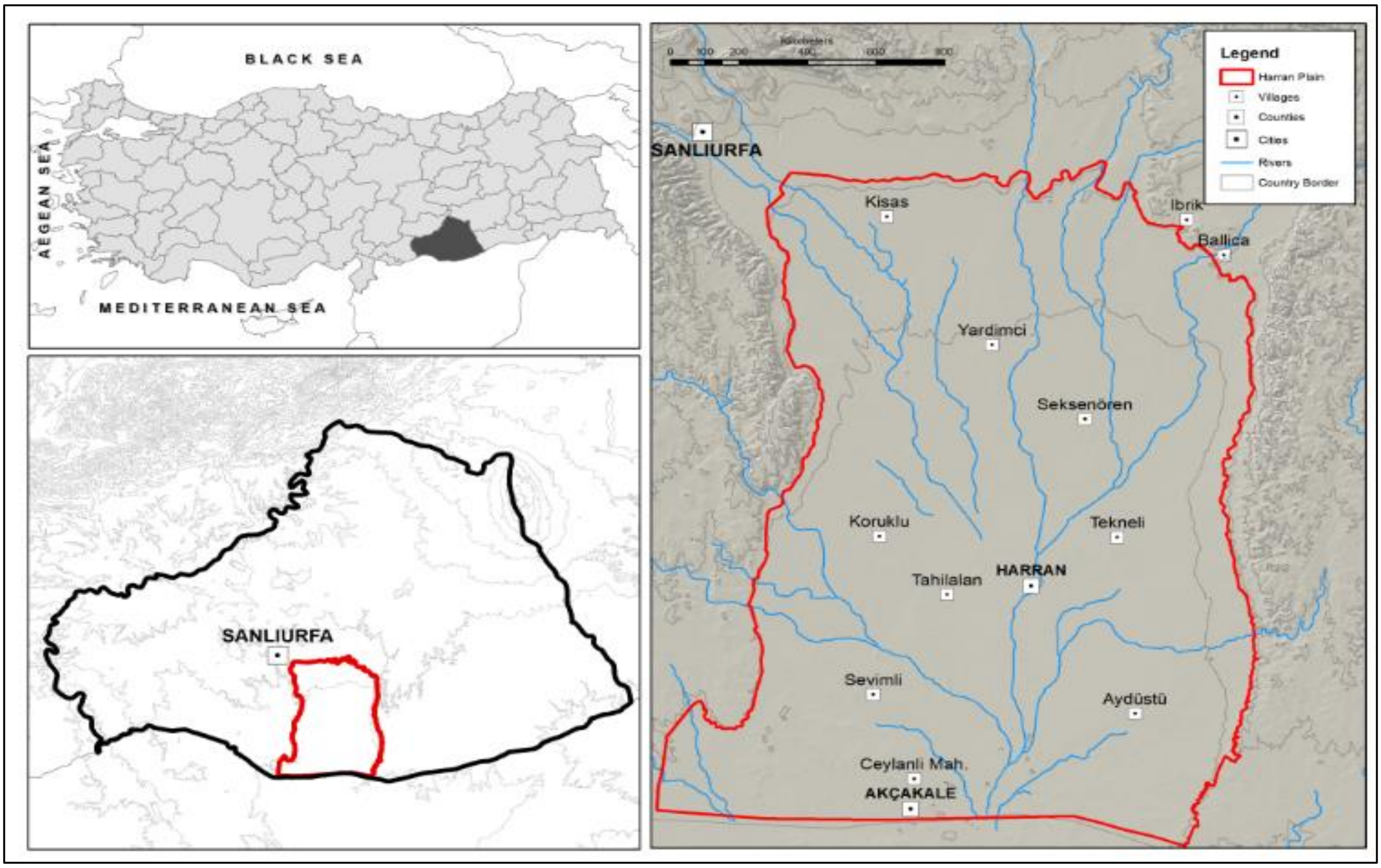

Figure 1: The location of Harran Plain.
Source: Authors, (2022).

The Turkish government initiated a detailed soil survey in 1988 prior to the construction of an irrigation network within the framework of GAP (Turkish acronym for Güneydoğu Anadolu Projesi-Southeastern Anatolia Project), with the goal of irrigating 1.8 million ha of land. The survey followed the 1975 Keys to Soil Taxonomy [27] and Soil Maps of the World [28]. Dinç et al. (1988) defined 25 soil series classified as Aridisols (now Inceptisols of Keys to Soil Taxonomy 12th edition due to revisions in soil moisture regime), Vertisols, and Entisols during the soil survey (Table 1) [29]. In addition to the 25 soil series, three varieties of the Harran, Sırrın, and Cepkenli series were defined, bringing the total number of 1988 soil series to 28. Soils of the plain are mainly clayey with high calcium carbonate (>%5) and pH above 7.5 [29].

Table 1: Soil series classification according to Soil Survey Staff (1975) and FAO-UNESCO (1974).

Soil Series	Soil Survey Staff (1975)	FAO-UNESCO (1974)
Fatik	Lithic Torriorthent	Lithosol
Gülveren	TypicPaleorthid	Calcic Xerosol
İkizce	VerticTorrifluvent	CalcaricFluvisol
Bellitaş	TypicTorrifluvent	CalcaricFluvisol
Kap	TypicPaleorthid	Calcic Xerosol
Akören	TypicCalciorthid	Calcic Xerosol
Gündaş	VerticCalciorthid	Calcic Xerosol
Karabayır	VerticCalciorthid	Calcic Xerosol
Harran I	VerticCalciorthid	Calcic Xerosol
Harran II	VerticCalciorthid	Calcic Xerosol
Sırrın I	VerticCamborthid	HaplicXerosol
Sırrın II	VerticCamborthid	HaplicXerosol
Beğdeş	TypicTorrert	Chromic Vertisol
Uğurlu	PaleoustollicTorrert	Chromic Vertisol
Gürgelen	TypicCalciorthid	Calcic Xerosol
İrice	TypicCalciorthid	Calcic Xerosol
Urfa	TypicTorrifluvent	CalcaricFluvisol
Konuklu	TypicCamborthid	HaplicXerosol
Kısas	TypicTorrert	Chromic Vertisol
Bozyazı	TypicTorrert	Chromic Vertisol
Çekçek	TypicTorrifluvent	CalcaricFluvisol
Sultantepe	VerticCalciorthid	Calcic Xerosol
Akçakale	TypicTorrert	Chromic Vertisol
Meydankapı	TypicCalciorthid	Calcic Xerosol
Ekinyazı	TypicCalciorthid	Calcic Xerosol
Hancığaz	TypicCalciorthid	Calcic Xerosol
Cepkenli I	TypicGtypsiorthid	GypsicXerosol
Cepkenli II	TypicGtypsiorthid	GypsicXerosol

Source: [29].

In 2018, 404 disturbed soil samples representing the entire plain were collected from 20 cm using global positioning system coordinates, 28 of which were resampled from 1988 soil survey points (Figure 2). 50 undisturbed soil samples were collected for bulk density analyses [30] and soil carbon mass analyses. Soil organic carbon (SOC) was calculated as tons per hectare (t.C.ha-1) for each point by calculating volume weights during laboratory analysis. The soil sample point values were integrated into a GIS environment using ArcGIS 10.1 to map the changes in SOC from 1988 to 2018 (Figure 2).

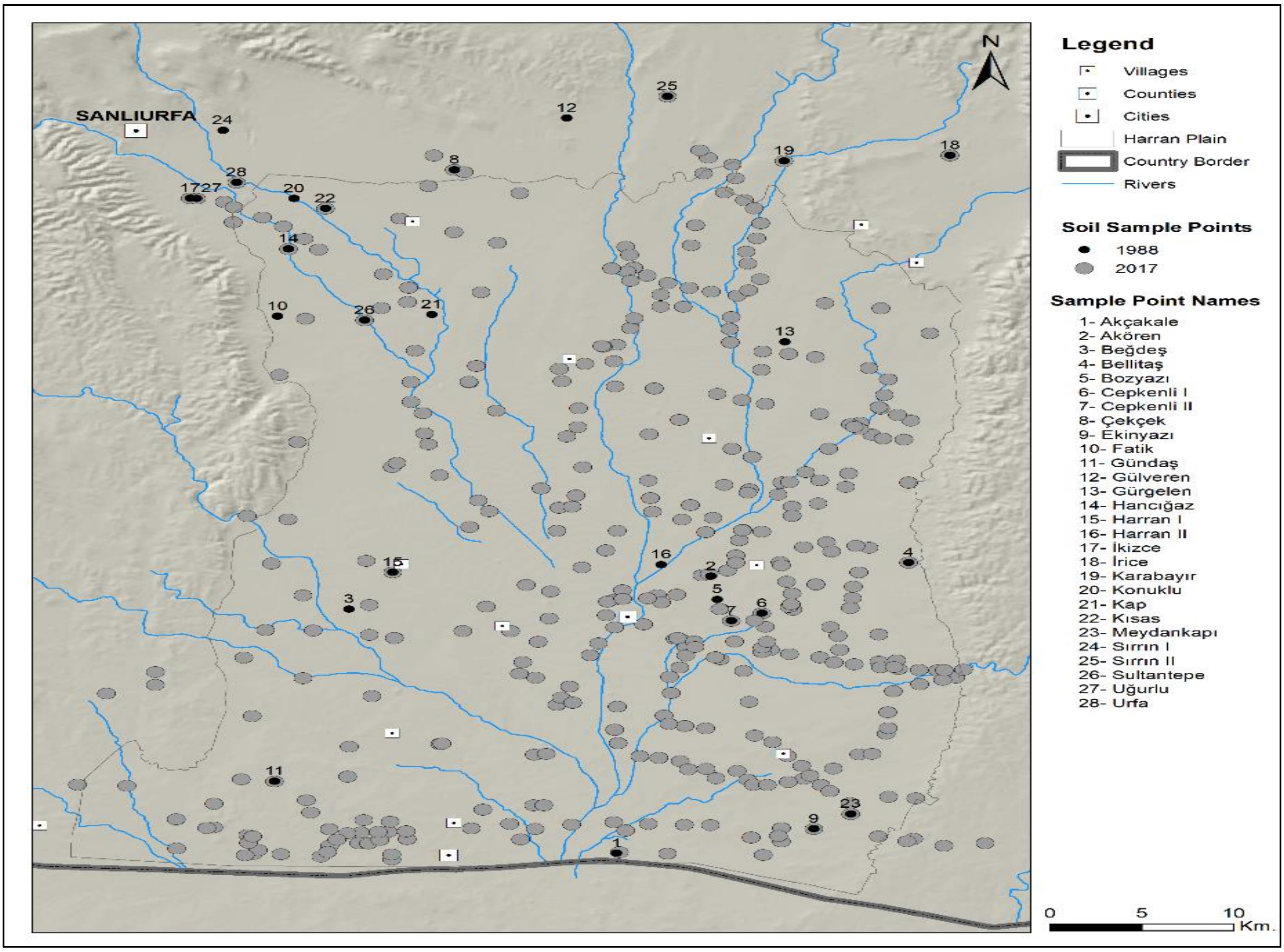

Figure 2: Soil sampling points.
Source: Authors, (2022).

II.2 METHODS

II.2.1 Soil Analyses

Soils were air-dried and sieved to a size of 2 mm. Shimadzu TOC-L CPN SSM 5000A/ASI was used to measure total organic carbon using 10 mg samples. A total of 28 samples collected in 2018 from the same points of the 1988 survey were analyzed by the Walkley-Black wet digestion method for calibration and comparison of soil organic matter with TOC results [30]. Furthermore, soil pH, EC, $CaCO^3$, and texture contents were analyzed using the Soil Survey Staff Laboratory Manual (2014) to assess any changes since 1988, as these properties affect SOC [31]. The SOC was estimated and integrated with the ESRI (2008) [32], [33] GIS software using time series analysis (1988 and 2018). Based on the distribution soil series given by Dinç et al., (1988) the georeferenced soil organic carbon levels were evaluated and mapped using geostatistical techniques [29], [34].

II.2.2 Soil Organic Carbon

SOC is calculated by comparing the organic matter and organic carbon of the 1988 and 2018 values as the percentage of organic matter because the 1988 data were expressed in percentage organic matter in soils (Table 2) but were converted to $t.C.ha^{-1}$ (area in ha x soil depth in m x bulk density in $gr.cm^{-3}$x %SOC) for a better understanding of the Harran Plain soil organic carbon. Although Pribly (2010) argued that using the value of 1,72 (assuming that 58 percent of organic matter is made up from carbon) when calculating organic carbon from organic matter in soils is a low value for most soils around the world, we chose to use this value in order to compare our study with other SOC studies. The equation used is as follows: Organic matter (%)=Total organic carbon (%) x 1.72 [35].

II.2.3 Economic Analyses

II.2.3.1 Infra and Ultrastructure Costs of Irrigation Project

This study attempts to demonstrate the cost of a unit of soil carbon increase in the Harran Plain following massive irrigation investments since 1995, i.e., when water from the Atatürk Dam was delivered to the Harran Plain via two parallel irrigation tunnels, each 26 km long with a diameter of 7.62 m and a construction cost of $585 million.

Irrigation investment calculations are complicated and can vary depending on the water source, whether the resource is used for other purposes, water transmission structures, and irrigation type [36], [37]. Thus, the share of irrigation was computed proportionally when calculating the irrigation investment expenses for the Harran Plain. In November 2019, the costs were calculated using the Central Bank's inflation calculation method [38], using pricing values obtained from the Ministry of Industry and Technology [39] and DSI (2017), as well as the General Directorate of Water Management [40], [41]. As of 2019, when this study was written, the exchange rate of 5.751[1] Turkish Lira (TL) to one US dollar was used as the base value for representing investment costs in US dollars.

II.2.3.2 Land Management Costs

The amount of fertilizer and irrigation needed for cultivation, as well as the field labor costs, were obtained through face-to-face survey interviews with 52 Harran Plain farmers who kept a record of their annual expenses. The interviews were evaluated using the purposeful sampling methodology [42]. Field labor expenses are also included in the calculation because they are the monetary equivalent of the human labor required for agricultural production. In other words, it is a cost of production that has an indirect impact on the SOC level.

III. RESULTS AND DISCUSSIONS

In short, except in saline areas, increased biomass as a result of irrigation and fertilization in the Harran Plain causes soil organic carbon to rise.

III.1 LAND USE

The Harran Plain soils, mainly clayey with high $CaCO_3$ and pH above 7.5, have been cultivated for decades for wheat and cotton, and maize has been the major cultivated crop for the last 15 years. In comparison to wheat, cotton, and maize production, vegetable and horticultural production is negligible. Before irrigation, cotton received almost no chemical fertilizer in the plain, while wheat received 650 kg. ha^{-1} fertilizer containing diammonium phosphate—$(NH_4)_2HPO_4$ (18% N -46% P) and urea—CH_4N_2O-(46% N). Following irrigation in 1995, maize, which was given approximately 980 kg ha^{-1} fertilizer similar to cotton, was introduced to the Harran Plain. Irrigated cotton receives 917.5 kg.ha^{-1} of fertilizer, while irrigated wheat receives 650 kg.ha^{-1}, all raising groundwater nitrate content above 50 mg/L [43]–[46]. If you don't care about environmental costs, you can say that using nitrogen fertilizers in combination with irrigation increased crop biomass, which in turn would have a positive effect on soil organic matter in the Harran Plain.

III.2 SOIL ORGANIC CARBON

Harran Plain's SOC has risen steadily since 1988, however the maximum value of 54.91 t C ha^{-1} in 2018 is lower than the highest amount of 69.7 t C ha^{-1} in 1988. The lowest value of 11.01 t C ha^{-1} in 2018 was, however, significantly higher than the lowest value of 5.54 tCha^{-1} of 1988 (Table 2, Figure 3). In cultivated soils, the highest SOC increase is found at Harran I and Karabayır Series, with 27.45 t C ha^{-1} (1.12 percent increase) and 26.46 t C ha^{-1} (1.05 percent increase), respectively. In other soils, such as Akören, Ekinyaz, and Urlu, the increase was assumed to be entirely due to irrigation. The Urfa series (grazeland) had the highest SOC among all plain soils in 2018, at 54.91 t C ha^{-1} (2.08 percent SOM) even down from 69.70 t C ha^{-1} (2.64 percent SOM) in 1988 is attributed to low grazing pressure, i.e. locals abandoning animal breeding in favor of high-income irrigated agriculture opportunities. However, at places where grazing was still occurring such as the Fatik Series, the SOC value was as low as 38.75 t C ha^{-1}. This high SOC amount in grazelands is manifested elsewhere even in earlier studies of the century [47]. The salinity build-up caused SOC to decrease in areas around Akçakale (Figure 4). Çullu et al. (2010) and Bilgili et al. (2017) suggest that the capillary rise of the saline water table due to excess irrigation is the cause of the salinity build-up in these areas [45], [48].

Table 2: The soil organic matter change from 1988 to 2018.

Soil Series	1988	2018	Change
	%	%	%
Fatik	1,60	1,70	0,10
Gülveren	1,05	1,17	0,12
İkizce	0,61	0,76	0,15
Bellitaş	1,49	1,52	0,03
Kap	0,66	0,77	0,11
Akören	0,39	0,93	0,54
Gündaş	1,38	1,42	0,04
Karabayır	0,22	1,27	1,05
Harran I	0,50	1,62	1,12
Harran II	0,66	1,38	0,72
Sırrın I	0,44	0,86	0,42
Sırrın II	0,50	0,97	0,47
Beğdeş	1,32	1,60	0,28
Uğurlu	0,22	0,43	0,21
Gürgelen	0,88	1,59	0,71
İrice	0,66	0,98	0,32
Urfa	2,64	2,08	**-0,56**
Konuklu	1,49	1,67	0,18
Kısas	1,05	1,38	0,33
Bozyazı	0,72	0,93	0,21
Çekçek	0,72	1,08	0,36
Sultantepe	0,88	1,17	0,29
Akçakale	0,83	0,70	**-0,13**
Meydankapı	0,44	0,43	**-0,01**
Ekinyazı	0,44	0,76	0,32
Hancığaz	1,27	1,42	0,15
Cepkenli I	0,94	1,11	0,17
Cepkenli II	1,05	1,14	0,09
Average	**0,89**	**1,17**	**0,28**

Source: Authors, (2022).

The overall SOC increase in the Harran Plain (Figure 4) is calculated by assigning zero value to the SOC of the settlements and distributing soil series values by regression kriging as follows:

$\sum$ [Soil organic carbon difference (ton C ha^{-1}) /soil series area (ha)] =ton C ha^{-1}

$\sum$ [2,131,614.81 ton C/142,770.78 ha] = 14.93 ton C ha^{-1}

[1]www.tcmb.gov.tr/wps/wcm/connect/EN/TCMB+EN/Main+Menu/Statistics/Exchange+Rates/Indicative+Exchange+Rates

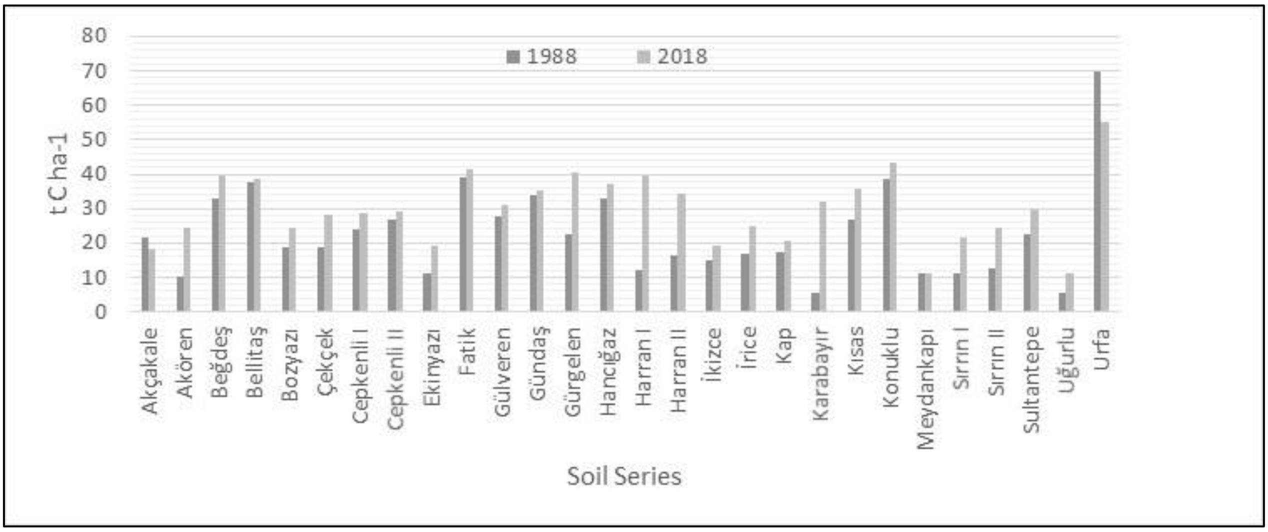

Figure 3: The soil organic carbon contents of the Harran Series in 1988 and 2018.
Source: Authors, (2022).

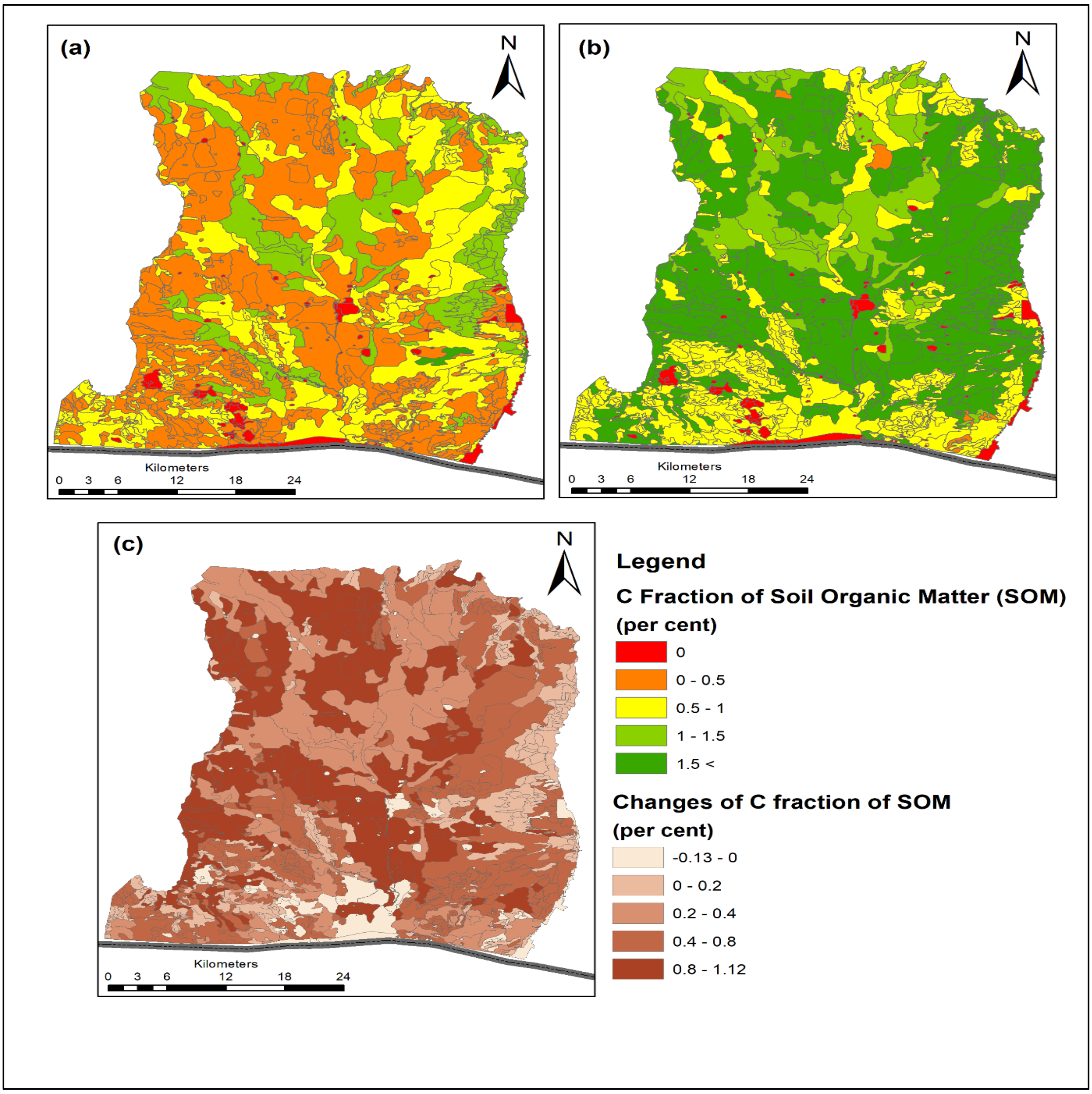

Figure 4: (a) SOC % in 1988, (b) SOC % in 2017; and (c) Changes of SOC between 1988 and 2018.
Source: Authors, (2022).

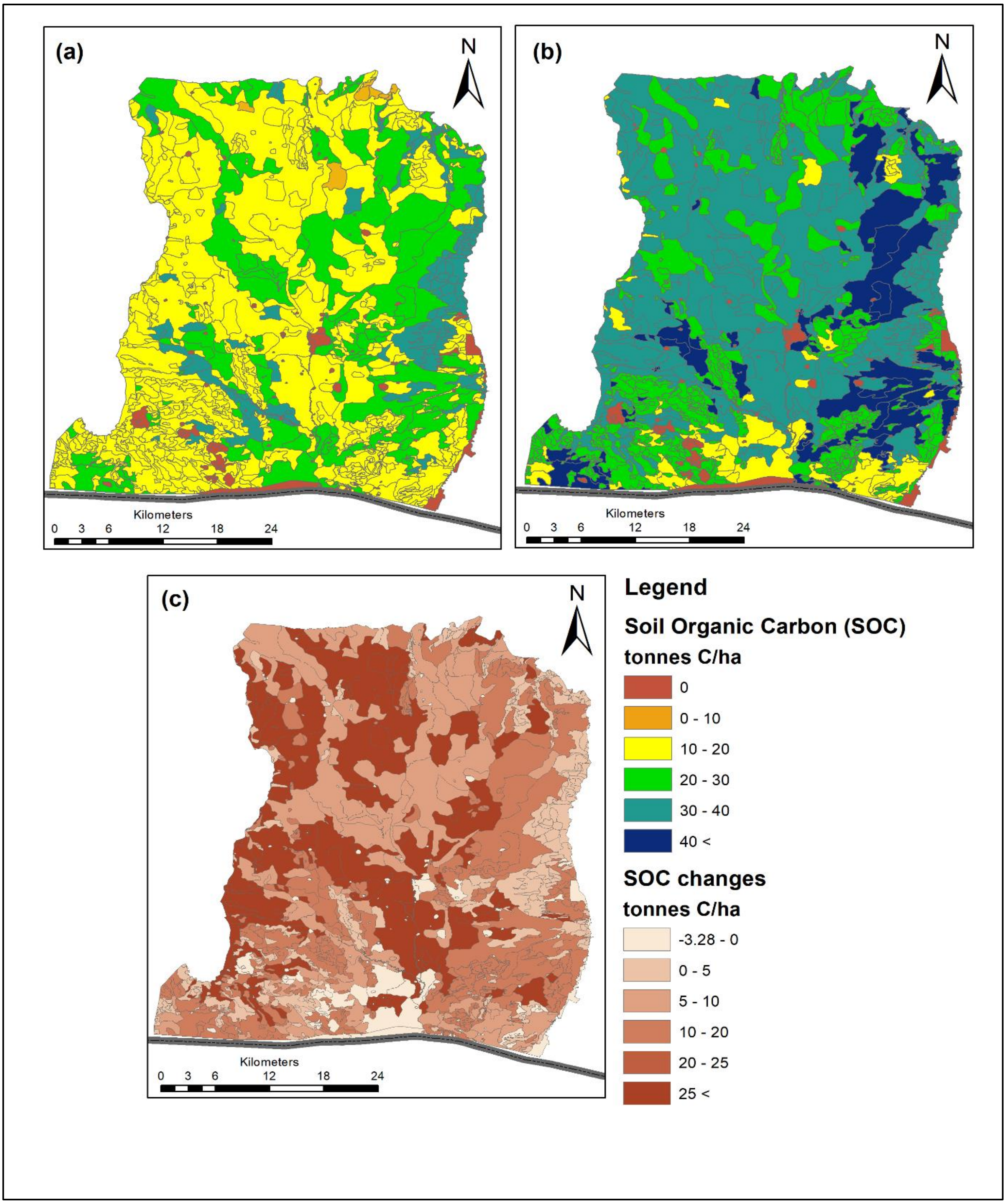

Figure 5. (a) SOC in 1988, (b) SOC in 2017; and (c) SOC changes between 1988 and 2018.
Source: Authors, (2022).

III.3 THE ECONOMIC ANALYSES OF IRRIGATION INVESTMENTS IN HARRAN PLAIN

The overall trend for SOC in the plain is an increase, which decision-makers may consider a successful achievement. The expense of increasing, on the other hand, necessitates a thorough examination of the strategies for raising soil organic carbon. The availability of water and crop pattern, according to this study, are the key determinants of soil organic carbon dynamics in Harran Plain, a semi-arid environment. Thus, we calculated the three major expenditure items since 1995, namely I. fixed investment, maintenance, and repair operating costs, II. fertilization costs, and III. irrigation and fertilization labor costs.

III.3.1 Fixed Investment, Maintenance, and Repair Operating Costs of Harran Irrigation

In the Harran Plain, where rain-fed farming was common, irrigation of soils began in 1995 in an area of 30 thousand hectares under the pretense of GAP and gradually spread to almost the entire Plain [49]. The Harran Irrigation Project is gravity-based, with 80.2 percent irrigated by gravity and 19.8 percent irrigated by pressurized systems as of 2019. Irrigation investment calculations are complex and may differ depending on the water source, whether this resource is used for purposes other than irrigation, the water transmission structures, and the irrigation type [50], [51]. As a result, the irrigation share was calculated proportionally in the irrigation investment costs. Harran Irrigation's fixed investment cost was determined to be $6170.78 (35,481.97 TL) ha^{-1} based on the calculations. Face-to-face interviews with field irrigation institutions (Irrigation Unions and Irrigation Cooperatives) and DSI reports were used to obtain annual maintenance-repair operating costs [41]. The annual maintenance-repair and operating cost for the Harran Plain is determined to be $246.45 (1,417.08 TL) ha^{-1} after separating gravity and pressurized irrigation costs. The total cost of the Harran Plain Irrigation facilities, fixed investments, and maintenance and repair operation costs were estimated to be $6417.23 (36,899.05 TL) ha^{-1}. The total cost of fixed investment, maintenance, and repair operating costs for the entire plain is $1,074,244,302 (Table 3).

Table 3: The 25 years of irrigation cost in Harran Plain (167400ha) (US$).

	Fixed Investments & Repairing	Fertilizer	Irrigation and Labor	Total
1 hectare	6417,23	799	117,25	7333,48
All Plain	1.074.244.302	3.343.815.000	490.691.250	4.908.750.552

Source: Authors, (2022).

III.3.2 Fertilizer Costs

The Harran Plain's land cover is made up of 99.37% field crops. The crop pattern is composed of 82.70% cotton, 15.83 percent wheat, and 1.47 percent other products and fallow. Maize, after wheat, has become a widely grown second crop in the Harran Plain in the last 20 years as Turkey's sugar and fodder needs have increased [42], [52]. The amount of fertilizer used was determined through face-to-face survey interviews with 52 Harran Plain record-keeping farmers chosen using the purposeful sampling method. The farmers reported that the total amount of fertilizer (base and top) used in cotton is 917.5 kg. ha^{-1}, with urea accounting for 81.25% and triple superphosphate accounting for 18.75%. This fertile amount is likewise valid for maize with a 960 kg.ha^{-1} application rate. It is stated that 650 kg of fertilizer is applied to a hectare of wheat, with 66.2 percent urea and 33.8 percent triple superphosphate. The fertilizer cost in the region has been calculated as $799 (4,597.05 TL) ha^{-1} based on valid 2019 prices [53]. A total of $3,343,815,000 is spent on fertilizing crops across the entire plain (Table 3).

III.3.3 Salinity Remediation Infrastructure Cost

III.3.3.1 Irrigation and fertilization labor costs

Interviews with farmers in several regions of the plain yielded data on the number of irrigation and fertilizer application. The irrigation figures vary depending on the amount of annual precipitation and the method of irrigation. Cotton is irrigated 10.94 times on average, according to farmers. In the Harran Plain, on the other hand, it was discovered that, on average, 6 irrigations are carried out for winter wheat, despite the fact that this ratio varies depending on precipitation. Fertilizations are usually done twice as often as a base and top fertilizer. The estimate was based on the agricultural products cost system (TAMSIS) and the statistics data network (IVA) of the Ministry of Agriculture and Forestry of the Republic of Turkey [54]. According to this, the Harran Plain's irrigation and fertilizer labor expenses are $167.38 (962.42 TL) ha^{-1} and $987 (56.77 TL) ha^{-1}, respectively, totaling $177.25. (1019.19 TL ha^{-1}). Over the course of 25 years, $490,691,250 was spent on irrigation and labor on the Harran Plain (Table 3).

III.4 THE COST OF SOIL ORGANIC CARBON IN HARRAN PLAIN

Irrigation of the Harran Plain began in 1995, and the use of chemical fertilizers improved biomass production after irrigation for farming. Following 25 years of irrigation, the SOC in the Harran Plain increased by 14.93 ton C ha^{-1}, or 0.28% SOC, except in a few locations (Figure 4). When the total expenses of $7333.48 are divided by 14.93 t C ha^{-1}, it can be said that one ton of soil organic carbon increase, i.e., 0.28% SOC (Table 1) accumulation costs $491.19 in the Harran Plain. Harran Plain's total SOC increase of 2,131,614.81 t C ha^{-1} can be estimated to cost $1,047,029,777. However, when COP 21 Paris initiative is taken into account the current 0.28% increase should be 2.66% (Over the course of 25 years, a 0.04 percent annual increase translates to a total accumulated increase of 2.66% C.). As a result, the current 0.28 percent increase, rather than the 2.66 percent increase, represents unsustainable land management in Harran Plain for SOC.

IV. CONCLUSIONS

Several studies have shown that decreasing soil organic carbon has negative consequences for climate, land use, and biodiversity. In addition to academic studies, these issues have become increasingly visible in the socio-economic sphere as a result of declining income, health, and quality of life. Countries have begun to take steps to increase SOC for the safety of their citizens and natural resources through a variety of measures. Increasing SOC through various land-use practices is one of the mitigation strategies. Irrigating dry and semi-arid fields to raise biomass is a common method among them because it creates revenue for communities while also raising SOC, especially in impoverished nations. Governments, such as Turkey's Southeastern Anatolia Project, set aside large sums of money to build irrigation networks. After 25 years of irrigation, SOC increased by 14.93 ton C ha (0.28 percent) across the plain. However, this falls short of the COP-21 Paris goal of a 0.04 percent yearly rise, which should be 2.66% rather than the existing 0.28 percent which somewhat revealed the unsustainable land management in Harran Plain. The cost of the 0.28% increase i.e. per t C ha-1 is $491.19 in the Plain which sums up $1,047,029,777 for 167.400 ha. This figure showed that rising SOC within the COP 21 target of 0.04% per year in semi-arid regions will be a costly strategy unless management is not just focused on output but also on ecosystem services. SOC, land productivity, and land use are the parameters of Land Degradation Neutrality, which aims to support ecosystem functions and services while also improving land quality. We believe that economic considerations should be considered when designing LDN studies in semi-arid regions, particularly in low-income nations. In a semi-arid region like the Harran Plain, attaining the “4 per 1000 initiative of COP 21 Paris” might cost $7,017 per year for a hectare if only dependent on irrigation and fertilization. Nevertheless, while irrigation and fertilization increase SOC, they also cause salinity build-up and pollution, both of which have a negative impact on SOC, as seen in the Harran Plain, and may result in higher land management costs.

V. AUTHOR'S CONTRIBUTION

The authors contributed equally to the study.
Conceptualization: Erhan Akça, Mehmet Ali Çullu, Mustafa Hakkı Aydoğdu, Günay Erpul, Gönül Aydın, Pınar Pamukçu Albers, Fatih Tufaner, Ahmet Çelik, Kamil Varınca, Uğur Zeydanlı, Melike Kuş, Mustafa Talha Gönüllü, Mehmet Reşit Sevinç, Hatice Parlakçı Doğan and Nihat Küçük.
Methodology: Erhan Akça, Mehmet Ali Çullu, Mustafa Hakkı Aydoğdu, Günay Erpul, Gönül Aydın, Pınar Pamukçu Albers, Fatih Tufaner, Ahmet Çelik, Kamil Varınca, Uğur Zeydanlı, Melike Kuş, Mustafa Talha Gönüllü, Mehmet Reşit Sevinç, Hatice Parlakçı Doğan and Nihat Küçük.
Investigation: Erhan Akça, Mehmet Ali Çullu, Mustafa Hakkı Aydoğdu, Günay Erpul, Gönül Aydın, Pınar Pamukçu Albers, Fatih Tufaner, Ahmet Çelik, Kamil Varınca, Uğur Zeydanlı, Melike Kuş, Mustafa Talha Gönüllü, Mehmet Reşit Sevinç, Hatice Parlakçı Doğan and Nihat Küçük.
Discussion of results: Erhan Akça, Mehmet Ali Çullu, Mustafa Hakkı Aydoğdu, Günay Erpul, Gönül Aydın, Pınar Pamukçu Albers, Fatih Tufaner, Ahmet Çelik, Kamil Varınca, Uğur Zeydanlı, Melike Kuş, Mustafa Talha Gönüllü, Mehmet Reşit Sevinç, Hatice Parlakçı Doğan and Nihat Küçük.
Writing – Original Draft: Erhan Akça, Mehmet Ali Çullu, Mustafa Hakkı Aydoğdu, Günay Erpul, Gönül Aydın, Pınar Pamukçu Albers, Fatih Tufaner, Ahmet Çelik, Kamil Varınca, Uğur Zeydanlı, Melike Kuş, Mustafa Talha Gönüllü, Mehmet Reşit Sevinç, Hatice Parlakçı Doğan and Nihat Küçük.
Writing – Review and Editing: Erhan Akça, Mehmet Ali Çullu, Mustafa Hakkı Aydoğdu, Günay Erpul, Gönül Aydın, Pınar Pamukçu Albers, Fatih Tufaner, Ahmet Çelik, Kamil Varınca, Uğur Zeydanlı, Melike Kuş, Mustafa Talha Gönüllü, Mehmet Reşit Sevinç, Hatice Parlakçı Doğan and Nihat Küçük.
Resources: Erhan Akça, Mehmet Ali Çullu, Mustafa Hakkı Aydoğdu, Günay Erpul, Gönül Aydın, Pınar Pamukçu Albers, Fatih Tufaner, Ahmet Çelik, Kamil Varınca, Uğur Zeydanlı, Melike Kuş, Mustafa Talha Gönüllü, Mehmet Reşit Sevinç, Hatice Parlakçı Doğan and Nihat Küçük.
Supervision: Erhan Akça, Mehmet Ali Çullu, Mustafa Hakkı Aydoğdu, Günay Erpul, Gönül Aydın, Pınar Pamukçu Albers, Fatih Tufaner, Ahmet Çelik, Kamil Varınca, Uğur Zeydanlı, Melike Kuş, Mustafa Talha Gönüllü, Mehmet Reşit Sevinç, Hatice Parlakçı Doğan and Nihat Küçük.
Approval of the final text: Erhan Akça, Mehmet Ali Çullu, Mustafa Hakkı Aydoğdu, Günay Erpul, Gönül Aydın, Pınar Pamukçu Albers, Fatih Tufaner, Ahmet Çelik, Kamil Varınca, Uğur Zeydanlı, Melike Kuş, Mustafa Talha Gönüllü, Mehmet Reşit Sevinç, Hatice Parlakçı Doğan and Nihat Küçük.

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RESEARCH ARTICLE OPEN ACCESS

RISK EVALUATION OF BELT CONVEYOR ACCIDENTS USING FAILURE MODES AND EFFECTS ANALYSIS AND EVENT TREE ANALYSIS

Pınar Mızrak Özfırat[1], Muharrem Kemal Özfırat[2], Mustafa Emre Yetkin*[3] and Çağatay Pamukçu[4]

[1] Department of Industrial Engineering at Manisa Celal Bayar University, Turkey.
[2, 3, 4] Dokuz Eylul University Mining Engineering Department, Turkey.

[1] http://orcid.org/0000-0003-2669-3135, [2] http://orcid.org/0000-0003-4074-1965, [3] http://orcid.org/0000-0002-4797-3841,
[4] http://orcid.org/0000-0003-1340-5931

Email: pinar.ozfirat@cbu.edu.tr, kemal.ozfirat@deu.edu.tr, *mustafa.yetkin@deu.edu.tr, cagatay.pamukcu@deu.edu.tr

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ABSTRACT

Belt conveyor haulage is an often-preferred haulage method in raw material transport of industrial facilities. Main components of the system often subject to breakdowns are belt, drums, roller systems and belt tension drum systems. Among these components, belt breakdowns are belt ruptures due to corrosion, inability of rotation due to corrosion and dust in cylinders and mechanical failures in drum systems and components. In this study, risk evaluation was carried out on probable risks due to breakdowns and faults in a bad conveyor facility. Realized accidents in industry are considered to specify risks. In the first step of the study, Failure modes and effects analysis was employed. Upon results of FMEA, event tree analysis was carried out for each risk to display and decrease severity degrees of risks.

I. INTRODUCTION

Belt conveyors are haulage systems used to transport large amount of stock materials to short, medium, or long distances in horizontal or inclined surfaces through an infinite belt between two drums. Material is transported on the belt. The belt is pulled by one or more drums, which is driven by one or more electrical engines and moves on pulley groups. Material is moved forward on the upper side of the belt and the belt returns to the beginning point empty on the lower side (Figure 1). Since belt conveyor haulage provides economical and efficient transportation of large capacities in long distances, there are many application areas even in today's mining industry [1].

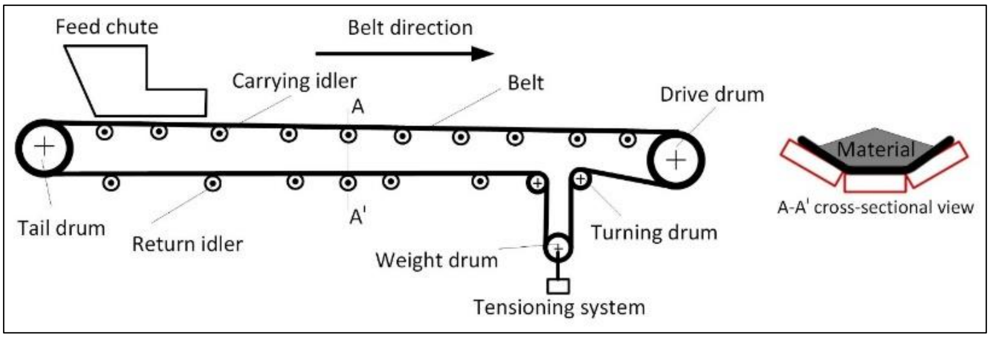


Figure 1: Schematic View of Belt Conveyor.
Source: Authors, (2022).

Belt conveyor is a strong machine with thousands of moving parts. These moving parts contain the risk of injuring a worker seriously. In addition, this injury may occur instantaneously. A regular belt conveyor moves with a constant speed of about 0.5 m/s to 10 m/s [1]. In fact, Conveyors load large amount of mechanical energy to an enormous elastic belt surrounded by tensioned structures. Tensioned belt carries tons of materials and usually up to 600 HP (450 kW) engines are used. When weight, inertia and kinetic energy are considered, enormous amounts of force may appear. Human body can produce power less than 1 HP. Therefore, it is impossible for human body to overcome forces produced by belt conveyor.

Two thirds of fatal belt conveyor accidents occur when belt is moving. Usually, worker's body is grabbed or squeezed by the conveyor during maintenance or cleaning near a moving belt conveyor [2]–[4]. Fatal accidents are usually caused by union of two unsafe applications. First one is maintenance without careful lock down, labelling, blocking, and testing of belt conveyor. Second one is contact with the belt conveyor with a tool or equipment. When these two unsafe behaviours come together, results are unfortunately very serious or fatal. Working around a closed but unlocked belt conveyor can even result in very serious accidents.

In a study of [3], 44 fatal accidents of belt conveyors are analysed according to the reasons of the accidents. It is seen that 96% of the accidents are due to human error. Therefore, it is very important to train workers in order to take and apply precautions. [5]–[9] used main principles and methods of risk analysis and work safety in their studies to decrease and prevent work accidents. [4], [10]–[14] explained in detail hazard sources, physical risk factors and necessary precautions to decrease work accidents in underground mines. Especially, [11] handled work safety applications in underground belt conveyors, which is also the main subject of this study.

In this study, risk factors were examined for underground belt conveyors using a Failure Mode and Effect Analysis (FMEA) and Event Tree Analysis (ETA) methods. In the first step of the methodology, five major risk factors were identified and analyzed using FMEA. In addition, preventive actions were determined, and each risk factor was evaluated together with preventive actions by FMEA. However, since belt conveyor accidents may cause disastrous results in terms of human health, interruption of haulage and production, residual risk of each risk factor was also examined using ETA.

II. DEFINITION OF THE RISK ANALYSIS METHODS USED IN THE STUDY

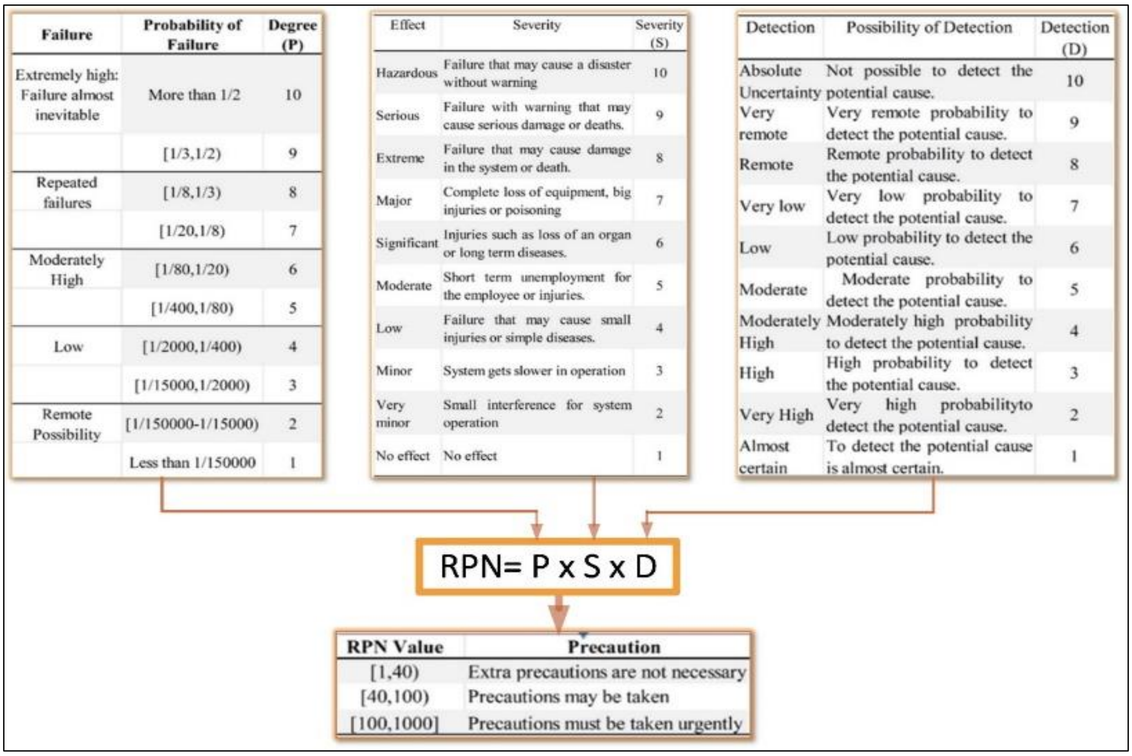
II.1 FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

Failure Modes and Effects Analysis (FMEA) is one of the frequently used methods in risk analysis and evaluation. Basically, FMEA depends on failures of systems and parts of systems and examines the effects of defined failures. Finally, results are evaluated which may occur due to a failure [15]. FMEA can be applied in many different industries. Failure mode is identified as a potential failure factor in the system [16]. Until now, FMEA has been used in many industries such as mining, aviation, automotive, electronics, chemistry, and production [17]–[27].

FMEA can be considered as a method of safety engineering. It is a quantitative method which handles the three parameters of the risk. These parameters are probability, severity and detectability. Risk probability (P) is the probability of occurrence of an event. Severity (S) is the seriousness degree of results. Detectability (D) is the level in which the risk can be realized before it happens. Risk priority number (RPN) is calculated by multiplying the three parameter values as in Equation 1.

$$RPN = P \times S \times D \quad (1)$$

When determining P, S and D values, FMEA scales given in Figure 2 are used [8], [12], [16].



Failure	Probability of Failure	Degree (P)
Extremely high: Failure almost inevitable	More than 1/2	10
	[1/3,1/2)	9
Repeated failures	[1/8,1/3)	8
	[1/20,1/8)	7
Moderately High	[1/80,1/20)	6
	[1/400,1/80)	5
Low	[1/2000,1/400)	4
	[1/15000,1/2000)	3
Remote Possibility	[1/150000-1/15000)	2
	Less than 1/150000	1

Effect	Severity	Severity (S)
Hazardous	Failure that may cause a disaster without warning	10
Serious	Failure with warning that may cause serious damage or deaths.	9
Extreme	Failure that may cause damage in the system or death.	8
Major	Complete loss of equipment, big injuries or poisoning	7
Significant	Injuries such as loss of an organ or long term diseases.	6
Moderate	Short term unemployment for the employee or injuries.	5
Low	Failure that may cause small injuries or simple diseases.	4
Minor	System gets slower in operation	3
Very minor	Small interference for system operation	2
No effect	No effect	1

Detection	Possibility of Detection	Detection (D)
Absolute Uncertainty	Not possible to detect the potential cause.	10
Very remote	Very remote probability to detect the potential cause.	9
Remote	Remote probability to detect the potential cause.	8
Very low	Very low probability to detect the potential cause.	7
Low	Low probability to detect the potential cause.	6
Moderate	Moderate probability to detect the potential cause.	5
Moderately High	Moderately high probability to detect the potential cause.	4
High	High probability to detect the potential cause.	3
Very High	Very high probabilityto detect the potential cause.	2
Almost certain	To detect the potential cause is almost certain.	1

RPN= P x S x D

RPN Value	Precaution
[1,40)	Extra precautions are not necessary
[40,100)	Precautions may be taken
[100,1000]	Precautions must be taken urgently

Figure 2: Probability, severity and detectability scales in FMEA.
Source: [8], [12] and [16].

After computing RPN, risks are categorized according to RPN level. If RPN value is greater than 100, precautions must be taken immediately to reduce P, S, D levels. If RPN value is found to be between 40 and 100, precautions should be taken, and risks should be kept under control. If it is less than 40, available precautions should be continued and risk is said to be tolerable [16]. RPN levels easily display the factors with highest risks, and precautions must be taken immediately for the highest priority risks. After taking precautions P, S and D values are evaluated and RPN is computed for the risks again. The cycle should be a continuous process until all risks are under control and within limits. In this study, FMEA procedure is integrated with ETA procedure. The flow of the algorithm can be seen in Figure 3.

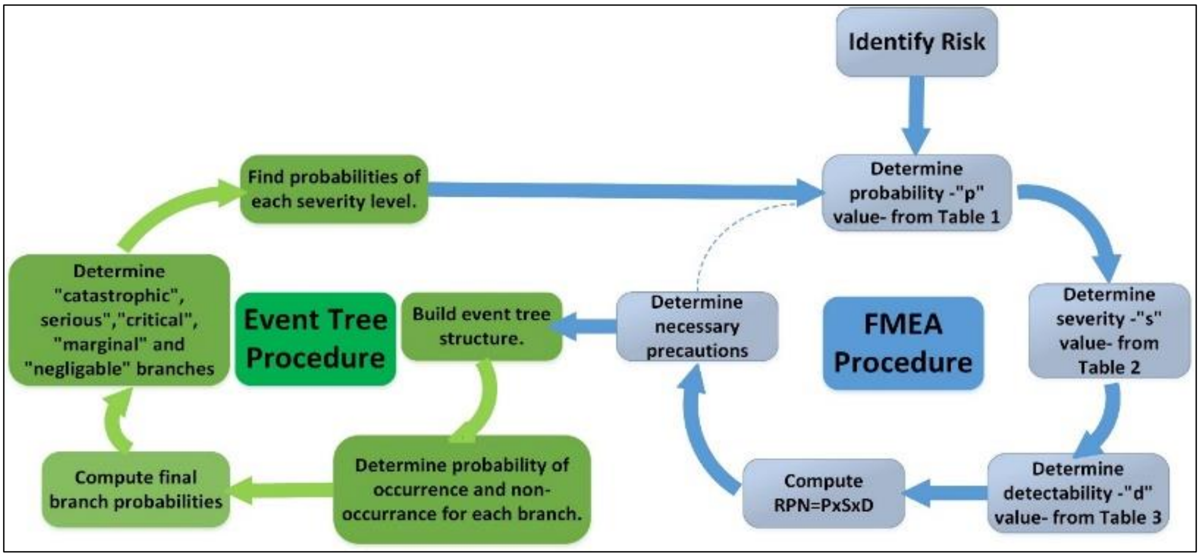


Figure 3: FMEA and ETA are integrated together for further analysis of risk severity degrees and probabilities.
Source: Authors, (2022).

As seen from Figure 3, in FMEA, the process is a continuous loop. The loop is closed by defining precautions and analysis restarts. However, in this study, after determining the precautions in FMEA, ETA is applied for each risk to analyze the severity degrees and their probabilities in further detail. However, risk analysis process is a continuous cycle. The cycle restarts after finding the probability levels of each severity level (catastrophic, serious, critical, marginal, negligible accidents) in ETA.

II.2 EVET TREE ANALYSIS (ETA)

ETA is a risk analysis method which defines root causes of an event, occurrence probabilities of undesired events, probabilities of precautions to avoid the event and classifies the degrees of results (disastrous, critical, serious, marginal, negligible) [13], [14], [28], [29]. ETA has found applications in many different industries. Event tree can be developed in five steps. These steps are defining the initiating event, defining the precautions, developing the tree, evaluation of the tree and classifying risks.

Event tree analysis starts with an initiating event. The tree splits into two branches as the occurrence of the event and non-occurrence. The probabilities of two branches can be stated as "p" and "1-p". The tree continues branching similarly for all precautions defined. Therefore, for "n" barrier there will be "2n" branches at the final level. Probability of a branch at the final level is found by multiplying probabilities of all previous level branches which is connected to the final branch considered. In the evaluation of the tree, each branch at the final level is classified as disastrous, critical, serious, marginal, and negligible. Finally, probability degrees of all disastrous branches are added to give the probability of occurrence of a disastrous risk. Similarly, probabilities for critical, serious, marginal and negligible risks are calculated. A schematic representation of an event tree can be seen in Figure 4.

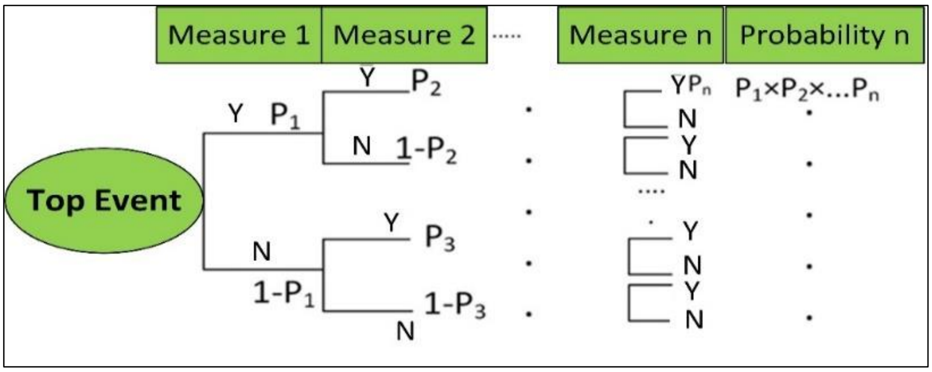


Figure 4: Structure of ETA.
Source: [4].

III. HAZARD IDENTIFICATION DURING BELT CONVEYOR OPERATION

Use of belt conveyors in human transportation is quite hazardous. Lack of emergency stop wire or assuming conveyor energy is cut off when emergency stop wire is pulled are among hazardous events. Another possible hazardous behaviour is inaccurate passing to the other of the side conveyor.

Belt conveyors are long systems, which split the production facility into two areas. Often operators may need to pass to the other side of the conveyor due to maintenance or service. An operator may attempt to pass over or below the conveyor to save time. There are several hazards that may be incurred when passing below the belt conveyor. Operations carried out near belt conveyors involve risks, which may result in serious injury or fatality. One of the mostly incurred accidents is being stuck in the moving belt conveyor or drum. A major proportion of these accidents occur during control, lubrication, maintenance, cleaning of belt conveyor and around area. Working below or around unprotected equipment, using hands to take out material between rollers, trying to turn rollers by hand, putting on/off protective cover of a working conveyor are very hazardous events. In addition, trying to remove materials drive or tail drums while conveyor is working, having loose clothes around belt conveyors, trying to stop a conveyor before cutting off energy are other hazardous behaviours. Among these hazards, five main events were considered and analyzed by FMEA.

III. 1 FMEA FOR BELT CONVEYOR ACCIDENTS

Five hazardous events in belt conveyor haulage were identified and analyzed by FMEA. These events are worker passing below the belt conveyor (F1), faults occurring during belt and drum cleaning (F2), unpermitted boarding on the belt conveyor (F3), insufficient maintenance of pulleys (F4) and no planned cleaning (F5). Calculations of risk priority numbers (RPN) and precautions are given in Table 1.

Table 1: FMEA table for belt conveyor accidents.

Failure Type	Current				Precautions to be taken	After precautions			
	P	S	D	RPN		P	S	D	RPN
Worker passing below the belt conveyor (F1): Worker may stuck in the belt conveyor	8	9	8	576	Cleaning operations or passing below the belt should not be permitted when the belt is in operation. If there is an obligatory case, belt should be stopped. Passing below the belt must be forbidden. Bridges should be placed in appropriate locations to provide passing over the belt.	4	9	1	36
Faults occurring during belt and drum cleaning (F2): Worker may stuck between drum and belt.	8	10	8	640	Workers should not be allowed near drums when belt conveyor is moving. Drums should be covered with protective covers.	3	10	3	90
Unpermitted boarding on the belt conveyor (F3).	6	10	5	300	Boarding on the belt should be stopped regularly to lubricate pulleys and make necessary maintenance. Belts should be made of non-flammable material.	3	10	1	30
Insufficient maintenance of pulleys (F4): Pulleys may tear up belt due to corrosion or belt fire due to friction.	6	7	9	378	Belt conveyor should be stopped regularly to lubricate pulleys and make necessary maintenance. Belts should be made of non-flammable material.	2	7	2	28
No planned cleaning (F5).	8	8	6	384	Training should be given to stop belt conveyor before cleaning. Cleaning operations should be show to the operators during training.	5	8	2	80

Source: Authors, (2022).

In Table 1, RPN values both for the current situation and after precautions are calculated. The decrease in RPN values can be seen in Table 2.

Table 2: Improvement rate of risks after corrective / preventive action.

Failure	Current Situation RPN Value	After corrective/preventive action RPN Value	Improvement rate %
F1	576	36	93.75
F2	640	90	85.94
F3	300	30	90.00
F4	378	28	92.59
F5	384	80	79.17

Source: Authors, (2022).

III. 2 EVENT TREE ANALYSIS OF EACH HAZARD (ETA)

Each of the five hazards defined in Table 1 was also considered using ETA.

III. 2.1 THE WORKER PASSES UNDER THE BELT CONVEYOR (F1)

Event tree is developed for event F1 (Figure 5). The precautions defined are:

- Building bridge to prevent people from passing under the belt conveyor: Probability of an accident decreases to 0.2.
- Regular cleaning under the belt conveyor: Probability can be decreased to 0.3.
- Putting a warning sign to prevent passing under the belt conveyor: Probability of an accident decreases to 0.3.
- Having belt conveyor stop wire: Probability of an accident decreases to 0.3.

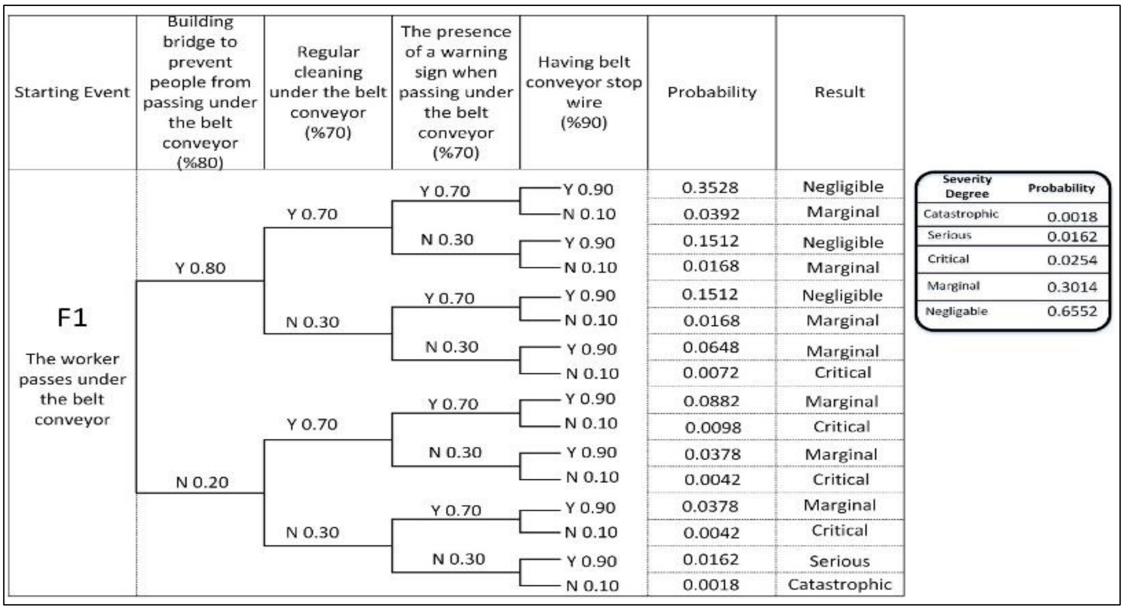


Figure 5: Event tree analysis diagram of F1.
Source: Authors, (2022).

It can be seen from Figure 4 that when these precautions are applied, probability of a catastrophic accident is 0.0018, which is very small. Probabilities of serious, critical, marginal, and negligible accidents are 0.0162, 0.0254, 0.3014, 0.6552, respectively. Therefore, severity of accidents is decreased considerable with the suggested precautions.

III. 2.2 FAULTS IN DRUM AND BELT CLEANING (F2)

F2 event is also considered using ETA. The tree developed can be seen in Figure 6. The suggested measures for event F2 are:

- Belt conveyor should be stopped during operation: Probability of accident reduces to 0.05.
- There should be backup workers (e.g., observers) during work.: Probability of accident reduces to 0.1.
- Belt conveyor stop wire: Probability of accident is decreased to 0.1.
- Planned maintenance: Probability of accident is decreased to 0.1.

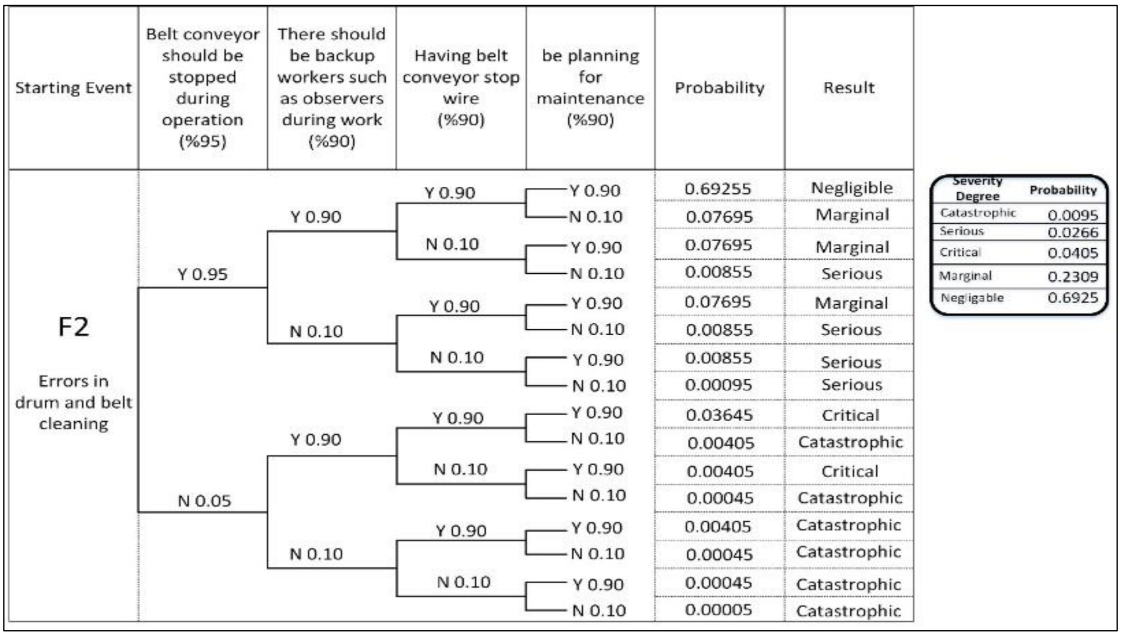


Figure 6: Event tree analysis diagram of F2.
Source: Authors, (2022).

As seen in Figure 6, in the result of ETA, probability of catastrophic and serious accidents is decreased considerably whereas probability of negligible accidents increases. Therefore, severity of accidents are taken under control with the suggested measures.

III. 2.3 UNPERMITTED BOARDING ON THE BELT (F3)

Similar to events F1 and F2, event F3 is also analyzed using ETA. Event tree is given in Figure 7. The defined measures for event F3 are:

- There should be an observer for belt conveyor boarding: Probability of accident reduces to 0.1.
- Boarding on the belt conveyor should be prohibited: Probability of accident reduces to 0.2.
- Prohibition of belt conveyor boarding should be clearly stated in trainings: Probability of accident reduces to 0.1.
- Observation cameras should be placed in certain points: Probability of accident reduces to 0.2.

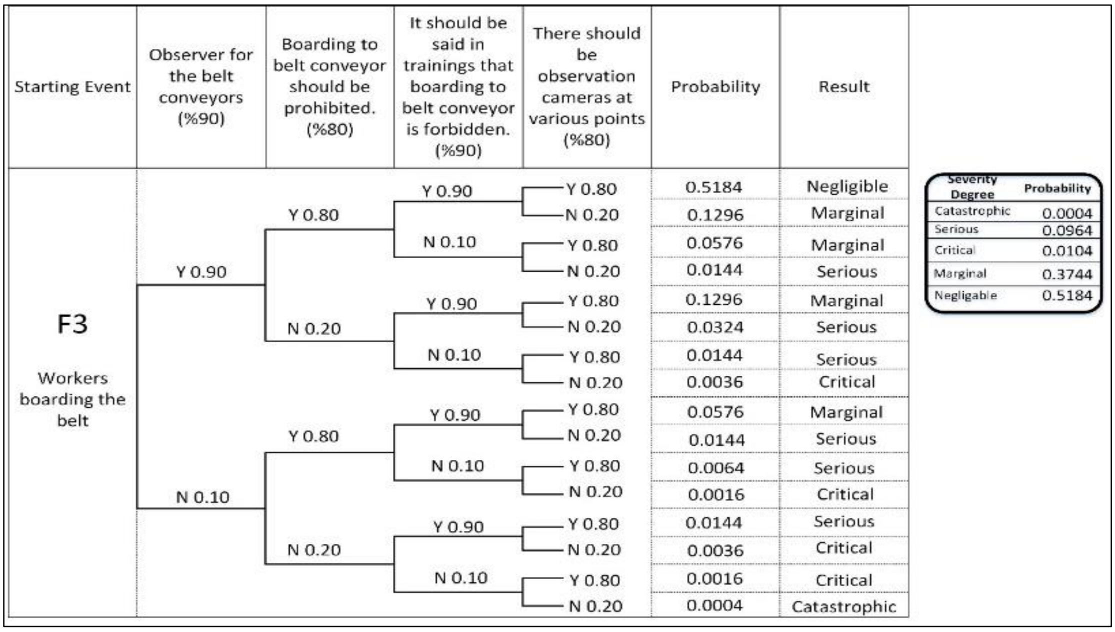


Figure 7: Event tree analysis diagram of F3.
Source: Authors, (2022).

It is seen from Figure 7 that probability of catastrophic accidents decreases to 0.0004. Also, as severity of accidents increases, probability decreases.

III. 2.4 INSUFFICIENT MAINTENANCE (F4)

Event tree developed for event F4, and the analysis can be seen in Figure 8. The measures that should be taken are:

- Rollers should be regularly lubricated and maintained: Probability of accidents decreases to 0.1.
- Belts must be fireproof (ex-proof material): Probability of accidents decreases to 0.1.
- Rotation of the belt conveyor should be smooth and aligned: Probability of accidents decreases to 0.2.
- Correct technical calculations should be done such as capacity and speed: Probability of accidents decreases to 0.2.

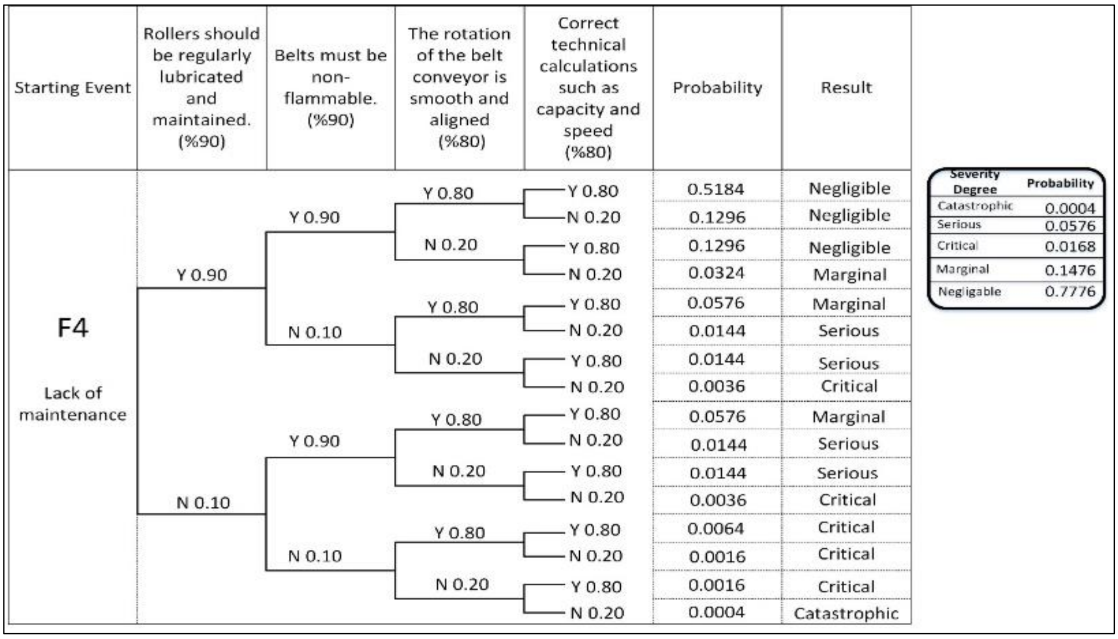


Figure 8: Event tree analysis diagram of F4.
Source: Authors, (2022).

Similar to previous event trees, it can be said for event F4 that severity and probability inversely changes, which is important to keep severity of accidents under control. Among the suggested measures, roller maintenance and non-flammable belts are especially important since they are proactive measure and can be able to prevent the initiating event.

III. 2.5 NO PLANNED CLEANING (F5)

Finally, event tree developed for event F5 and the analysis can be seen in Figure 9. The suggested measures are:

- Planning should be made regularly for cleaning operations: Probability of accidents decreases to 0.05.
- Belt conveyor should be stopped during cleaning: Probability of accidents decreases to 0.05.
- Cleaning area should be separated by a safety strip: Probability of accidents decreases to 0.1.
- Maintenance and cleaning records should be kept, and information should be provided: Probability of accidents decreases to 0.2.

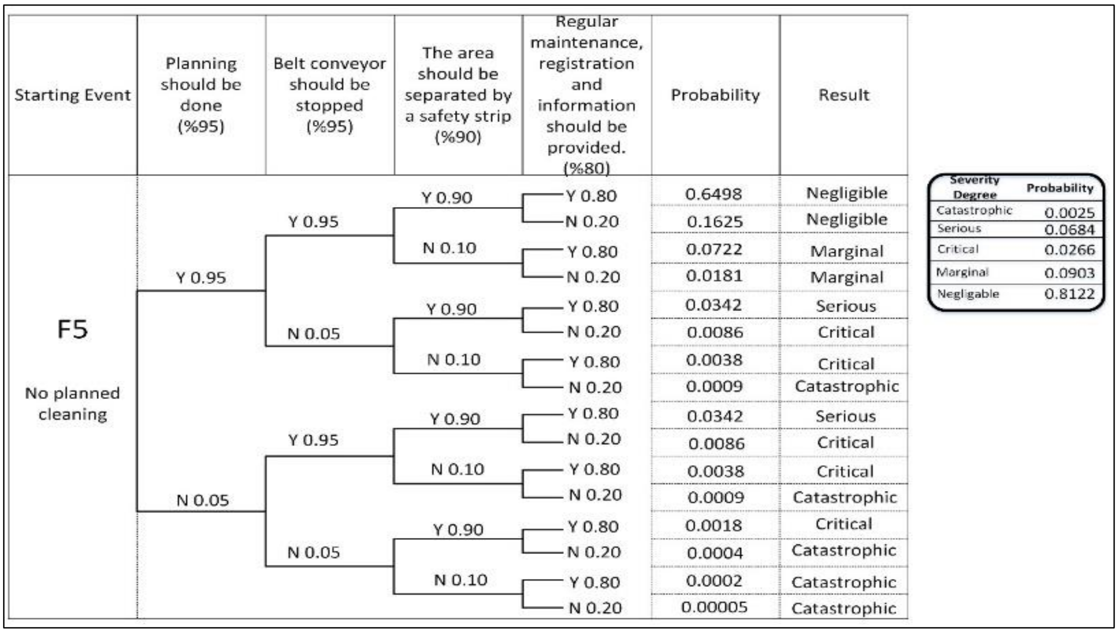


Figure 9: Event tree analysis diagram of F5.
Source: Authors, (2022).

In Figure 9, it is also shown that as severity of accident increases, probability decreases. Especially, planning and safety strip measures are proactive. In other words, these measures are important to prevent the initiating event.

IV. RESULTS AND DISCUSSIONS

Belt conveyors are always risky elements in work safety since they are moving equipment. Even when someone presses the stop button, it takes time until the conveyor stops. Therefore, it is more important to use proactive measures to prevent accidents. Even if all necessary measures and precautions are taken, risk cannot be decreased to zero but it can be kept under acceptable limits.

In this study, five major risks were identified in use of belt conveyors. In the first step of risk analysis, FMEA was used to find risk priority numbers of each risk. Then, each risk was further handled with ETA to examine the severity levels of possible work accidents and the corresponding probabilities.

In FMEA application, the risk value of all five risks were found to be intolerably high without any precautions (Table 1). By defining all the necessary preventive and corrective actions, RPN values were decreased by 90% on the average (Table 2) and all the risks were taken under control. However, to see the detailed effects of suggested measures, ETA was carried out for each risk. In other words, scenario analysis was carried out for cases success and failure in suggested measures. By this way, severity degrees and their probabilities for each case were computed. The summarized results of ETA are given in Table 3.

Table 3: Results of ETA for the five initiating events.

Event	F1	F2	F3	F4	F5	Average
Risk Class	Probability					
Catastrophic	0.0018	0.0095	0.0004	0.0004	0.0025	0.0029
Serious	0.0162	0.0266	0.0964	0.0576	0.0684	0.0530
Critical	0.0254	0.0405	0.0104	0.0168	0.0266	0.0239
Marginal	0.3014	0.2309	0.3744	0.1476	0.0903	0.2289
Negligible	0.6552	0.6925	0.5184	0.7776	0.8122	0.6912
Total	1	1	1	1	1	

Source: Authors, (2022).

In Table 3, five types of risk classes in ETA can be seen. These are catastrophic, serious, critical, marginal, and negligible risks. For all of the five events, it is clearly shown that as severity of the accidents increases, probability decreases under the defined measures. In addition, probability of an accident with catastrophic results is 0.29% on the average which is quite small and tolerable. When catastrophic, serious, and critical accidents are considered together, the total probability turns out to be 7.98% on the average. This situation shows that the suggested measures are very effective in taking the risks under control and they should be applied and followed appropriately.

V. CONCLUSIONS

This study serves to be a unique example in belt conveyor applications which encompasses FMEA, being a milestone risk analysis method in safety and ETA, which is a crucial qualitative and quantitative risk analysis method in engineering sector. In this study, risk analysis was carried out for belt conveyors, which is one of the mostly used haulage methods in industry. Firstly, risks that may occur in belt conveyor haulage were identified and FMEA was applied. Then to analyze the initiating events in more detail, ETA was used for each defined risk. In the results of the study, by use of suggested measures and barriers, it is shown that occurrence of severe accidents can be decreased considerably. In addition, it is important to make risk analysis continuously in belt conveyor facilities to keep risks under control and prevent accidents. By this way, it can be possible to keep operators safe and healthy as well as to prevent production and economical losses.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.
Methodology: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.
Investigation: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.
Discussion of results: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.
Writing – Original Draft: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.
Writing – Review and Editing: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.
Supervision: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.
Approval of the final text: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.

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RESEARCH ARTICLE OPEN ACCESS

RADIOLOGICAL RISK ASSESSMENT OF ^{238}U, ^{232}Th AND ^{40}K IN THE TOP SOILS OF AHERO PADDY FIELDS OF KISUMU COUNTY, KENYA

Kere Wanyama Mukanda*[1], Michael Nakitare Waswa[2] and Linda Ouma[3]

[1, 2, 3] Department of Science, Technology and Engineering; Kibabii University, P.O BOX 1699- 50200, Bungoma, Kenya.

[1] http://orcid.org/0000-0003-2667-8525, [2] http://orcid.org/0000-0003-2479-862X, [3] http://orcid.org/0000-0002-4975-2495

Email: *kerewanyama2018@gmail.com, mwaswa@kibu.ac.ke, oumachieng@gmail.com

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ABSTRACT

A radiological risk assessment of ^{238}U, ^{232}Th and ^{40}K in the top soils of Ahero paddy fields of Kisumu County has been measured using NaI(TI) gamma ray spectroscopy. A total of 17 samples were collected at a depth of 15 - 20 cm and measured for activity concentrations of three radionuclides which were used to calculate the absorbed dose rates and Annual effective dose rates of the samples. Samples were collected from fields at various stages of farming process i.e., four (4) weeks after transplanting (field 1), during transplanting (field 2), after harvesting and land ploughed (field 3) and a control field (field 4) where rice farming had not been done for 2 years. The average activity concentrations for the three radionuclides for field 1 were 32.63 ± 1.63 Bq/kg for ^{238}U, 104.69 ± 5.20 Bq/kg for ^{232}Th and $75.00 \pm 3.2\ 6$ Bq/kg for ^{40}K. The average activity concentrations of the radionuclides from field 2 were 16.97 ± 0.84 Bq/kg, 68.03 ± 3.40 Bq/kg and 70.31 ± 3.51 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively. The average activity concentrations of the radionuclides from field 3 (post harvesting) were 28.92 ± 1.44 Bq/kg, 91.73 ± 4.58 Bq/kg and 122.60 ± 6.13 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively. The average activity concentrations of the radionuclides were 29.74 ± 1.48 Bq/kg, 121.11 ± 6.05 Bq/kg and 87.51 ± 4.37 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively. The average Absorbed Dose Rates were 81.50 ± 4.07 nGy/h for field 1, 52.59 ± 2.62 nGy/h for field 2; 74.68 ± 3.73 nGy/h for field 3 and 91.79 ± 4.59 nGy/h for field 4. The values were below the permissible limit of 1500 nGy/h, thus the radiological risk associated with the top soils of the Ahero Paddy fields of Kisumu County, Kenya is insignificant.

I. INTRODUCTION

The origin of radionuclides of Uranium ^{238}U, Thorium ^{232}Th and Potassium ^{40}K dates back to the formation of the Earth [1]. The three radionuclides are found in significant concentrations in various environmental media such as water, soil sediments, plants and foodstuffs [2] and their contents in the soil are directly related to the weathered bedrock. The radionuclides of ^{238}U, ^{232}Th and ^{40}K forms a major source of radiation exposure to the largest group of human population [3]. The radionuclides along with essential nutrients may be absorbed from the soil via the plant roots and transported to other parts of the plant. When they get in edible parts of the crop; they can cause internal exposure to human beings [4].

It is worth noting that ^{238}U and ^{232}Th are radiotoxic elements if they exceed permissible levels whereas ^{40}K is both radiotoxic and nutritionally important [5]. Humans and their foodstuffs are exposed to various types of radiations that originate from primordial, cosmogenic, terrestrial and natural decay series radionuclides [6]. Human beings ingest and inhale radionuclides via consumption of food, water and air respectively. ^{238}U, ^{232}Th and ^{40}K and their numerous progeny are the common radionuclides available in food [7]. An amount of eighty three percent annual effective dose is experienced by individuals due to natural decay series radionuclides, whereas sixteen percent is contributed by primordial ^{40}K and the remaining one percent is due to anthropogenic radionuclide. Soil to plant and plant to human beings is one of the foremost corridors for transmission of radionuclides [8]. It should be noted that rice is one of the main food consumed by the Kenyan population both in the rural and urban areas. Consequently, human exposure owing to the ingestion of radionuclides via consumption is global concern [9]. Whichever is the mode of exposure, it's a fact that ionizing radiation is detrimental to human health [10].

Human activities such as Agricultural practices have continued to make significant additions to the radioactivity levels of the soil. The use of inorganic fertilizers to replenish both micro and macro elements lost and other agrochemical inputs are associated with the release and subsequent accumulation of natural and artificial radionuclides in the agricultural soils and nearby water sources [11]. The discharge from machines used in production of rice also adds to the overall radionuclide concentration of the soils. The large scale rice farming in Ahero paddy fields is not void of use inorganic fertilizres, agrochemicals, untreated water and mechanical implements. These operations have consequential effects on radioactivity levels of the soil and the whole farming environment [11]. Notwithstanding the economic benefits to the community and government; the knowledge of natural radioactivity due to ^{238}U, ^{232}Th and ^{40}K was important in order to qualify the radiological safeness of the soils as well as categorizing the radiological hazards to the farmers and the general public.

II. MATERIALS AND METHODS

II. 1 STUDY AREA

The study was done in Ahero paddy fields of Muhoroni SubCounty of Kisumu County, Kenya whose population is 151799 (2019 census). It is located on latitude 00°9´´S and longitude 34°56´´E and at an altitude of 1160 m above sea level. The other crops grown here includes soy beans, maize and tomatoes but on a small scale. The source of water for irrigation in this paddy fields is from River Nyando [12]. The soils in the paddy fields are suitable for irrigation of rice due to their low percolation rates. The main rock types that surround the Ahero paddy fields are granites and granodiorites on the north and south while on the eastern and north western are phonolites.

Figure 1: Route Map of Ahero irrigation scheme.
Source: Authors, (2022).

II.2 SAMPLE COLLECTION AND PREPARATION

The top soil samples within the depths of 15 - 20 cm were collected from three paddy fields where rice had been cultivated and from the control site field.

The rice fields were demarcated as field 1, field 2, field 3 and field 4. The field 4 (control site) was 1 km away from the fields 1, 2 and 3. Five soil samples were collected from each of the fields 1, 2 and 3 while two samples were collected from field four (control site). The samples were collected using the manually constructed hand auger and trowel. The top most layers of soil were cleared first to get rid of pebbles and roots from the soil. In each field, five [5] soil samples were collected from the three fields 1, 2 and 3. The samples were then put in containers properly labeled to avoid mix up. The samples were transported to the laboratory and spread on prewashed and labeled polythene mats in an open floor for two weeks for the samples to dry. In order to achieve a constant weight, the samples were manually pulverized using a mortar and pestle and then allowed to pass through a 2.00 mm sieve (< 2.00 mm particles were used). Soil samples from uncultivated land (for 2 years) at about 1 km from the fields which served as a control site was also collected and prepared in the same way. 170 g of each sample from the fields was weighed in to cylindrical plastic containers of uniform geometry which were soaked in dilute Sulphuric acid and then rinsed with distilled water to avoid external contamination of samples. The containers were properly labeled and hermetically sealed for a minimum of 30 days to allow for the radioactive secular equilibrium to be reached between parent and daughter radionuclide before embarking on gamma counting.

II.3 GAMMA RAY SPECTROSCOPY

Each sample was placed in a NaI(Ti) γ ray spectrometer that was shielded to prevent stray radiations. The system included an oxford PCA-P multichannel analyzer (MCA) card and its software for spectral acquisition and analysis. The gamma ray spectrometer was calibrated using certified samples of ^{238}U, ^{232}Th and ^{40}K. The peaks of corresponding to ^{232}Th (2615 KeV), 1460 KeV (^{40}K) and 1765 KeV (^{238}U) were considered for the respective activity concentrations. Each sample was put in the NaI(Ti) detector for measurement for a period of 30000 seconds. Distilled water was also put in the detector to provide background measurement.

II.4 DETERMINATION OF ACTIVITY CONCENTRATIONS OF THE RADIONUCLIDES

The spectra for ^{238}U, ^{232}Th and ^{40}K were obtained using the peaks as follows: 1765 KeV (^{214}Bi), 2615KeV (Ti) and 1460 KeV ((^{40}K). The activity concentration was computed using equation 1 in Bq/kg [13].

$$A_i(Bqkg^{-1}) = \frac{NC_i}{\mathcal{E}\times Y_i\times m\times t} \quad (1)$$

Where A_i is the activity concentrations of the i^{th} radio nuclide in Bq/kg^-, ε is the efficiency of the detector at the energy of the i^{th} radionuclide, N_{ci} is the net counts of the i^{th} radionuclide in the corresponding photo peak after background subtraction, Y_i is the emission probability of the i^{th} radionuclide, m is the mass of the sample in kg and t is the counting time.

II.5 ESTIMATION OF ABSORBED DOSE RATE (ADR)

The radiation absorbed dose rate, ADR was estimated for radiation risk assessment to quantify the amount of radiation energy that may be deposited per unit time on a potentially exposed person [11]. The absorbed dose rate was calculated using the activity concentration and the conversion factors [14]. The conversion factors for ^{238}U, ^{232}Th and ^{40}K were 0.462, 0.604 and 0.0417 respectively. Equation 2 shows the equation used in computing ADR [15].

$$ADR = 0.462A_u + 0.604_{Th} + 0.0417_{Ak} \quad (2)$$

Where A_u, A_{Th} and A_k are activity concentrations of ^{238}U, ^{232}Th and ^{40}K in $Bqkg^{-1}$ respectively [16].

III RESULTS AND DISCUSSION

III.1 ACTIVITY CONCENTRATIONS

It can be noted that the mean activity concentrations of the three radionuclides for field 1 were 32.63 ± 1.63 Bq/kg for ^{238}U, 104.69 ± 5.20 Bq/kg for ^{232}Th and 75.00 ± 3.26 Bq/kg for ^{40}K. The field 1 is the one in which rice had already been transplanted and the rice seedlings were a month old and some fertilizer had been applied. The activity concentration of ^{238}U was higher than the world permissible level of 45 Bq/kg and although that of ^{238}U was below the world permissible limit of 33 Bq/kg; it was still high. Their high concentrations can be attributed to the phosphatic fertilizers that had been applied apart from the geology of the place characterized by underlying granitic rocks. The activity concentrations of ^{40}K were below the world permissible limit of 420 Bq/kg [17]. The average concentrations of the radionuclides from field 2 where transplanting was being done were 16.97 ± 0.84 Bq/kg, 68.03 ± 3.40 Bq/kg and 70.31 ± 3.51 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively. It can be noted from these values that it's only ^{232}Th that had higher activity concentrations above the world acceptable limit of 45 Bq/kg; this can be attributed to either underlying rocks of the field or River Nyando where water for irrigation originates that contains this radionuclide.

The average concentrations of the radionuclides from field 3 (post harvesting) where harvesting had be done and ploughed were 28.92 ± 1.44 Bq/kg, 91.73 ± 4.58 Bq/kg and 122.60 ± 6.13 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively. The activity concentrations of ^{238}U and ^{232}Th had higher values than the world permissible limits. At this stage, top dressing had been done twice and this may also have added to increased activity concentrations.

The field 4 that had not been ploughed for two years and was a control field unfortunately also recorded higher concentrations of ^{232}Th. The average concentrations of the radionuclides were 29.74 ± 1.48 Bq/kg, 121.11 ± 6.05 Bq/kg and 87.51 ± 4.37 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively. This field had been cultivated continuously previously. The continuous use of inorganic phosphatic fertilizers whose origin is from rocks that contains high concentrations of Uranium and Thorium accumulates in the soils increasing their activity concentrations.

Although some of the activity concentrations for ^{238}U and all for ^{232}Th were higher; they were below the 1000 Bq/Kg for both radionuclides [18], thus the soils are not hazardous to the human population interacting with them.

Graphical representation of the activity concentrations for all the samples in this work are as shown in Figure 2.

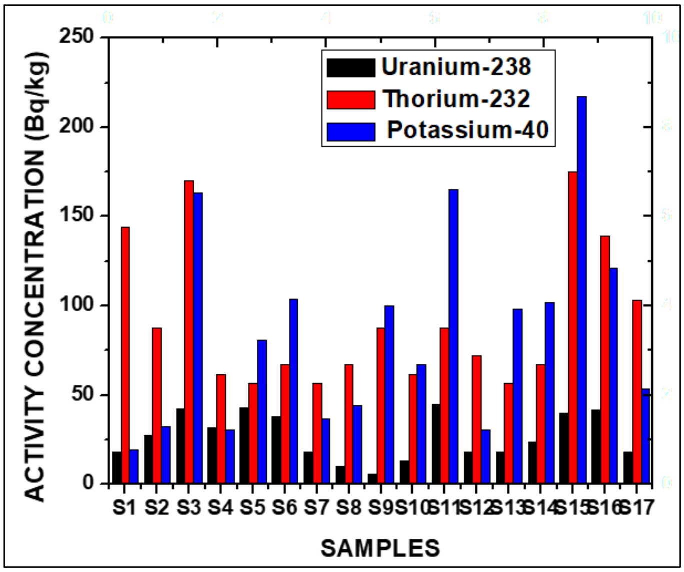

Figure 2: Graphical representations of activity concentrations of the radionuclides in this study.
Source: Authors, (2022).

III.2 ABSORBED DOSE RATE (ADR)

The average Absorbed Dose Rates were 81.50 ± 4.07 nGy/h for field 1, 52.59 ± 2.62 nGy/h for field 2, 74.68 ± 3.73 nGy/h, for field 3, and 91.79 ± 4.59 nGy/h for field 4 (Figure 3). The values obtained from the samples were represented in Figure 3 below.

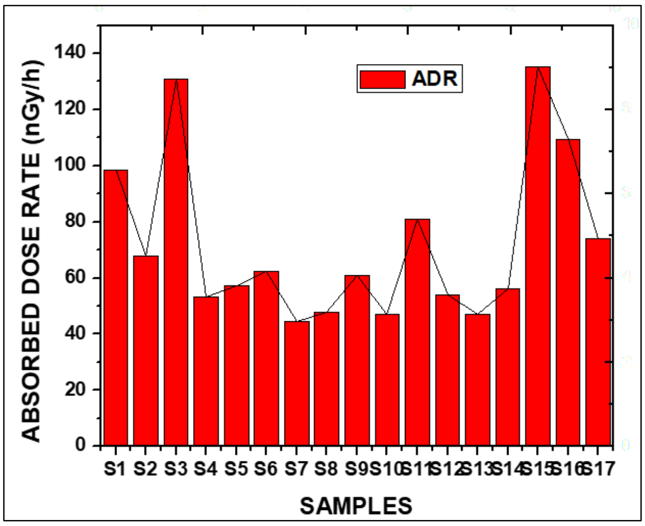

Figure 3: Representation of Absorbed Dose Rate in this work.
Source: Authors, (2022).

It can be noted that apart from field 2 where transplanting was being done; all the other fields had Absorbed Dose Rate values above the world value; 60 nGy/h Figure 3). The values are higher because the activity concentrations were also higher and since Absorbed Dose Rates are calculated from these values; they contributed to the higher values. Despite their higher values, they were below the world acceptable limit of 1500 nGy/h [19].

IV. CONCLUSION

Radiological risk assessment of ^{238}U, ^{232}Th and ^{40}K have been measured in the top soil samples collected from Ahero Paddy fields of Kisumu County, Kenya using gamma ray spectroscopy. The average activity concentrations for the three radionuclides in all the four were within the permissible levels. The average Absorbed Dose Rates (ADR) were 81.50 ± 4.07 nGy/h for field 1, 52.59 ± 2.62nGy/h f for field 2; 74.68 ± 3.73 nGy/h for field 3 and 91.79 ± 4.59 nGy/h for field 4. All the ADR average values were below the permissible limit of 1500 nGy/h. The average annual effective dose rate AED (in) and an average AED (out) for field 1 were 0.30 ± 0.01 mSv/y and an average AED (out) of 0.2*0* ± *0.01* mSv/y, an average AED (in) of 0.19 ± *0.01* mSv/y, an average AED (out) of 0.20 ± *0.01* mSv/y, for field 2, an average AED (in) of 0.28 ± *0.01* mSv/y and an average AED (out) of 0.18 ± *0.01* mSv/y for field 3 and an average AED (in) of 0.34 ± *0.01* mSv/yand an average AED (out) of 0.2*3* ± *0.01* mSv/y, for field 4. All the annual effective dose rates of the samples from all the fields were below the world acceptable limit of 1 mSv/y, hence there is minimal exposure risk to the general population at study area. There is need for radiological survey to be done on the rice components that includes rice grains, rice stalks and rice roots to provide a single analytical and information data base of radiation hazard safety.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Wanyama Mukanda Kere, Michael Nakitare Waswa, Linda Ouma.
Methodology: Wanyama Mukanda Kere and Michael Nakitare Waswa.
Investigation: Wanyama Mukanda Kere and Michael Nakitare Waswa.
Discussion of results: Wanyama Mukanda Kere, Michael Nakitare Waswa and Linda Ouma.
Writing – Original Draft: Wanyama Mukanda Kere.
Writing – Review and Editing: Wanyama Mukanda Kere and Michael Nakitare Waswa.
Resources: Wanyama Mukanda Kere.
Supervision: Michael Nakitare Waswa and Linda Ouma.
Approval of the final text: Wanyama Mukanda Kere, Michael Nakitare Waswa and Linda Ouma.

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VII. COMPETING INTEREST STATEMENT

The authors declare no conflict of interest.

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RESEARCH ARTICLE OPEN ACCESS

SPATIAL ASSESSMENT OF GROUNDWATER DEGRADATION USING PHYSICOCHEMICAL ANALYSIS AND GIS: CASE STUDY OF THE BASEMENT COMPLEX OF ADO EKITI, SOUTHWEST NIGERIA

Akintunde Akinola Oyedele*[1], Jonathan Segun Adekanmi[2], Abel Ojo Talabi[3], Lekan Olatayo Afolagboye[4] and Olufemi Felix Ojo[5]

[1] Department of Physics, Ekiti State University, Ado – Ekiti, Nigeria.
[2] Department of Civil Engineering, Federal Polytechnic, Ado – Ekiti, Nigeria.
[3, 4, 5] Department of Geology, Ekiti State University, Ado – Ekiti, Nigeria.

[1] http://orcid.org/0000-0003-0428-7566, [2] http://orcid.org/0000-0002-9798-6931, [3] http://orcid.org/0000-0002-1733-3368, [4] http://orcid.org/0000-0002-4365-3269, [5] http://orcid.org/0000-0002-9280-6030

Email: *akintunde.oyedele@eksu.edu.ng, adekanmi_js@fedpolyado.edu.ng, abel.talabi@eksu.edu.ng, lekan.afolagboye@eksu.edu.ng, felixfemi.ojo@eksu.edu.ng

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ABSTRACT

Spatial assessment of groundwater degradation has been carried out in Ado–Ekiti using physicochemical analysis and Geographical Information System (GIS). Groundwater samples from 108 wells were analyzed on a regional basis. Application of GIS enabled the preparation of various thematic maps which were analysed in terms of groundwater quality standards for drinking and domestic utility. The thematic maps of pH, Total Hardness, Total Dissolved Solids (TDS), Chloride, Calcium and Nitrate concentrations produced were re-classified for integration in a GIS environment to produce the groundwater quality map. Anthropogenic influences were observed on the groundwater quality status of the study area as non-potable groundwater was delineated at the built-up areas and regions adjacent to streams and rivers. The integration of the thematic maps proved useful for the delineation of zones of groundwater quality suitable for human consumption and domestic purposes. Spatial analysis of the groundwater quality is essential for a proper understanding of the present environmental challenges and a projection into the future. This will facilitate quick decision-making for holistic groundwater development and management.

I. INTRODUCTION

The need for the evaluation of groundwater quality in any area where the majority of the population derive their potable water from the shallow aquifers has been recognised [1-3]. The quality of water remains a vital concern for mankind since it is directly linked with human existence and welfare. In developing countries, it is a general remark that high proportions of diseases are directly related to poor drinking water quality and unhygienic conditions [4, 5].

The utility of water is constrained by its quality which may render it unfit for specific purposes. This underlines the importance of water quality assessment in groundwater resources development and management. Contamination of groundwater could result from inherent composition of aquifer material and anthropogenic sources due to human activities. Leachate from dumpsites, mining activities, buried petroleum pipes/tanks, latrines and septic tanks, indiscriminate disposal of domestic and industrial solid wastes and the widespread use of chemical products such as pesticides, herbicides, and solvents may endanger groundwater quality. A direct consequence might be a threat to public health [6-8].

Urbanization presents increasing challenges of how to ensure adequate water supplies and a suitable water environment. It is noted that humans have exerted large-scale changes on the terrestrial biosphere through land use including agriculture, mining, and waste management [9, 10]. According to [11] groundwater as the main source of potable water supply for domestic, industrial and agricultural uses has been under intense pressure of degradation and contamination due to urbanization, industrial and agricultural related activities. [3] remarked that the quality of shallow groundwater system in the weathered basement aquifer is increasingly being endangered by urbanization, industrial activities, and the emerging threat of impacts of climatic changes. [4] observed an increase in environmental pollution with urbanization in Ekiti State. The highest percentage of pollution was reported in Ado-Ekiti. [12] examined the relationship of some socio-economic factors and household sanitation in Ado-Ekiti. An indifferent status was observed for the general attitude of the residents towards household sanitation and waste disposal. The large dependence on groundwater resources puts premium on its quality status.

II. THEORETICAL REFERENCE

Some studies have been conducted on quality status of surface water and groundwater from boreholes and hand-dug wells in Ado-Ekiti. [13] reported an assessment of physicochemical status of water samples from major dams in Ekiti State, including the Ureje dam located in Ado-Ekiti. [14] subjected water samples taken randomly from twelve hand-dug wells at three selected areas of Ado-Ekiti to some physicochemical and microbiological analyses with a view to assessing the suitability for drinking and other domestic applications. [15] carried out physical, chemical and bacteriological tests on water samples randomly collected from ten hand-dug wells to express the groundwater quality in Ado-Ekiti metropolis. Such studies only considered physicochemical parameters and/or the bacteriological status of the water at discrete instances. There have been no reports on groundwater quality mapping on Ado-Ekiti at a regional level. Spatial variation of the groundwater quality has not been reported.

Remarkably, some studies have used geographic information system (GIS) as a database system in order to prepare maps of water quality according to concentration values of different chemical constituents [16, 17]. The work of [18] demonstrated the effectiveness of geographic information system in groundwater quality mapping. The study utilized data from physicochemical analysis of 76 water samples collected from bore wells and open wells representing the entire area. Thematic layers of Total Dissolved Solids (TDS), Total Hardness (TH), Cl^- and NO_3^- were overlaid in a GIS environment. GIS has emerged as a powerful tool for creating spatial distribution maps. It would be useful to visualize the spatial variation of certain physicochemical parameters, integrate relevant thematic layers and generate groundwater quality map for Ado-Ekiti metropolis.

This paper presents the spatial assessment of groundwater degradation in the basement complex of Ado–Ekiti using physicochemical analysis and GIS techniques.

II.1 SITE DESCRIPTION AND GEOLOGY

The study area, Ado-Ekiti, Southwestern Nigeria, lies between latitude 7° 33′ and 7° 42′ North of the Equator and longitude 5° 11′ and 5° 20′ East of the Greenwich Meridian (Fig. 1). The area is underlain by the basement complex of Southwestern Nigeria comprising the migmatite–gneiss–quartzite complex, charnockitic and dioritic rocks, older granites and unmetamorphosed dolerite dykes (Figure 2). The region experiences a tropical climate with mean annual temperature of 27°C and distinct wet and dry seasons. About 75% of all rainfall events are of moderate to high intensities. Light showers of less than 10 mm/hr account for only 25%. The major rivers and streams draining the area include Alamoji, Elemi, Ireje; Omisanjana and Awedele Streams [19, 20].

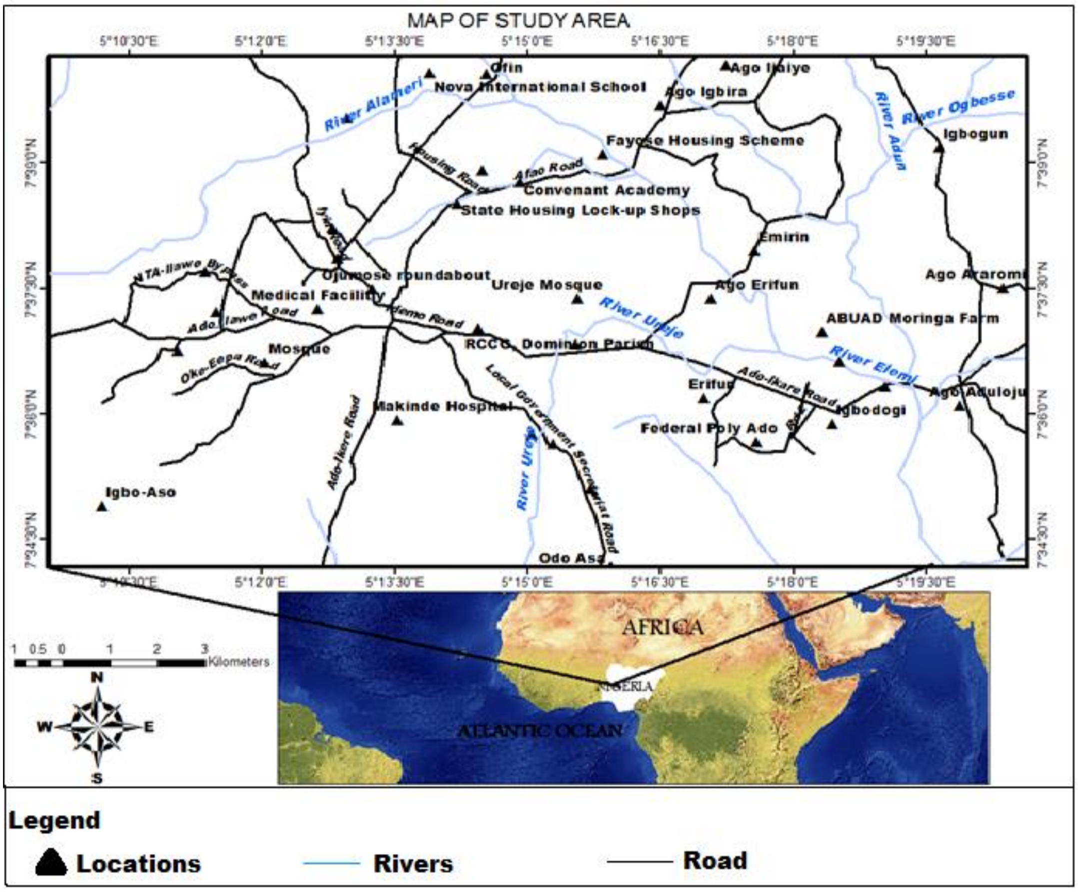

Figure 1: Location map showing the study area.
Source: Authors, (2022).

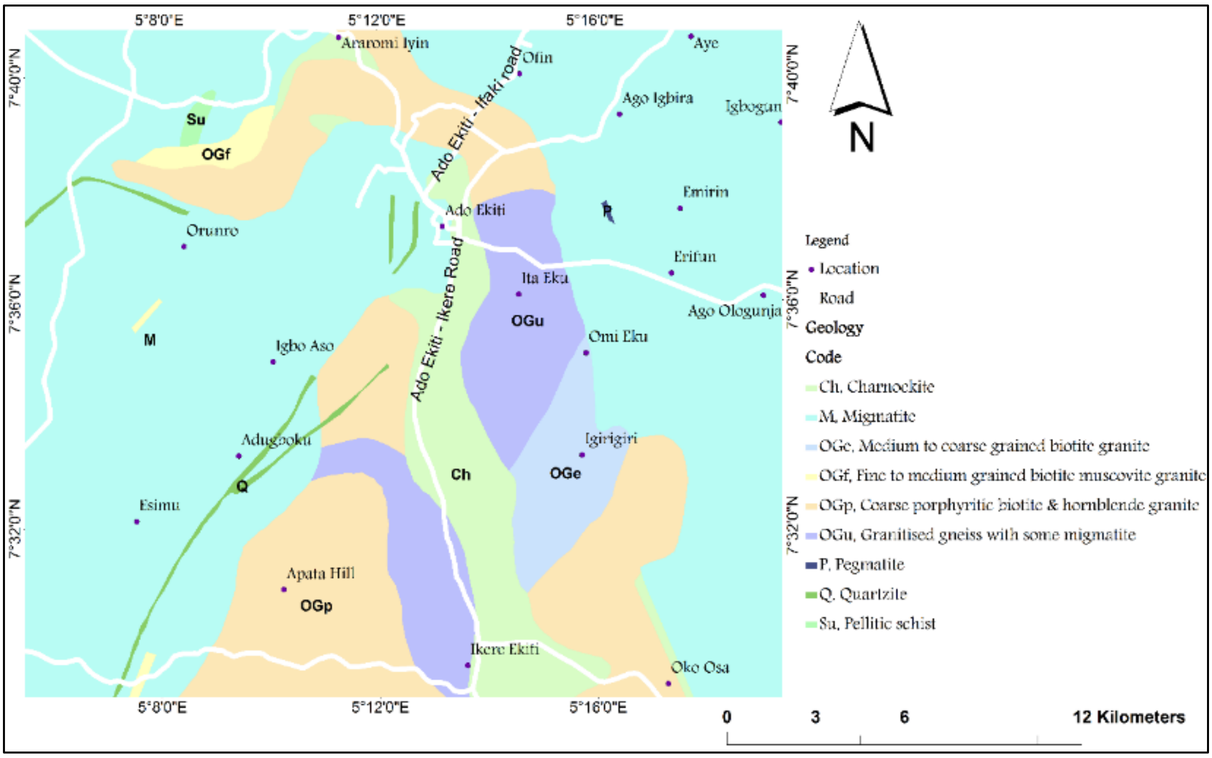

Figure 2: Geological Map of Ado-Ekiti.
Source: Authors, (2022).

III. MATERIALS AND METHODS

Groundwater samples were taken from 108 wells across the metropolis on a regional basis (Figure 3). The samples were analyzed for pH, Total Hardness, Total Dissolved Solids (TDS), Chloride, Calcium and Nitrate concentrations. The physicochemical analysis of the water samples were carried out with a view to determining the potability according to the provisions of the Nigerian Industrial Standard (NIS) and World Health Organization (WHO) for potable water. Standard sampling and laboratory procedures were followed throughout the process [2, 7, 13].

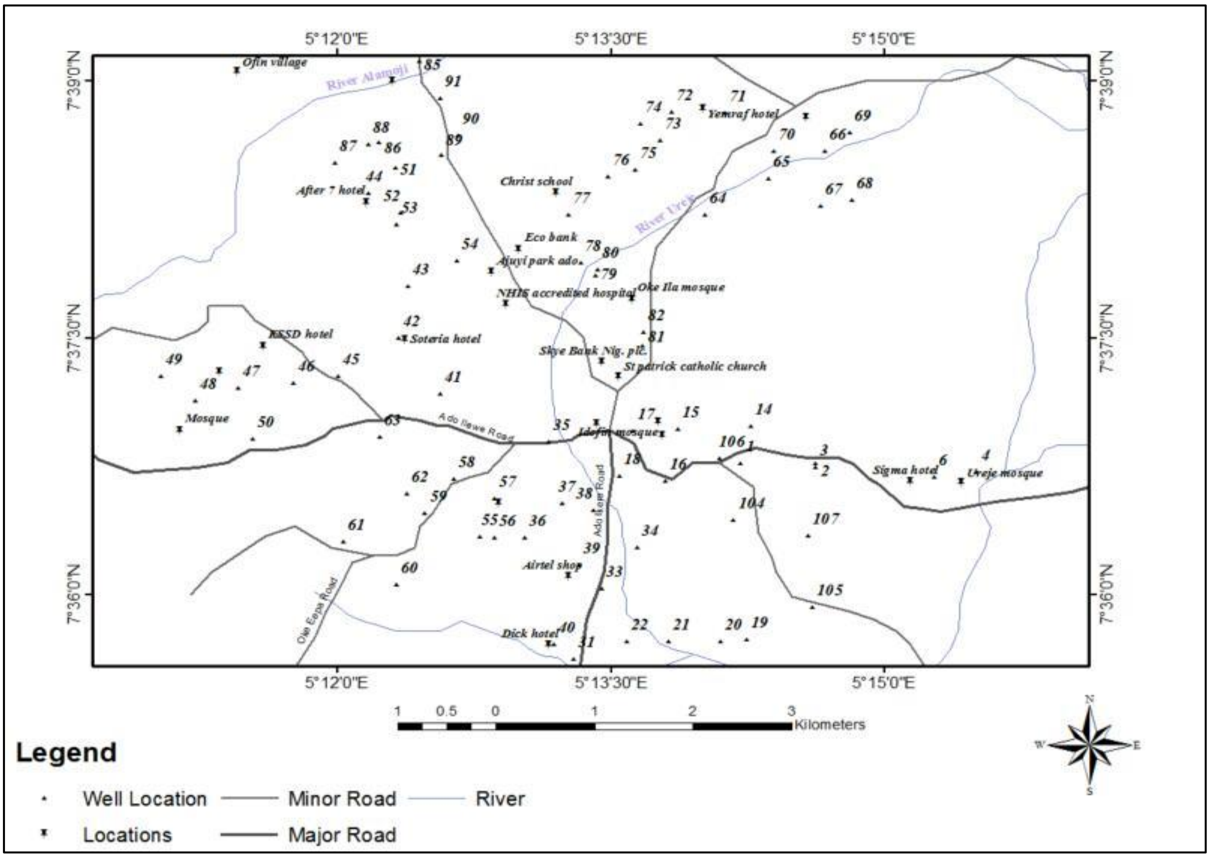

Figure 3: Location map of the study area showing the well points.
Source: Authors, (2022).

The results of the tests were recorded alongside the co-ordinates of the sampling points using a hand-held Garmin 12-Channel GPS Receiver. ArcGIS 10.2.2 was used to perform all operations including geo-referencing, derivation of thematic layers and the Weighted Index Overlay Analysis. GIS application for storing, displaying, and analyzing spatial data permitted creation of the data base [18, 21, 22].

The spatial distribution maps of concentrations of the selected parameters were prepared to show the variation in concentrations of the parameters in water samples across the study area using inverse distance weighted (IDW) raster interpolation technique of the spatial analyst module in ArcGIS software. Groundwater quality map was generated for the metropolis to provide an overview of present groundwater quality status.

IV. RESULTS AND DISCUSSIONS

IV.1 PHYSICO-CHEMICAL ANALYSIS

The summary of the results of the physico-chemical analysis are presented in Table 1. The colour rating of the water samples varied across all the sampling points with the range of 5 - 60 HU and mean value of 15.58 (SD =12.35) HU. Colour in water is attributable to materials in solution. It may be indicative of dissolved organic material. Inorganic contaminants, such as metals, are also common causes of colour. The values of the suspended solids in the water samples varied from 0.00 to 455; with the mean value of 16.95 (SD = 52.67) mg/l.

Table 1: Summary of Descriptive Statistics of Physico-chemical Parameters.

Parameters	Minimum	Maximum	Mean	Std. Deviation
Colour (HU)	5.00	60.00	15.58	12.35
Turbidity (NTU)	0.65	105.50	12.48	14.81
Temp (°C)	4.25	33.00	30.92	2.70
Electrical Conductivity (µS/cm)	0.79	77.00	13.20	13.62
Total Solid (mg/l)	0.50	420.00	42.16	72.57
Suspended Solid (mg/l)	0.00	455.00	16.95	52.67
Dissolved Solids (mg/l)	0.00	405.00	33.57	64.10
pH	3.50	8.20	6.50	0.88
Calcium (mg/l)	3.20	346.00	51.76	51.05
Magnesium (mg/l)	6.30	220.00	51.29	39.22
Chloride (mg/l)	0.51	480.00	53.38	71.94
Total Hardness (mg/l)	20.00	420.00	112.23	67.40
Nitrate (mg/l)	0.00	50.00	3.80	11.29

Source: Authors, (2022).

Turbidity, a measure of suspended minerals, bacteria, plankton, and dissolved organic and inorganic substances, varied from 0.65 to 105.5 NTU with a mean of 12.48 (SD = 14.81) NTU. The materials may also include dust particles and colloidal organic matter. High value of turbidity might be due to high sediment discharge from run - off as suggested by corresponding high colour values. Toxic contaminants can cling to suspended particles, which in turn may be ingested by humans and ultimately invoke health problems [6, 7]

The pH values varied from 3.50 to 8.20 with an average of 6.50 ± 0.88 for the study area. pH is a measure of the hydrogen ion concentration in water. It indicates level of acidity or alkalinity. Drinking water with a pH between 6.5 and 8.5 generally is considered satisfactory. Waters with a pH above 8.5 may have a bitter or soda-like taste. The primary cause of a low pH is the addition of acidic rain water. Other ions found in groundwater such as nitrates and sulphates may result in lower pH. Highly acidic water may result in pipe corrosion, causing the possible release of iron, lead, or copper into the tap water. A low pH may discolour the water and give it a bitter taste [19, 23-25].

The total dissolved solids (TDS) averaged 33.57 mg/l with standard deviation of 64.10 mg/l. Total dissolved solids give a direct measurement of the interaction between groundwater and subsurface minerals. High TDS, greater than 1000 mg/l, is commonly objectionable or offensive to taste. TDS levels over 2,000 mg/l are generally considered undrinkable due to strongly offensive taste. A high TDS (levels above 1,000 mg/l) may promote corrosion of pipes / plumbing systems and appliances [14, 17, 22].

Electrical conductivity (EC) reflects the degree of salinity. It is a direct function of the total salt content in water. As low as EC value of 250 µS/cm is prescribed for drinking water [24-26]. Electrical conductivity varied from 0.79 to 77 µS/cm with a mean of 13.20 µS/cm and most frequently occurring value of 5.00 µS/cm across the study area. High values of electrical conductivities imply high salinity [7, 8, 18].

The concentrations of calcium in the wells ranged between 3.20 and 346 mg/l with average value of 51.76 ± 51.50 mg/l while values obtained for magnesium ranged between 6.30 and 220 mg/l with an average of 51.29 ± 39.22 mg/l. Total Hardness in the samples varied from 20 to 420 mg/l with a mean of 112.23 ± 67.40 mg/l. Total Hardness, made up of temporary hardness and permanent hardness, is due to the presence of certain salts, such as carbonates, bi-carbonates, chlorides and sulphates, of calcium and magnesium dissolved in it [6, 8, 24].

Chlorides concentrations in the wells varied widely between 0.51 and 480 mg/l with mean value of 53.38 (SD = 71.94) mg/l. An increase in the normal chloride content of water may indicate possible pollution from human sewage, animal manure or industrial wastes. An upper limit of 250 mg/l has been set for chloride ions. Objectionable salty taste and laxative effect which aids corrosion in hot-water plumbing fixtures are often associated with high concentrations of chloride ions [11, 15, 25].

Concentrations of nitrates values were moderate in most of the water contact sites except in some few sampling points where the values were high; the mean value being 3.80 (STD = 11.29) mg/l. Nitrate is harmful when it is above the WHO /NSI standard of 10 mg/l for drinking water [6, 14, 19]. Nitrates indicate contamination by anthropogenic activities, such as agriculture, industry, domestic effluents and emissions from combustion engines [19, 28, 29]. Extreme ingestion of nitrates in drinking water has been connected with the risk of methemoglobinemia/blue baby syndrome in humans [23, 30].

IV.2 HYDRO-GEOCHEMICAL CONTOUR MAPS

To demonstrate the regional dispersion of the dissolved ions, the results of the physicochemical analysis of the water samples are presented in the form of hydro-geochemical contour maps (Figures 4 - 9). Almost all the hydro-geochemical maps of the measured parameters show fairly similar patterns. The peripheral parts of the study area have low values and the contours are widely spaced. Contour spacing irregularly decrease towards the centre of the metropolis. The irregular spacing indicates uneven distribution of ions probably due to uneven rate of water movement within the aquifer. This is a consequence of differential soil permeability from one point to another which is characteristic of aquifers in the basement complex [1-3].

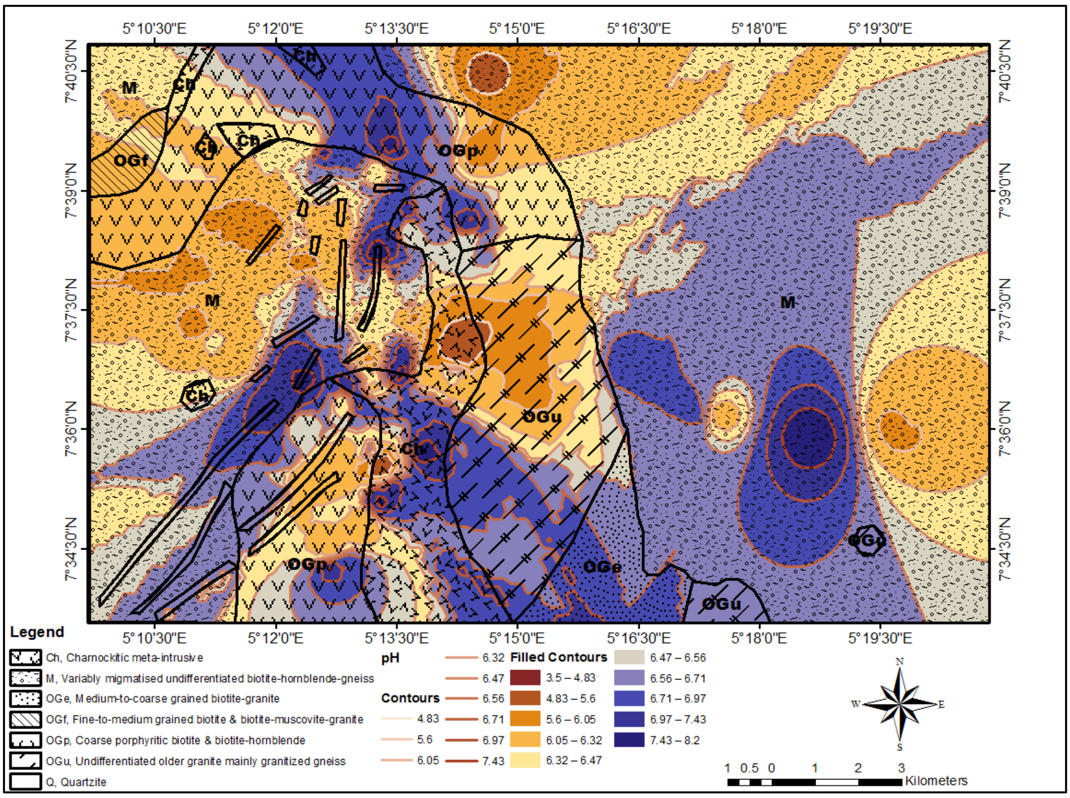

Figure 4: Spatial variation of pH in the study area.
Source: Authors, (2022).

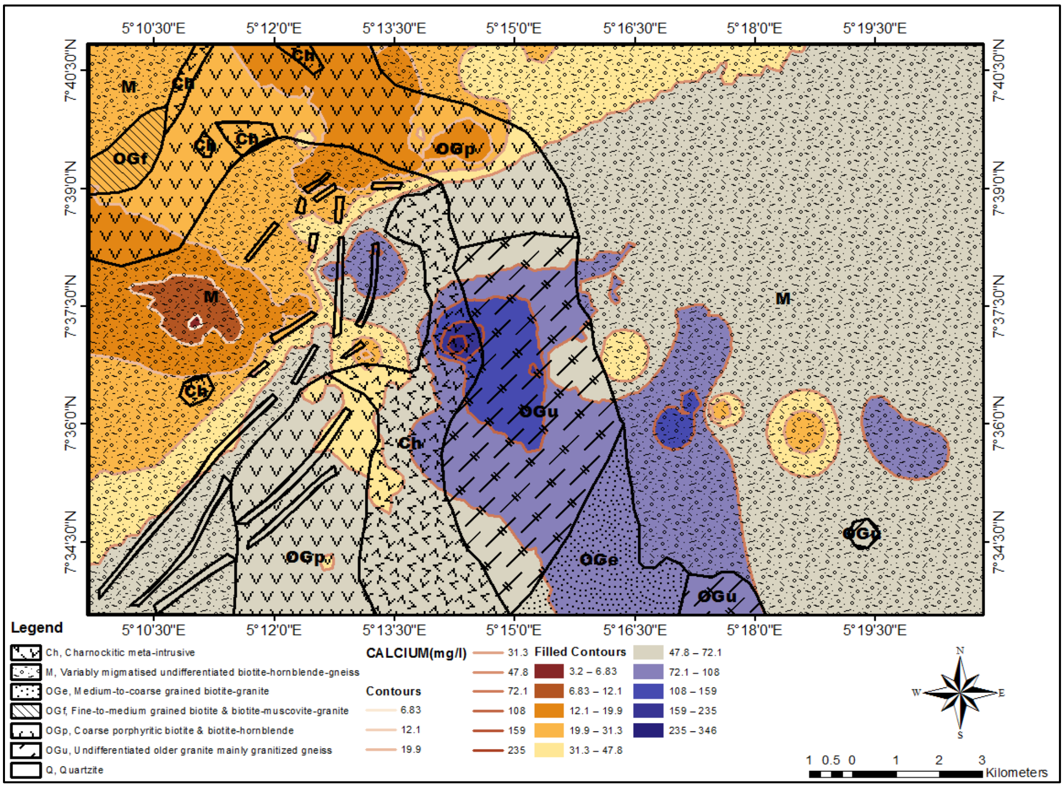

Figure 5: Spatial variation of Calcium in the study area.
Source: Authors, (2022).

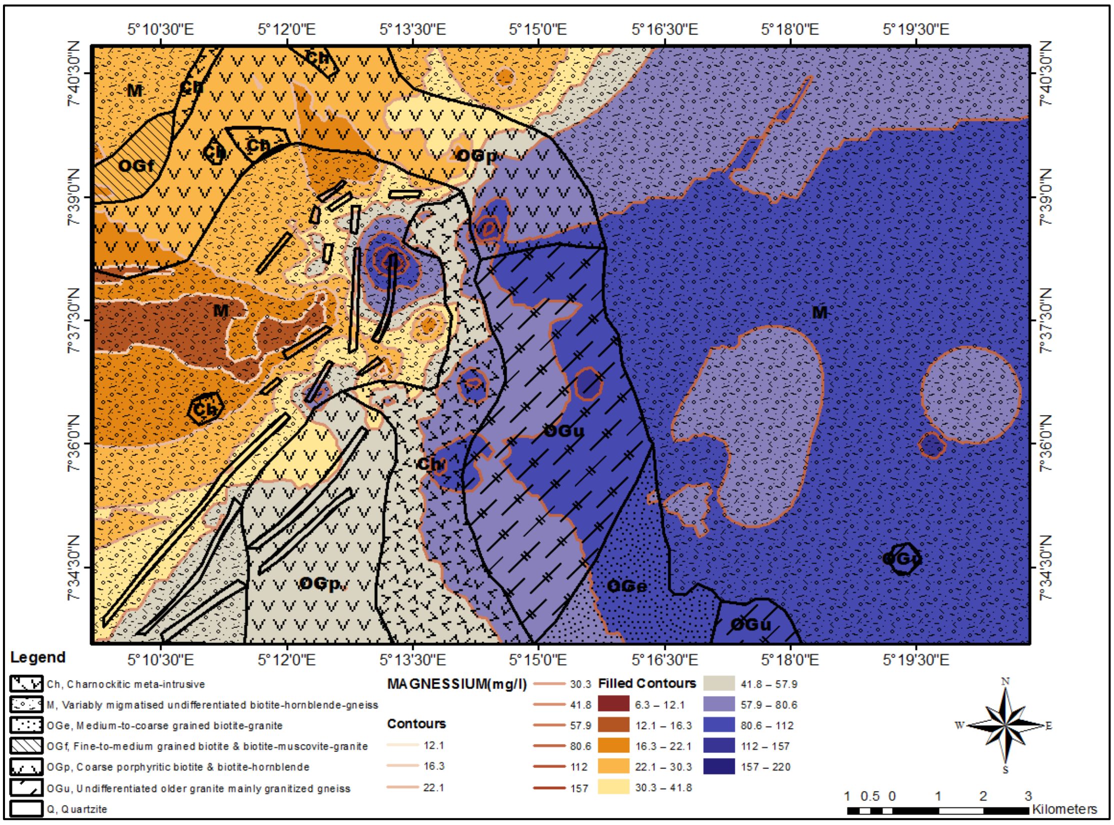

Figure 6: Spatial variation of Magnesium in the study area.
Source: Authors, (2022).

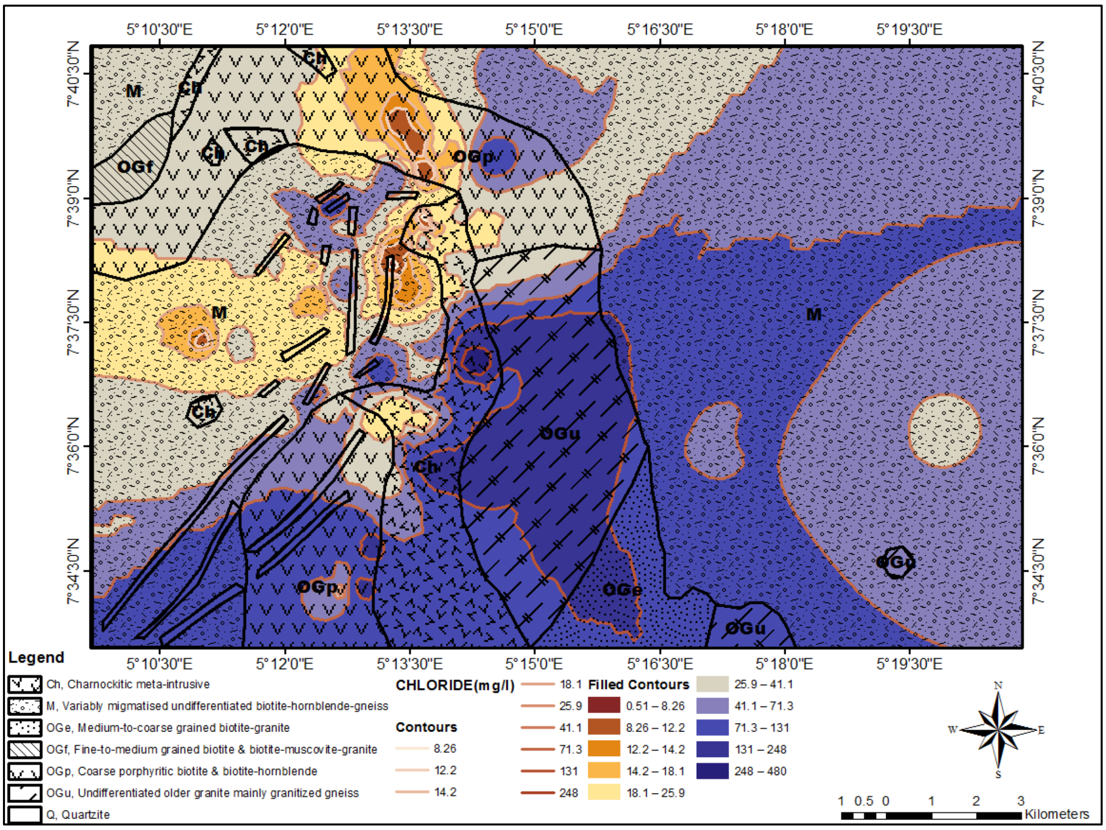

Figure 7: Spatial variation of Chloride in the study area.
Source: Authors, (2022).

The contours cut across geological boundaries indicating the reduced influence of geology in determining the water chemistry. The contours seem to follow the demography of the area. High values are found in the densely populated parts of the study area while low values are found in the outskirt and sparsely populated parts [27, 3]. Contamination often occurs in areas with high population density, industries, and agricultural activities, where groundwater is frequently used as a freshwater source [10, 19, 29].

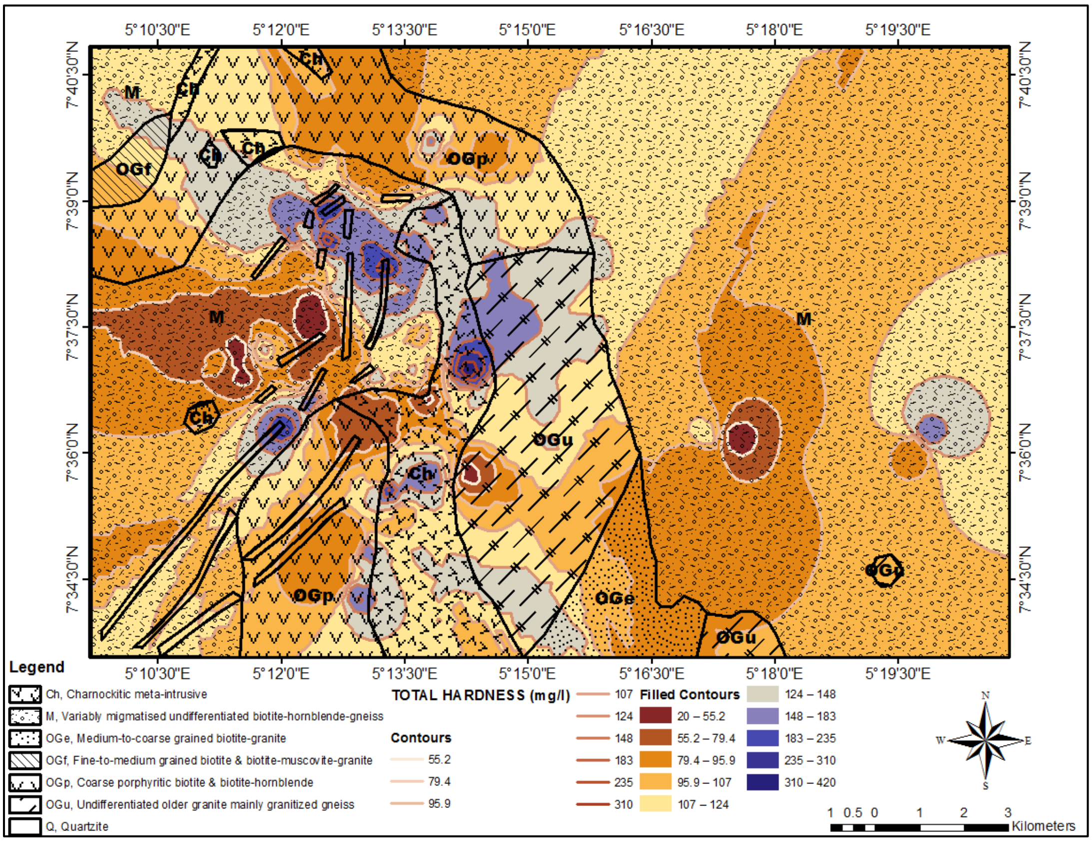

Figure 8: Spatial variation of Total Hardness in the study area.
Source: Authors, (2022).

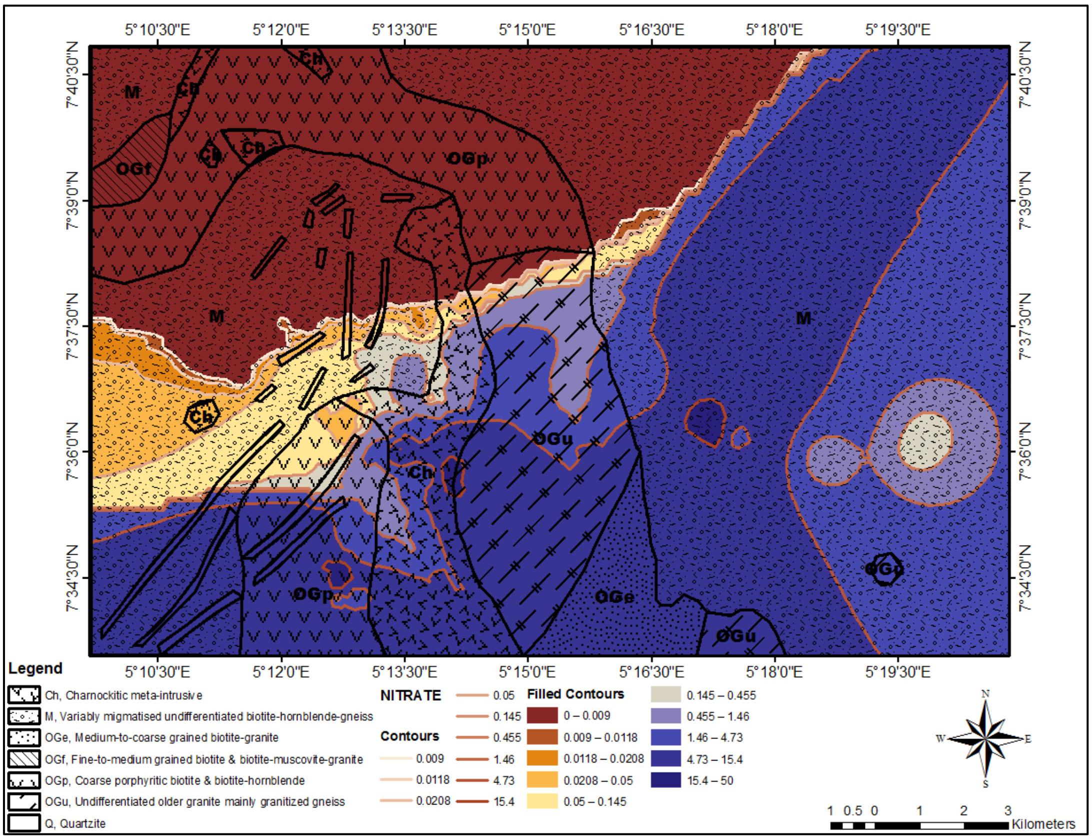

Figure 9: Spatial variation of Nitrate in the study area.
Source: Authors, (2022).

IV.3 THE GROUNDWATER QUALITY MAP

The Groundwater Quality Map of the study area, Figure 10, was produced by integrating re-classified thematic layers of Nitrate, pH, Total Hardness, TDS, Chloride and Calcium using the weighting of Table 2. Data of relevance can be integrated by weighted index overlay method to produce appropriate models [18, 21-23].

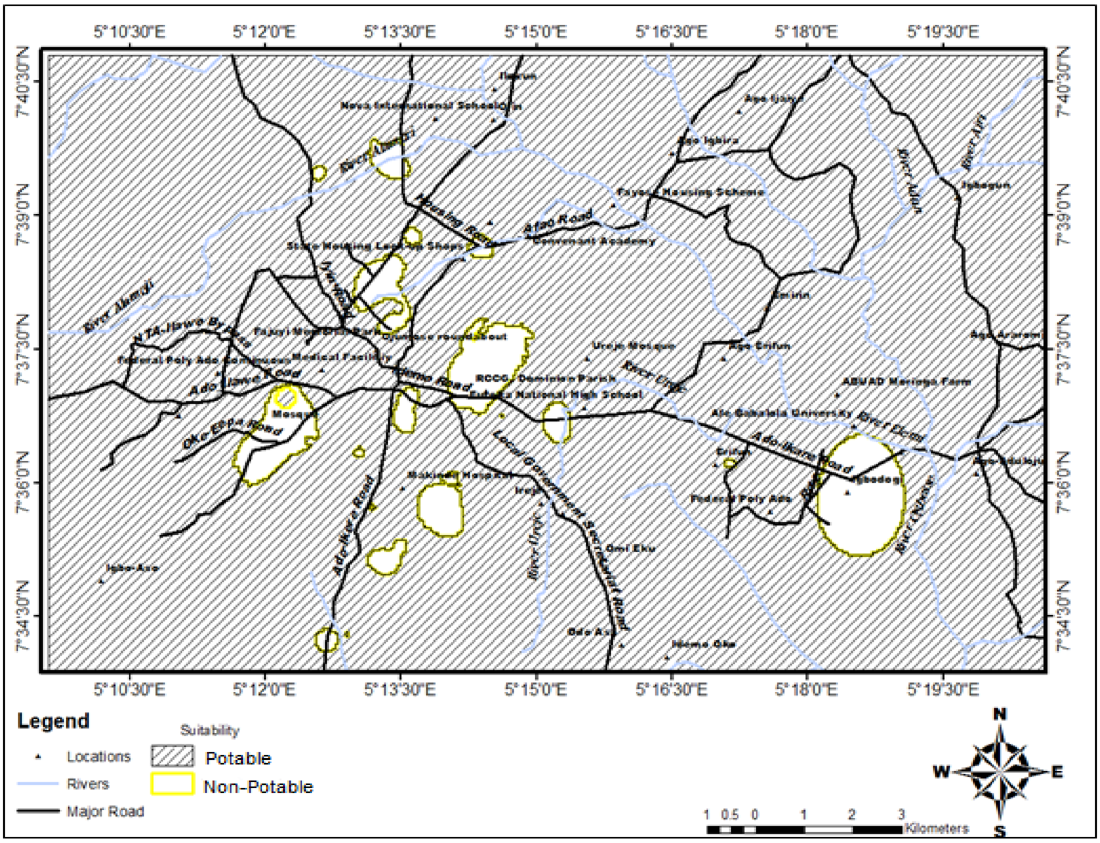

Figure 10: Groundwater Quality Map of the study area.
Source: Authors, (2022).

Table 2: Classification of Themes for Groundwater Quality for Domestic Purposes.

Parameters	Classes	Scale value	Rank
pH	< 7 Acidic 7 Neutral > 7 Alkaline	1 3 1	20
Calcium	< 75 mg/l most desirable 75 - 200 mg/l max allowable > 200 mg/l	3 2 1	15
Chloride	< 250mg/l most desired limit > 250mg/l max allowable Limit	3 1	15
Total Hardness	< 75mg/l soft 75 - 150 mg/l moderately hard 150 - 300 mg/l hard > 300 mg/l very hard	4 3 2 1	15
Total Dissolved Solid	< 300 mg/l Excellent 300 - 377 mg/l Good	3 1	10
Nitrate	< 45 mg/l > 45 mg/l	3 1	25

Source: [24, 25].

The map revealed that the potable groundwater in the study area covered an areal extent of 248.87km^2 with non-potable groundwater over an areal extent of 9.73km^2 occurring at portions along the northwestern, southwestern, southeastern flanks and the central region.

According to [27], the management of groundwater quality requires a multidisciplinary approach with sufficient reflections on the continuous human pressure on natural resources. Regions adjacent to streams and rivers commonly have records of non-potable groundwater. These observations underline the processes of urbanization, industrialization and fast population growth in Ado-Ekiti. It is observed that houses have been built very close to the banks of the rivers and streams. Such streams are used for disposal of domestic, industrial and urban wastes. The natural attenuation effects of the streams might have been over- stretched. Consequently, the groundwater quality might be compromised [4, 12, 19].

Human activity imprints were observed on the hydro-geochemistry of the study area. Densely populated regions have groundwater with high concentration of dissolved ions while the areas of low population exhibit low concentration of dissolved ions. The shallow aquifers are potentially vulnerable to pollution from point sources such as agricultural (fertilizers), domestic (waste dumps, latrines) and industrial sources, except where surface layers are of poor permeability and afford some protection of the underlying aquifers. The study of [29] suggests that specific attention should be paid to land management. Generally, nitrate and nitrite contamination of groundwater occurs due to the use of inorganic fertilizers, household and industrial waste, septic tank leakage, alongside waste from landfills [3, 22].

Great care should be taken to protect domestic and public water supplies from pollution. Indiscriminate siting of refuse dumps and other waste disposal facilities should be discouraged to avoid the unpleasant consequences of polluting the near surface/shallow hand – dug wells. [31] reported that numerous landfills in the urban area could trigger groundwater pollution that could become a major health problem for nearby dwellings. The authors remarked that the plume would extend towards the main fracturing direction of the crystalline bedrock.

Groundwater quality conditions can be supervised by making regular monitoring wells to mitigate pollution [29]. The work of [32] emphasized the need to protect groundwater resources. The study made recommendations for groundwater management including environmentally sound groundwater use. Compliance with proper treatment of effluents and wastes in line with the NIS and WHO standards should be encouraged and put in place.

V. CONCLUSIONS

The use of physicochemical analysis in a GIS platform resulted in the development of an efficient spatial data management with a data base on groundwater quality. The study revealed non-potable groundwater at the built-up areas and regions adjacent to streams and rivers. The shallow aquifers are potentially vulnerable to pollution from agricultural (fertilizers), domestic (waste dumps, latrines) and industrial sources, except where surface layers are of poor permeability and afford some protection of the underlying aquifers. The integration and analyses of various thematic maps proved useful for the delineation of zones of groundwater quality suitable for domestic purposes. With the implementation of GIS, large volume of geospatial data and information are not only maintained in a standard format but can be revised and updated with additional features. Sustainable groundwater development and management are thus facilitated at real time.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Oyedele, Talabi and Adekanmi.
Methodology: Oyedele, Talabi and Afolagboye.
Investigation: Oyedele, Ojo, Afolagboye and Adekanmi.
Discussion of results: Oyedele, Ojo, Adekanmi and Afolagboye.
Writing – Original Draft: Oyedele.
Writing– Review and Editing: Talabi, Ojo and Afolagboye.
Resources: Oyedele, Ojo, Adekanmi and Afolagboye.
Supervision: Talabi and Adekanmi.
Approval of the final text: Oyedele, Adekanmi, Talabi, Afolagboye and Ojo.

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