12-2022

A Multi-Criteria Ranking System for Prioritizing Maintenance of Levee Systems in Arkansas

Nguyen Danh Phan

University of Arkansas, Fayetteville

A Multi-Criteria Ranking System for Prioritizing Maintenance of Levee Systems in Arkansas

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Industrial Engineering

by

Nguyen Danh Phan
California State University Long Beach
Bachelor of Science in Marketing, 2015
University of Arkansas
Master of Science in Operation Management, 2019

December 2022
University of Arkansas

This thesis is approved for recommendation to the Graduate Council.

Shengfan Zhang, PhD
Committee Chair

Michelle Barry, PhD
Committee Member

Gregory Parnell, PhD
Committee Member

Abstract

There are 208,009 properties in Arkansas that have more than a 26% chance of being severely affected by flooding over the next 30 years, which represents 13% of all properties in the state. A levee system is designed to reduce the flooding risk for urban and rural communities; however, most of the state's levees have been significantly outdated or built with engineering standards less rigorous than current best practices. The Levee Safety Action Classification (LSAC), as recorded in the National Levee Database (NLD), communicates the risk associated with living behind a particular levee and assists local, state, and federal stakeholders in identifying and prioritizing funding needs. It is expected that LSAC will decrease as flood risk decreases. However, in some cases, the LSAC for a particular levee may stay High even if it is in perfect condition when the area behind it is densely populated or significantly developed. We develop a multi-criterion ranking framework, integrating Principal Component Analysis (PCA) and Multi-Criteria Decision-Making (MCDM) methods (i.e., a CRITIC-TOPSIS approach), for prioritizing maintenance of the Arkansas levee systems in Arkansas using the NLD data. The results show the rankings from each method are not significantly different from each other. When compared to the LSAC, it is important to note that the top-ranked levee systems obtained using the PCA or CRITIC-TOPSIS ranking method often have a low to moderate LSAC. Therefore, they are mostly in low priority of maintenance by according to the US Army Corps of Engineers (USACE), despite having a higher probability of being in poor conditions or having design and performance issues. Moreover, we perform a cost-benefit analysis, comparing the operating and maintaining costs with the associated benefits to determine maintenance prioritization. Additionally, we propose other modeling frameworks, such as multi-objective decision analysis (MODA) and sequential decision-making methods, that are suitable for this problem but cannot be implemented in this research due to limited data and stakeholder involvement.

Acknowledgement

I would like to express my deepest appreciation to my research advisor, Dr. Shengfan Zhang, for believing in me and providing continual support throughout this research. Her guidance has carried me through figuring out the methodology and presenting the research work as clearly as possible. I would also like to thank my committee members, Dr. Gregory Parnell and Dr. Michelle Barry, for their brilliant feedback and suggestions on how to improve my research further. I would also like to give special thanks to my friend, Luis Munoz, my research would not be possible without his invaluable data.

Finally, I would like to thank the Maritime Transportation Research and Education Center, funded by the U.S. Department of Transportation under Grant Award Number 69A3551747130, for supporting this research.

Table of Contents

1. Introduction 1

1.2 Motivation and objective 2

1.3. Literature review 3

2. Methodology 5

2.2 Principal Component Analysis (PCA) 10

2.3 CRITIC weights/ TOPSIS ranking 11

3. Results and comparison 12

3.1 PCA ranking results 12

3.2 CRITIC objective weights /TOPSIS rankings results 15

3.2 Comparison of the results 18

3.3 Cost-benefit analysis 19

Appendix A. Principal Component Table calculated using PCA 26

Appendix B. Estimate Maintenance Cost for each Levee in Arkansas 29

Reference 31

List of Tables

Table 1. LSAC Classification Rating Definitions 2

Table 2. Pros and cons of each MCDM related methods for multi-criteria ranking problems 5

Table 3. Description of different criteria 6

Table 4. Arkansas levee data summary table of numeric criteria 6

Table 5. Multinomial logistic regression results for LSAC classification 8

Table 6. Confusion Matrix 9

Table 7. Model Accuracy 9

Table 8. Arkansas Levee system's ranking calculated by PCA 14

Table 9. Correlation coefficient of each criterion 15

Table 10. Standard deviation, conversion of preference values and weights of criteria. 16

Table 11. AR levee ranking calculated using TOPSIS with CRITIC weights 17

Table 12. List of Arkansas levee systems for cost-benefit analysis 21

List of Figures

Figure 1. Count of FEMA Accreditation Rating 7

Figure 2. Count of Inspection Rating 7

Figure 3. Proposed levee ranking methods 10

Figure 4. PCA Scree Plot Diagram 13

Figure 5. PCA Correlation Plot 13

Figure 6. Linear Regression Plot for PCA and CRITIC TOPSIS rankings 18

Figure 7. Maintenance cost vs value chart 22

Figure 8. Swing Weight Matrix Template. 23

Figure 9. A visualization of a sample Markov chain 24

1. Introduction

During the last few decades, climate change has become a global concern, affecting natural systems, and causing more frequent and intense weather events. Higher temperatures increase the amount of water that evaporates into the air, which can increase precipitation intensity, duration, and frequency [1]. Even moderate amounts of rainfall can cause severe damage, especially in urban areas where flooding is a growing problem. During the spring of 2019, Arkansas suffered massive flooding because of extreme precipitation events along the Arkansas River [2]. It is important to note that flood intensity and probability are influenced by multiple anthropogenic factors aside from climate change, including rapid urbanization, expansion of impervious surfaces, and vegetation removal [3].

Flooding is a devastating disaster that results in loss of life, property damage, crop destruction, etc. In a flooding event, communications systems, and infrastructure, such as roads, bridges, and power stations, may be damaged. Flooding may cause some economic activities to stop, forcing people to leave their homes and disrupting everyday life. There are also long-term consequences of infrastructure damage, such as disruptions of water supplies, wastewater treatment, electricity, transportation, communication, education, and health care [4]. Communities in floodplains can be economically vulnerable as they lose livelihoods, purchasing power, and land value.

There are 208,009 properties in Arkansas that have more than a 26% chance of being severely affected by flooding over the next 30 years, which represents 13% of all properties in the state [5]. A levee system is designed to reduce the flooding risk for urban and rural communities; however, most of the state's levees have been significantly outdated or built with no appropriate design and engineering. Recent flooding and levee failures in Arkansas, especially the recent events in 2019, have also highlighted the current state of the levees and the urgent need for a proactive approach to levee maintenance.

1.2 Motivation and objective

The National Levee Database (NLD) is maintained by the U.S. Army Corps of Engineers (USACE), which contains information about the location and characteristics of approximately 2,000 levee systems that fall under USACE programs. The Levee Safety Action Classification (LSAC), recorded in the NLD, communicates the risk associated with living behind a particular levee and assists local, state, and federal stakeholders in identifying and prioritizing funding needs. LSAC is a classification system identifying risk by looking at three different criteria: hazards (the probability of a levee being breached), performance (how a levee system performed in the past, and how it is expected to perform in the future) and consequence (the number of people and infrastructure that will be impacted when an event exceeds design capacity) [6]. A levee that reduces the risk for a dense population will receive a higher risk classification compared to a similarly constructed levee with a smaller population, because its consequences of failure are more significant. There are six levels of the LSAC classification system, as described in Table 1:

Table 1. LSAC Classification Rating Definitions

Very High (1)	Likelihood of inundation due to breach and/or system component malfunction in combination with loss of life, economic, or environmental consequences results in very high risk.
High (2)	Likelihood of inundation due to breach and/or system component malfunction in combination with loss of life, economic, or environmental consequences results in high risk.
Moderate (3)	Likelihood of inundation due to breach and/or system component malfunction in combination with loss of life, economic, or environmental consequences results in moderate risk.
Low (4)	Likelihood of inundation due to breach and/or system component malfunction in combination with loss of life, economic, or environmental consequences results in low risk.
Very Low (5)	Likelihood of inundation due to breach and/or system component malfunction in combination with loss of life, economic, or environmental consequences results in very low risk.
No Verdict	Not enough information is available to assign risk

A Very Low or Low LSAC indicates extremely low consequences of failure. It is still possible, however, for a levee system with these classifications to have performance and maintenance issues. In contrast, a well-maintained levee system with perfect performance can often be assigned a high-risk classification if the area behind the levee is populated, developed, or has critical infrastructure. It is expected that LSAC will decrease as flood risk decreases. However, in some cases, the LSAC for a particular levee may stay High even if it is in perfect condition when the area behind it is densely populated or significantly developed. It is notable that USACE uses the LSAC as a basis to prioritize funding needs and proceed with further actions related to levees. Due to a limited maintenance budget, the levees with high failure consequences may deplete the entire budget, leaving the ones that need maintenance to be degraded till they fail. Therefore, we are motivated to develop indicators that consider more related and important factors than LSAC for assessing maintenance needs and funding.

The goal of this thesis is to demonstrate how multi-criteria decision making (MCDM) can be implemented to identify Arkansas' critical levees that are essential for ensuring safety and reducing economic loss from closures of roadways and bridges. Our study will review MCDM methods in infrastructure maintenance and decide which methods or combinations of methods are most suitable for solving the problem. To implement the MCDM methods, we incorporate a set of criteria based on the information collected from NLD to rank levee systems. The developed rankings for critical levees in Arkansas can facilitate the development and deployment of an appropriate maintenance plan. We also propose other methods that potentially have improved results but cannot be applicable in this thesis due to a lack of data.

1.3. Literature review

MCDM techniques have been proven to support industrial organizations in aligning their business and operational objectives with the options presented through a structured and justified approach. Applying a hybrid technique that uses the best features of each MCDM technique can improve the accuracy and reliability of the results to make the best decision. There have been several studies that have combined different MCDM methods into hybrid approaches. Elzbieta and Karolina [7] selected the most environmentally favorable option among variants of expressway sections in North-Eastern Poland. They proposed a hybrid approach in which both classic Analytic Hierarchy Process (AHP) and Fuzzy AHP were used for factor weighting, while two other methods were used to develop final rankings: Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS) and PROMETHEE. The results of the conducted multi-criteria analysis almost overlap with the choice made in the analyzed environmental impact report. Shengji et al. [8] proposed using Principal Component Analysis (PCA), a dimension reduction technique, and AHP as two alternatives for interpreting oil test data for transformer insulation in place of the traditional empirical formula (EF) used by asset managers. They showed that PCA has the advantage in working directly with data to explore parameter relations as well as ranking transformers according to their conditions. AHP, on the other hand, presents a way to coherently aggregate criteria in a flexible hierarchical setup for identifying the weightage of the oil test parameters before the interpretation of measurements. The interpreted conditions based on PCA and AHP, along with a track-record proven EF, are similar, particularly for transformers at the extreme end of the insulation condition. Babatunde and Ighravwe [9] determined a hybrid renewable energy source (HRESs) for a rural community using technical, economic, and techno-economic criteria, which combines the importance of criteria by linking the Criteria Importance through Inter-criteria Correlation (CRITIC) and TOPSIS as the solution method.

We summarize the pros and cons of the methods mentioned above in Table 2. In this thesis, we develop a multi-criteria ranking-framework, integrating Principal Component Analysis (PCA) and Multi-Criteria Decision-Making (MCDM) methods (i.e., a CRITIC-TOPSIS approach), for prioritizing maintenance of the levee systems in Arkansas using the NLD data. In addition, we propose other methods that can be developed to solve the problem with potentially improved results. However, we are not able to implement the modeling due to lack of data.

Table 2. Pros and cons of each MCDM related methods for multi-criteria ranking problems

Methods	Pros	Cons
PCA	Reduces the noise in the data and produces independent, uncorrelated variables	The new variables created will have different meanings than the original dataset (i.e., loss of interpretability).
CRITIC	Assign a higher weight to a criterion with a higher contrast intensity and a higher conflict with other criteria.	Has a shortcoming in properly capturing the conflicting relationships between criteria since it merely utilizes the Pearson correlation for this purpose. Studies indicate that this correlation does not always denote the actual relationships between criteria.
AHP	Easy to use; scalable; hierarchy structure can easily adjust to fit many sized problems; not data intensive.	In cases when the number of criteria or alternatives is high, the demanding pairwise comparisons may increase the complexity of the problem and decrease the consistency of pairwise comparisons.
TOPSIS	It has a simple process; easy to use and program; the number of steps remains the same regardless of the number of attributes.	Its use of Euclidean Distance does not consider the correlation of attributes; it is difficult to weigh and maintain the consistency of judgment.

2. Methodology

We use the data from the National Levee Database (NLD), a congressionally authorized database published and maintained by USACE, for this research. The database includes nearly 2,220 levee systems totaling approximately 14,150 miles in length. The database is intended to serve as a dynamic, searchable inventory of information about all known levee systems in the US and be a key resource for supporting decisions and actions affecting levees [10]. In this research, we focus on the data in Arkansas, which contains approximately 115 levee systems and approximately 2,060 miles of levees. Due to the database's high level of non-standardization at the current state, 76 levees are considered for this study as they have the most complete information.

This paper considers eleven criteria relevant to flood fighting, design, construction, operation, maintenance, repair, and inspection. The criteria and their corresponding description have been presented in Table 3. The descriptive statistics of the quantitative variables are summarized in Table 4. The frequency of the FEMA Accreditation Rating and Inspection Rating are plotted in Figures 1 and 2, respectively.

Table 3. Description of different criteria

Criteria	Abr.	Description
1. Average Height	H	The average height, in feet, of the entire levee system.
2. Buildings at risk	B	The estimated number of structures in the leveed area.
3. Days since last inspection	I	Days since the last time inspection was performed.
4. Levee length	L	The length, in miles, of the entire levee system.
5. Leveed Area SQ mile	SQ	Estimated area of a flood plain from which flood water is excluded by the levee system.
6. Population at risk	P	The estimated population within the leveed area.
7. Levee segment	S	A discrete portion of a levee system that is operated and maintained by a single entity.
8. Overtopping AEP	AEP	Probability value based on a hydrological interpretation of the likelihood of occurrence.
9. Property Value	PV	An estimated sum of the structure value, structure contents and vehicles in the leveed area. This value does not include land value, economic productivity loss or transportation infrastructure value (i.e., bridges, runways, roads.)
10. FEMA Accreditation Rating	AR	A rating by FEMA to determine whether the levee system meet the design, data, and documentation requirements
11. Inspection rating	IR	The rating is based on the levee inspection checklist, which includes 125 specific items dealing with operation and maintenance of levee embankments, floodwalls, interior drainage, pump stations, and channels.

Table 4. Arkansas levee data summary table of numeric criteria

	Unit	Min	1st Qu.	Median	Mean	3rd Qu.	Max
1. Average height	Feet	5.5	11.575	14.5	0.20	17.75	33
2. Building risk	Building	1	44	191	34	944	58066

3. Days since last inspection	Days	1197	3198	4444	52	4623	4820
4. Levee length	Miles	0.49	4.0	10.36	0.30	21.62	277.32
5. Leveed area SQ Mile	Sq mile	0.02	1.62	13.95	2.16	46.94	5265.99
6. Population	People	3	90	492	67	2063	135261
7. Levee Segment	Segment count	1	1	1	0.02	2	6
8. Overtopping AEP		0.0002	0.001	0.002	0.00007	0.005	0.1
9. Property Value	Million $	0.11	10.85	53.89	5.62	230.24	9717.13

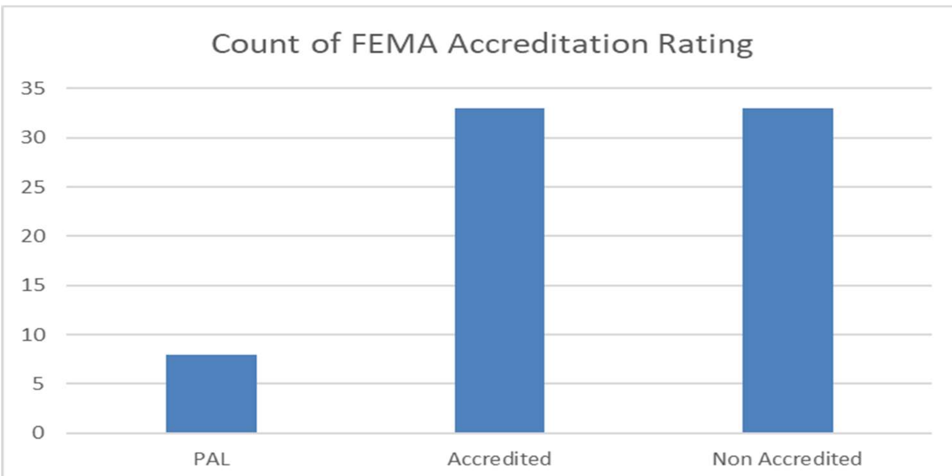

Figure 1. Count of FEMA Accreditation Rating

Figure 2. Count of Inspection Rating

Levee Safety Action Classification (LSAC) provides a systematic, evidence-based estimation of the likelihood and consequence of existing and future risks associated with levee systems. LSACs range from Very High risk (immediate action recommended) to Very Low risk (maintain routine activities). LSACs are used by USACE to prioritize resources across the portfolio and to organize widespread levee-related risk information into reasonably commensurate groupings for action. We perform a multinomial logistic regression model to assess the relationship between LASCs and each of the criteria presented in Table 3.

Table 5. Multinomial logistic regression results for LSAC classification

LSAC		Coef.	Std. Err.	z	P >|z|	[95% Conf. Interval]	
High	Intercept	-174.50	8.10	-21.54	0.00	-190.373	-158.622
	Segment count	0.08	0.08	1.01	0.31	-0.07	0.23
	Miles	1.28	0.64	1.99	0.05	0.02	2.54
	Overtopping AEP	-0.27	0.27	-1.00	0.32	-0.80	0.26
	Leveed Area SQ Mile	-2.79	1.43	-1.95	0.05	-5.60	0.01
	Days since inspection	0.36	0.16	2.16	0.03	0.03	0.68
	Population	4.64	3.46	1.34	0.18	-2.14	11.42
	Property value	2.67	1.25	2.15	0.03	0.23	5.11
	Building risk	-3.78	3.32	-1.14	0.25	-10.29	2.72
	Average height	-0.26	0.14	-1.85	0.06	-0.53	0.01
	Inspection rating (Unacceptable)	129.64	10.60	12.24	0.00	108.88	150.41
	FEMA -Accredited	11.50	5.28	2.18	0.03	1.16	21.85
	FEMA - PAL	18.15	1.04	2.66	0.01	4.76	31.55
Moderate	Intercept	-2.77	2.35	-1.18	0.24	-7.37	1.83
	Segment count	-0.014	0.039	-0.362	0.72	-0.09	0.06
	Miles	0.205	0.113	1.817	0.07	-0.02	0.43
	Overtopping AEP	-0.010	0.057	-0.177	0.86	-0.12	0.10
	Leveed Area SQ Mile	-0.91	0.61	-1.49	0.14	-2.10	0.28
	Days since inspection	-0.006	0.019	-0.32	0.75	-0.04	0.03
	Population	0.76	0.78	0.98	0.33	-0.76	2.29
	Property value	0.06	0.41	0.15	0.88	-0.75	0.87
	Building risk	0.13	0.60	0.22	0.83	-1.05	1.31
	Average height	0.01	0.03	0.54	0.59	-0.04	0.07
	Inspection rating (Unacceptable)	-0.87	0.93	-0.93	0.35	-2.69	0.95
	FEMA -Accredited	1.24	6.83	1.19	0.24	-0.81	3.28
	FEMA - PAL	1.02	1.49	0.69	0.49	-1.90	3.93
(LSAC == low is the base outcome)			AIC: 108.4906		Residual Deviance: 56.4906		

The following conclusions can be made based on the results from Table 5 and using a significant level of 0.05. When the LSAC is high compared to low, criteria including miles, leveed area square mile, days since the inspection, property value, inspection rating, and FEMA accreditation rating are statistically significant. When comparing LSAC between moderate and low classifications, we can see that none of the criteria is significant.

To test the accuracy of the multinomial logistic regression model, we create a confusion matrix as shown in the following Table 6 and model prediction accuracy in Table 7.

Table 6. Confusion Matrix

	Low	High	Moderate
Predicted Low	42	1	8
Predicted High	0	6	0
Predicted Moderate	2	0	8

Table 7. Model Accuracy

	Low	High	Moderate
Predicted Low	0.95	0.023	0.18
Predicted High	0.0	0.86	0
Predicted Moderate	0.13	0	0.5

We can see that this model has an accuracy measure of 83.58%. More specifically, the multinomial logistic regression model can correctly predict a low LSAC at 95% and a high LSAC at 86%. However, it does not perform well when predicting LSAC moderate, which only has an accuracy of 50%. We can conclude that the LSAC does not utilize all of the criteria provided by the National Levee database, and the method of how the USACE comes to assign the LSAC may require additional information that is not publicly available and thus remains a black box to us.

The primary factors determining LSAC are elevation, hydraulic history, performance, and consequence. Since the data does not provide the full level of details connected to how the USACE finalizes the classification, we propose a ranking framework for Arkansas levee systems using PCA as well as a combination of CRITIC and TOPSIS methods. The purpose of the ranking is for maintenance prioritization decisions using the given dataset. The final ranking will be compared between each method used as well as with the LSAC. The proposed flowchart is presented in Figure 3. We explain each method in the following sections.

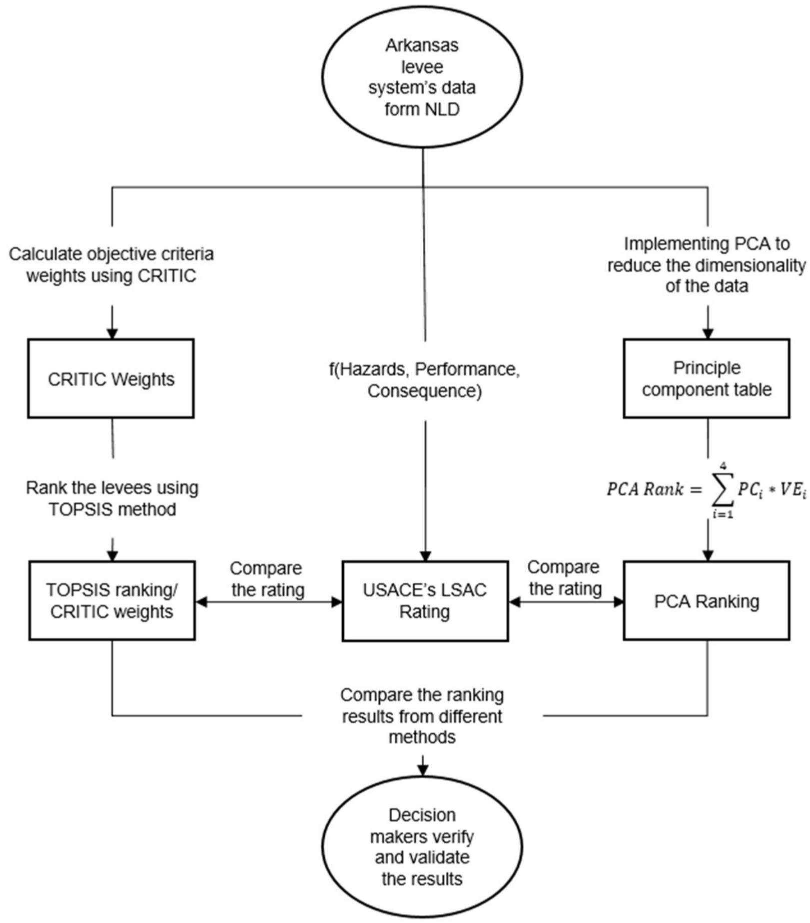

Figure 3. Proposed levee ranking methods

2.2 Principal Component Analysis (PCA)

The PCA method is a multivariate technique that reduces the dimensionality of a set of interrelated variables while retaining the maximum possible variations present in the data set [11]. In this paper, we use PCA to identify the independence among different criteria, which means that the distribution of one does not depend on the others. Then, PCA will transform the columns of a dataset into a new set of features called principal components (PC) [12]. The principal components are obtained from a linear combination of the original variables. The first component has the largest possible variance; the second component is computed with the requirement of being orthogonal to the first components. The same requirement applies to the other components. The inertia assigned to each principal component is in decreasing order from the first component. Generally, the number of principal components coincides with the number of variables in the data set. Nevertheless, the magnitude of inertia carried by each component is used as a criterion to discard those components that do not describe much of the data variability. Therefore, the variable space is reduced to the significant, or relevant, feature space [13]. Combining the data from each column of the PC table with their corresponding amount of variance, we can complete an objective ranking for the levee systems of Arkansas and then compare it with rankings computed using other methods in the thesis.

2.3 CRITIC weights/ TOPSIS ranking

The CRITIC method is based on the standard deviation proposed by Diakoulaki et al. (1995), which uses correlation analysis to measure the value of each criterion. CRITIC is used as our primary method to calculate the objective weights of each criterion and eliminate possible bias associated with subjective evaluation. In addition, CRITIC considers both the contrast intensity and the conflicting relationship held by each decision criterion. In the CRITIC method, the standard deviation is used to measure the contrast intensity of each criterion, then distribute more weight to the one with a higher contrast intensity. The rationality is that it is reasonable to assume that a criterion whose scores differ more from one alternative to another will provide more meaningful information. Thus, from a decision-making perspective, such a criterion should be given more weight than criteria with homogeneous scores. The criteria used in MCDM are often contradicting to each other. The CRITIC method addresses the conflicting relationships among criteria using the Pearson correlation coefficient [14], which ranges between −1 and 1. When the coefficient is zero, it implies that the two criteria are independent of each other. Meanwhile, two criteria with a high positive coefficient share much redundant information, thus not delivering extra value and playing a smaller role in the decision-making process. By adhering to this principle, based on certain formulas, the CRITIC method ensures that a criterion with a higher degree of conflict or a lower degree of redundancy is assigned with a higher weight.

The TOPSIS method was first developed in 1981 by Yoon and Hwang on the assumption that there is an ideal and non-ideal solution. The chosen alternative should have the shortest distance to the positive ideal solution and the farthest distance to the ideal negative solution [15]. This thesis will combine the TOPSIS method with the objective criteria weights from the CRITIC method.

3. Results and comparison

3.1 PCA ranking results

PCA is a technique that reduces the dimensions of a dataset while keeping the original data variation. The principal component table computed based on the data set of Arkansas levee systems can be found in Appendix A. Principal components are new variables that are constructed as linear combinations or mixtures of the initial variables. These combinations are derived in such a way that the new variables (i.e., principal components) are uncorrelated and most of the information within the initial variables is compressed into the first components. Thus, the idea is an eleven-dimensional data gives us eleven principal components, but PCA tries to put maximum possible information in the first component, then maximum remaining information in the second and so on. The scree plot in Figure 4 shows the variance explained by each of the principal component and cumulative percentages. The result of the Scree plot shows that PC1 + PC2 + PC3 + PC4 + PC5 + PC6 explains nearly 95% of the variance in the dataset.

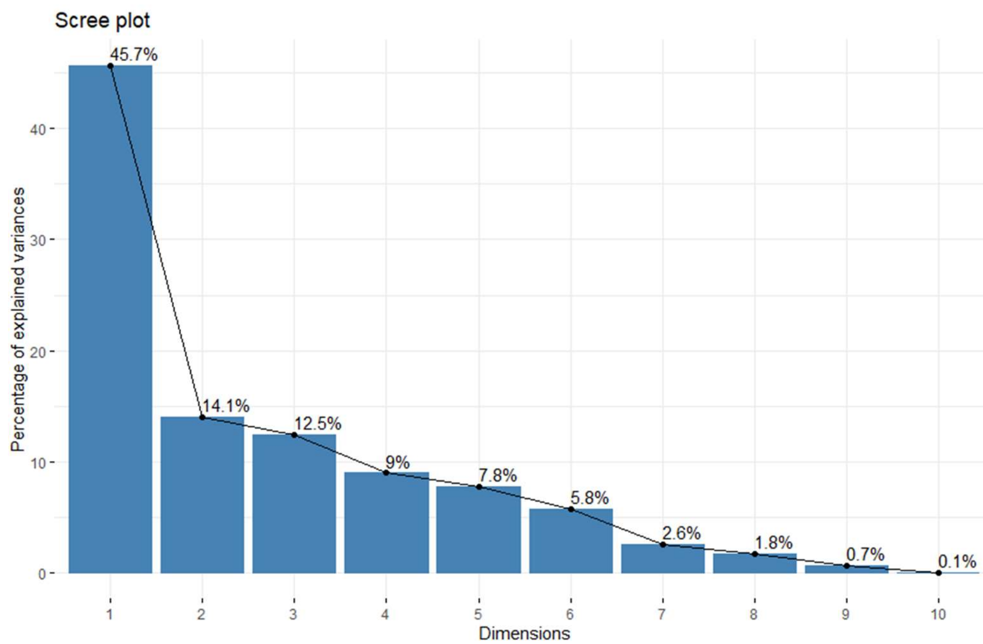

Figure 4. PCA Scree Plot Diagram

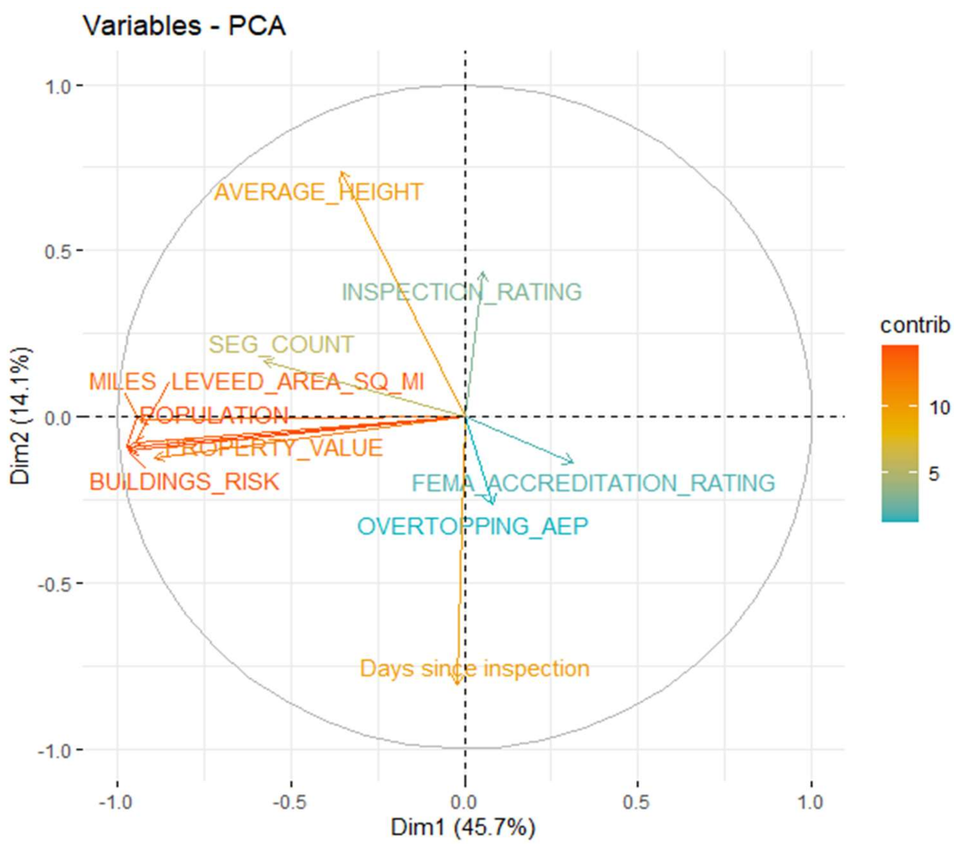

Figure 5. PCA Correlation Plot

From the correlation plot in Figure 5, we have PC1 on the x-axis and PC 2 on the y-axis. Within the circle there are arrows representing the criteria of our dataset. We can see that there is a high correlation between the population with other criteria including building risk, levee length, property value, and leveed area square miles. These criteria are also positively correlated with the number of levee segment. On the contrary, the levee average height is negatively correlated to the overtopping AEP; number of days since inspection is negatively correlated to the inspection rating; and FEMA accreditation rating is negatively correlated to the levee segment count.

To complete the ranking for Arkansas levee systems using PCA, we calculate the PCA ranks using Equation (1), which aggregates the normalized and scaled version of the six PCs with respect to their variance explained (VE) as illustrated in Figure 4. It should be noted that this PCA rank calculation can incorporate all eleven PCs. Nevertheless, the difference in results would be small; thus, the PCA rank based on six PCs would be sufficient. The top ten and last seven rankings are presented in Table 6.

$$PCA\ Rank = \sum_{i=1}^{6} PC_i VE_i \quad (1)$$

Table 8. Arkansas Levee system's ranking calculated by PCA

Rank	System Name		PC1	PC2	PC3	PC4	PC5	PC6
1	West of Morrilton	1.06	-0.99	1.59	1.18	1.16	-0.55	0.24
2	Sainte Genevieve Levee System No. 2	0.70	0.84	-1.33	-1.35	0.34	-0.31	-0.53
3	Kaskaskia Island Drainage & Levee District System	0.65	-0.68	0.14	0.87	1.70	-0.29	2.13
4	Bois Brule Levee & Drainage District System	0.63	0.42	0.12	-0.04	0.77	-1.06	-1.18
5	Red River LB AR	0.57	-8.49	-1.37	-1.28	-3.34	1.00	-1.53
6	Des Arc Levee System	0.54	0.49	2.25	1.10	-1.18	0.67	0.17
7	Columbia Drainage & Levee District No.3 System	0.52	0.82	-1.24	-0.75	-0.16	-0.12	0.17
8	Festus Crystal City Levee System	0.50	0.46	-0.86	-0.88	0.13	0.05	0.35

9	Prairie du Rocher / Edgar Lake System	0.48	0.49	1.45	-1.57	-0.55	0.97	-0.22
10	Hempstead County AR	0.48	0.68	-0.42	0.10	-1.05	0.77	0.75
70	North Little Rock to Gillette	-0.44	0.05	-0.65	-1.08	0.91	-0.11	-0.17
71	Mississippi and White Rivers Below Helena System	-0.57	0.75	-0.40	1.07	-0.58	-0.80	-0.08
72	Little River Drainage District Levee of Missouri System	-0.92	0.16	3.00	-1.75	0.35	1.85	0.30
73	West Bank St. Francis Floodway System	-1.61	-3.96	0.11	1.31	1.90	-1.56	-0.54
74	St. Francis East to Big Lake West System	-1.76	0.77	-1.69	5.11	1.50	3.82	-2.20
75	Big Lake and St. Francis Floodway East System	-4.54	0.20	-0.09	-0.28	0.15	-0.98	-1.42
76	Commerce MO - St. Francis River System	-6.93	-1.07	0.16	1.27	-0.86	-0.55	0.12

3.2 CRITIC objective weights /TOPSIS rankings results

CRITIC is a correlation-based technique that uses analytical testing to extract underlying information in the decision criteria. It determines weights by exploiting the contrast intensity and the conflicting nature of the criteria. CRITIC method has introduced the concept of conflict to MCDM. It is commonly used to generate objectives weights for MCMD techniques. We calculate the objective weights for eleven criteria including levee segment (S), levee length (L), Overtopping AEP (AEP), leveed area square mile (SQ), days since inspection (I), population (P), property value (PV), building risk (B), inspection rating (I), FEMA accreditation rating (AR), and average height (H). Through the implementation of CRITIC, we calculate the Pearson correlation coefficient to measure the strength of relationship among all criteria.

Table 9. Correlation coefficient of each criterion.

	S	L	AEP	SQ	I	P	PV	B	IR	AR	H
S	1	0.69	0.04	0.44	0.13	0.43	0.34	0.40	0.17	-0.11	0.38
L	0.69	1	-0.03	0.88	0.08	0.88	0.77	0.86	0.05	-0.18	0.30
AEP	0.04	-0.03	1	-0.05	0.14	-0.07	-0.06	-0.06	0.07	0.24	-0.07
SQ	0.44	0.88	-0.05	1	0.03	0.98	0.79	0.94	-0.09	-0.20	0.28
I	0.13	0.08	0.14	0.03	1	0.03	0.01	0.01	-0.23	-0.03	-0.43
P	0.43	0.88	-0.07	0.98	0.03	1	0.89	0.98	-0.08	-0.25	0.25

PV	0.34	0.77	-0.06	0.79	0.01	0.89	1	0.94	-0.07	-0.26	0.15
B	0.40	0.86	-0.06	0.94	0.01	0.98	0.94	1	-0.09	-0.25	0.22
IR	0.17	0.05	0.07	-0.09	-0.23	-0.08	-0.07	-0.09	1	0.20	0.05
AR	-0.11	-0.18	0.24	-0.20	-0.03	-0.25	-0.26	-0.25	0.20	1	-0.3
H	0.38	0.30	-0.07	0.28	-0.43	0.25	0.15	0.22	0.05	0	1

Table 9 shows correlations between eleven criteria. It can be seen that population (P) continues to have a fairly strong positive relationship with other criteria such as levee length (L), with a correlation of 0.88, leveed area SQ mile, with a correlation of 0.98, property value, with a correlation of 0.89, and building risk, with a correlation of 0.98. All the remaining criteria have a low positive (negative) relationship or negligible correlation with each other. Combining the information from table 5 with the calculated standard deviation σ for each criteria, we can calculate the information given by a criteria using Equation (2).

$$c_i = \sigma_i \sum_{k=11}^{11} 1 - r_{ik} \qquad (2)$$

Where c_i is the information given by i[th] criteria and r_{ik} is the linear correlation between indicators i and k. The weights are computed by Equation (3) and the objective weight for each criterion is shown in Table 10.

$$cw_i = \frac{c_i}{\sum_{i=1}^{11} c_i} \qquad (3)$$

Table 10. Standard deviation, conversion of preference values and weights of criteria.

	σ_i	c_i	cw_i
1. Levee Segment	0.26	1.85	8.19%
2. Levee length	0.14	0.82	3.61%
3. Overtopping AEP	0.14	1.35	5.98%
4. Leveed area Sq Mile	0.12	0.74	3.27%
5. Days since inspection	0.29	2.99	13.21%
6. Population	0.13	0.79	3.50%
7. Property Value	0.14	0.94	4.14%
8. Building risk	0.15	0.90	4.00%
9. Inspection rating	0.50	5.00	22.09%
10. FEMA Accreditation Rating	0.48	5.29	23.36%
11. Average Height	0.21	1.96	8.65%

In the next step, criteria weights are used with the TOPSIS method for the determination of the levee system's ranking. The weight assessment of criteria defined the importance of one criterion over the other criteria. The final ranking of AR levees can be found in Table 11.

Table 11. AR levee ranking calculated using TOPSIS with CRITIC weights

Rank	System Name	Si^+	Si^-	$Si^-/(Si^- + Si^+)$
1	West of Morrilton	0.067	0.073	0.523
2	Commerce MO - St. Francis River System	0.072	0.068	0.484
3	White River Levee System	0.075	0.056	0.428
4	Dardanelle Levee/Carden Bottom Levee	0.077	0.057	0.426
5	Grand Tower / Degognia Levee System	0.079	0.057	0.418
6	East of Morrilton	0.081	0.057	0.411
7	Bois Brule Levee & Drainage District System	0.081	0.056	0.408
8	Point Remove Creek Drainage and Levee District	0.081	0.056	0.407
9	Village Creek White River Mayberry Levee District	0.082	0.056	0.406
10	McKinney Bayou - Mid - North	0.082	0.055	0.403
70	Faulkner County Levee District No. 1	0.100	0.013	0.114
71	North Little Rock Levee and Floodwall	0.100	0.013	0.114
72	Rock Creek Levee	0.099	0.013	0.112
73	Sainte Genevieve No. 3 Levee System	0.099	0.012	0.104
74	Des Arc Levee System	0.099	0.011	0.103
75	Clarendon Levee System	0.099	0.011	0.098
76	Cape Girardeau Flood Protection System	0.100	0.008	0.070

3.2 Comparison of the results

The ranking results of all suggested methods plotted in Figure 6, together with the LSAC assigned by the USACE. To see how close the ranking from two different methods compares to each other, I perform a linear regression analysis. The analysis results show that we have a multiple R square of 0.6734, which means that the ranks from PCA is fitting fairly well to the ranking from CRITIC-TOPSIS. each approach is suitable for taking advantage of all the criteria available in the NLD since the rankings from each method are not significantly different from each other. Moreover, the top-ranking levee systems obtained using PCA or CRITIC-TOPSIS ranking method often have a low to moderate LSAC. Therefore, they are most definitely in low priority of maintenance by the USACE despite having a higher probability of being in poor conditions or having design and performance issues.

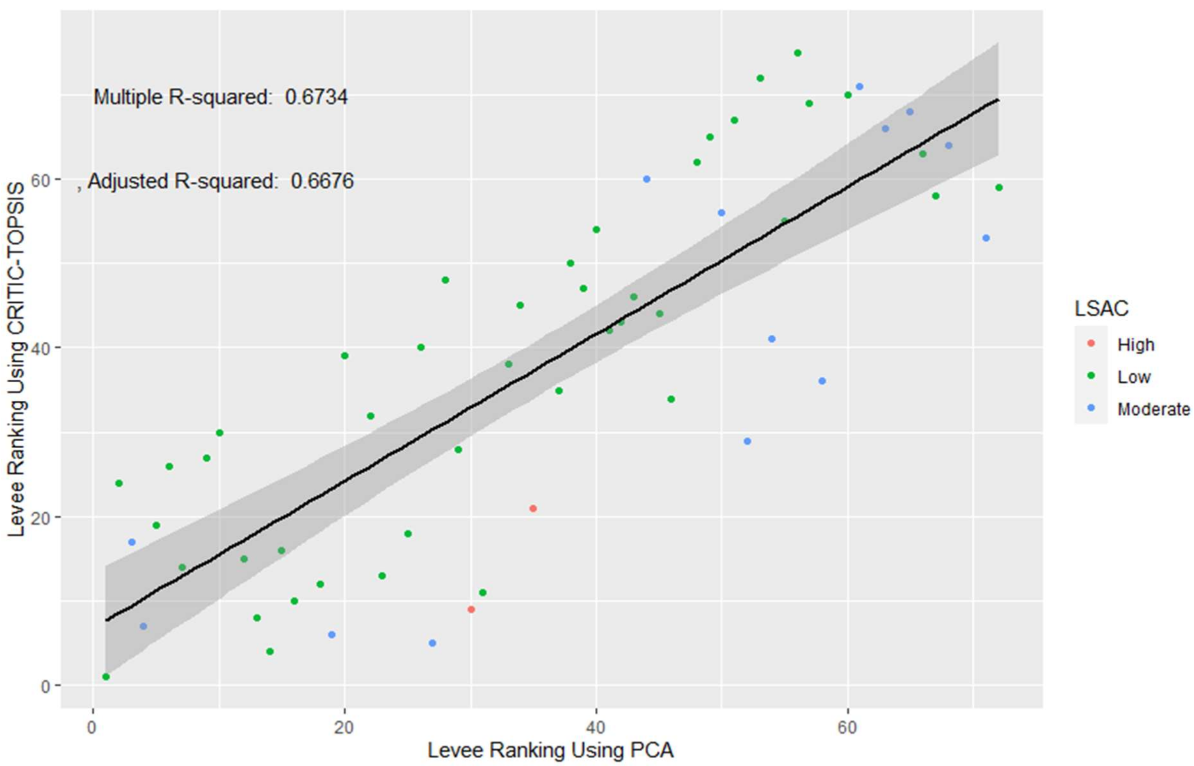

Figure 6. Linear Regression Plot for PCA and CRITIC TOPSIS rankings

3.3 Cost-benefit analysis

Using the ranking results, we perform a cost-benefit analysis to facilitate the maintenance decisions. Cost-benefit analysis compares the operating and maintaining costs and benefits associated with the levee systems to determine whether the levee should be prioritized for maintenance. As the detailed cost are often estimated and documented at the local level, cost associated with levee repair, operation, and maintenance are not always available in public documents. Collecting and verifying such information is time-consuming, but accurate information on these costs is urgently needed to support maintenance decisions. Several studies have attempted mathematical modeling for projecting operating and management (O&M) and repair costs. Han Suk and Christine [15] proposed an optimization model that minimizes damage risks for the levee systems in Arkansas, using the National Levee Database for the majority of their data. Data concerning levee repairs appear to be related to the height and characteristics of the levees. Levees are repaired are calculated using Equation (4):

$$C_i = 5280 * l_i * o_i, \tag{4}$$

where $5280 * l_i$ is the conversion of levee length from miles to feet and o_i is the cost of repair based on height, which is shown in the Equation (5):

$$o_i = \frac{1.5275}{overtopping\ ACE_i}. \tag{5}$$

However, this formula assigns a higher repair cost for a low-risk levee with an overtopping AEP of 0.0002 ($7,637.5 per foot) compared to a high-risk levee with an overtopping AEP of 0.1 ($15,275 per foot), which seems counterproductive.

In another study, Miller [16] constructed a linear model of O&M expense for newly constructed hurricane protection infrastructure post Hurricane Katrina using the statistical technique of ordinary least square regression. His analysis employs detailed information on levee characteristics, such as the acres of right-of-way, numbers of floodgates, and pump stations, combined with historical O&M expenditures by the levee districts. Since the data on acres of levee right-of-way were not given by the levee district, he estimates the acres of levees based on the length and height, assuming that all levee systems have a standardized design. Thus, the estimated acres are calculated using the Equation (6):

$$\text{Levee right} - \text{of} - \text{way ancres} = \frac{5{,}280 * \text{miles} * (10 + 25.4 * \text{height})}{43{,}560}. \tag{6}$$

The following regression model was formulated based on the historical data on O&M expenditures from 1996 to 2004, combined with other measures such as acres and the number of floodgates and pump stations.

$$\text{Exp}_{\text{it}} = \text{a}_{1\text{t}} + \text{a}_2 * \text{acres}_\text{i} + \text{a}_3 * \text{floodgates}_\text{i} + \text{a}_4 * \text{pumps}_\text{i} + \text{e}_\text{i}, \tag{7}$$

Where Exp_{it} is expenditures on O&M in 2009 dollars by levee district i in year t, $acres_i$ is the number of acres of levee-right-of-way maintained by levee district i, floodgate and $pump_i$ is the number of floodgates and pump stations in levee district i. e_i is an error term specific to levee district i, and a_{1t} is specific to each observation year (1996 – 2004).

The primary strength of the approach outlined above is that it is based on historical costs, which reflect actual costs incurred, local labor, contractor rates, as well as needed supplies and equipment. However, we do not have access to historical data in Arkansas for our study, and infrastructure repair and maintenance cost may differentiate from state to state as well as from one levee district to another. Despite the limitations that may decrease the cost estimation's accuracy, partial application of Equation (7) may be sufficient for the study. We will continue to improve our maintenance cost estimation once there is development of data availability and quality.

For a levee system to be considered in the cost-benefit analysis, we assume following conditions need to be satisfied. First, it must be in the top ten of the maintenance lists calculated through implementing the CRITIC-TOPSIS method. Second, it has an LSAC at a minimum of Moderate. The list of levee systems is presented in Table 12.

Table 12. List of Arkansas levee systems for cost-benefit analysis

Rank	System Name	Maintenance cost (U.S.$ thousands)	Pi	LSAC
1	West of Morrilton	$ 78.08	0.52	Low
2	Commerce MO - St. Francis River System	$ 3,513.53	0.48	Moderate
3	White River Levee System	$ 260.83	0.43	Moderate
4	Dardanelle Levee/Carden Bottom Levee	$ 191.36	0.43	Low
5	Grand Tower / Degognia Levee System	$ 360.87	0.42	Moderate
6	East of Morrilton	$ 87.50	0.41	Moderate
7	Bois Brule Levee & Drainage District System	$ 319.40	0.41	Moderate
8	Point Remove Creek Drainage and Levee District	$ 36.91	0.41	Low
9	Village Creek White River Mayberry Levee District	$ 126.43	0.41	High
10	McKinney Bayou - Mid - North	$ 56.44	0.40	Low
17	Kaskaskia Island Drainage & Levee District System	$ 120.36	0.40	Moderate
20	West Bank St. Francis Floodway System	$ 818.97	0.39	High
21	Mississippi and Ohio Rivers Levee System at Cairo & Vicinity	$ 273.49	0.39	High
22	St. Francis East to Big Lake West System	$ 553.72	0.38	High
25	Big Lake and St. Francis Floodway East System	$ 786.21	0.36	Moderate
29	Big Five Levee System	$ 456.42	0.34	Moderate
31	North Little Rock to Gillette	$ 376.42	0.33	High
33	Head of Fourche Island to Pennington Bayou	$ 123.49	0.31	High
36	Memphis - Wolf River Backwater Levee System	$ 89.65	0.31	Moderate
41	Inter-River Levee System	$ 119.34	0.31	Moderate
52	Fort Smith Levee District No. 1	$ 7.72	0.30	Moderate
53	Mississippi and White Rivers Below Helena System	$ 1,323.12	0.23	Moderate
56	Butler County Drainage District No. 12	$ 18.64	0.20	Moderate
60	Massey Alexander Levee District	$ 48.59	0.13	Moderate
64	New Madrid-Sikeston Ridge Levee System	$ 55.44	0.13	Moderate
66	Riverdale Private Levee	$ 15.44	0.12	Moderate
68	Newport Levee District	$ 56.47	0.12	Moderate
71	North Little Rock Levee and Floodwall	$ 10.11	0.11	Moderate
76	Cape Girardeau Flood Protection System	$ 11.65	0.07	Moderate

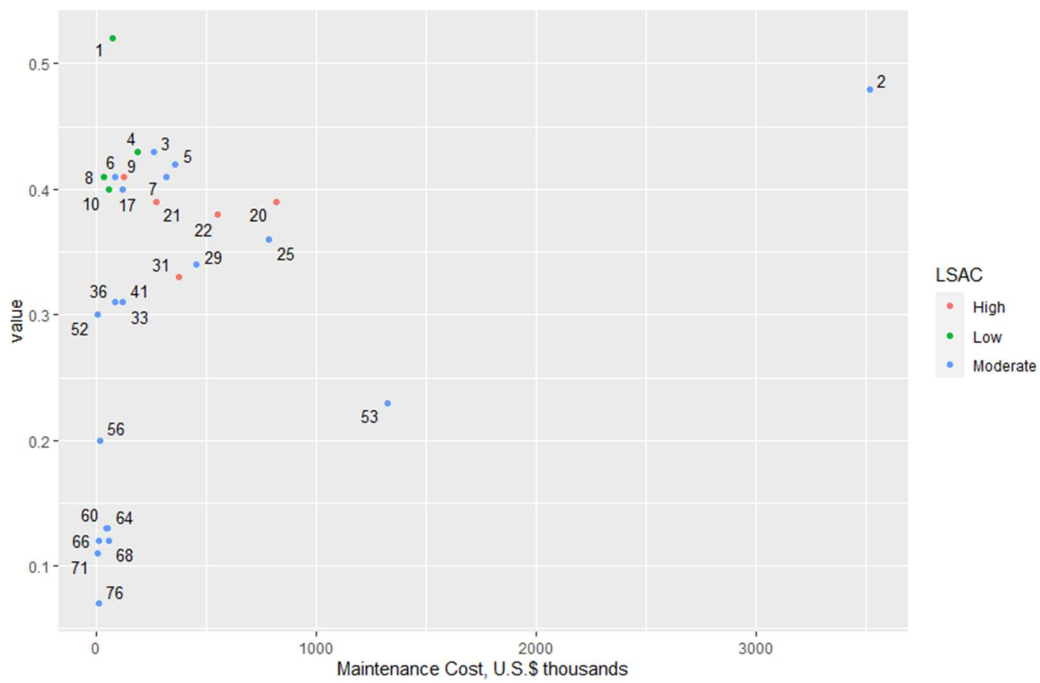

Figure 7. Maintenance cost vs value chart

Based on the plot in Figure 7, the levee system ranking 3, 4, 5, 6, 7, 8, 9, 10, 17, and 21 should have a high prioritization for maintenance. Since these levees not only have a high ranking in our list but also have a high to moderate LSAC and relatively low maintenance cost estimates.

4. Conclusion and Future Scope

There are several limitations in our proposed methodology. Firstly, our study is limited to only the data available through NLD. There can be other criteria important in the decision-making process that we do not have related data to quantify. The ranking results can be described as a snapshot at one particular time rather than a basis for future actions and planning. We have stakeholder input when constructing the MCDM framework, however, the interaction with stakeholders is limited. Given the limitations, there are opportunities for improvement in future research.

Future research should focus on acquiring more information, since the improved data availability and quality has the potential to greatly increase the effectiveness of the proposed model. In addition, we need to engage the experts from USACE in the process of rating the criteria and determining the levee system rankings. For levee system maintenance is a complex problem that requires participation of multiple stakeholders from local, state and federal agencies, one option is the application of the Swing Weight Method (SWM). One important component of the SWM is the swing weight matrix, which is shown in the Figure 8.

		Importance of the value measure to the decision makers and stakeholders (intuitive)		
		Low	Medium	High
Impact of the value measure on the decision (factual)	High			
	Medium			
	Low			
	Not relevant			

Figure 8. Swing Weight Matrix Template.

Unlike other traditional weighting methods, swing weights are assigned to value measure based on the importance and variation of the scale of the value measures. To be more specific, a criteria should be given a high weight if it is considered to be an important factor in the decision process. However, we also evaluate the weight by “swinging” the value of the criteria from its worst to its best value. If we find out that there is little range of variation in the criteria measure scale, we will place less weight on those criteria during the decision process. The levee system rankings can be obtained using the Equation (8).

$$v(x) = \sum_{i=1}^{n} w_i v_i(x_i), \tag{8}$$

Each value function $v_i(x_i)$, measures returned to scale on the range of the value measure and convers a score (x_i) to a value. The weights quantify the trade-offs between value measures that assess the achievement of objectives. The weights are normalized to sum to 1. Since our values do not depend on the alternative, the additive value model has no index for the alternatives, and we use Equation (8) to evaluate every levee system.

Another improvement is to develop a reliability model applying the Markov decision Process (MDP) for the purpose of scheduling and optimization of levee system’s maintenance.

A Markov Chain is a mathematical system stating that the state of the process at time t +1 depends on the state of the process at time t, but is independent of the state of the process at anytime prior to t. In other words, the probability of a levee system performing as expected in the future is dependent solely on its current state and our decision to perform maintenance or not. Our goal is to find an optimal maintenance plan that minimize the total cost over the whole period of the decision process. The details of how we can implement MCP are described as below

s = {1, 2, 3} is a set of levee system conditions, 1: Acceptable, 2: Minimally acceptable, 3: Unacceptable.

A = {1, 2, 3} is a set of all possible actions, 1: do nothing, 2: basic maintenance, 3: improvement.

r(s, a, s') = is the reward for taking action a in state s, improve or deteriorate the current state of levee system.

p_t (s'| s, a) defines a transition probability that when the state is in s and action a is taken, then the next state will be s' with probability p_t (s'| s, a).

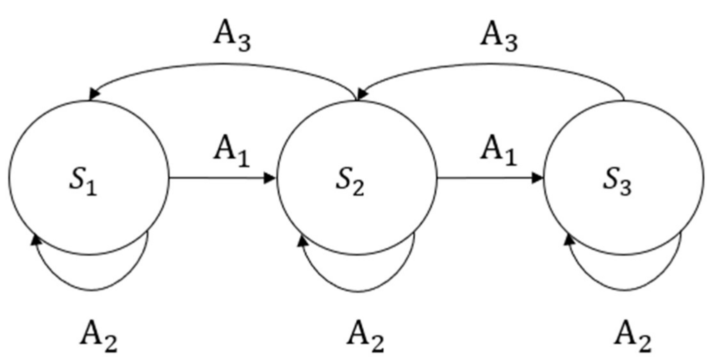

Figure 9. A visualization of a sample Markov chain

Markov transition probability matrix p_t (s'| s, a) is a matrix whose element of i^{th} row and j^{th} column denotes the transition probability p_t (s' = j | s = i, a) It is assumed that the process can move from state i to state j only if j ≥ i. And the levee can deteriorate only one state of a time

$$p_t\ (s'|\ s,\ a_t) = \begin{bmatrix} p_t\ (1|\ 1, a_2) & p_t\ (2|\ 1, a_1) & 0 \\ p_t\ (1|\ 2, a_3) & p_t\ (2|\ 2, a_2) & p_t\ (3|\ 2, a_1) \\ 0 & p_t\ (2|\ 3, a_3) & p_t\ (3|\ 3, a_1) \end{bmatrix}$$

Policy π produce a path (episode):

$\pi_{1:}$ s_1; a_2, r (1, a_2, 1), s_1; a_1, r (1, a_1, 2), $s_{2.}$

$\pi_{2:}$ s_2; a_2, r (2, a_2, 2), s_2; a_1, r (2, a_1, 3), s_3; a_3, r (3, a_3, 2), $s_{2;}$ a_3, r (2, a_3, 1), $s_{1.}$

$\pi_{3:}$ s_3; a_2, r (3, a_2, 3), s_3; a_1, r (3, a_1, 4), s_4; a_3, r (4, a_2, 3), s_3; a_3, r (3, a_3, 2), $s_{2;}$ a_3, r (2, a_3, 1), $s_{1.}$

…..

γ is a discount factor; future costs are discounted when converted into present value.

$$V\ ([s1, s2, \ldots, sn]) \ = \sum_{t=0}^{\infty} \gamma^{t} R(s_t)\, , \gamma \ \in \ (0,1], \tag{9}$$

Objective function for maximizing the total reward:

$$V_\pi = \max E\ [\textstyle\sum_{t=1}^{N} \gamma^{t} R(s_t)] \tag{10}$$

We will continue exploring these methods and relevant data collection and parameter calibration to improve maintenance decision for levee systems.

Appendix A. Principal Component Table calculated using PCA

System Name	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
AR River North Bank	-0.99	1.59	1.18	1.16	-0.55	0.24	-0.19	-0.08	0.06	-0.04	0.23
Batesville Levee and Floodwall	0.84	-1.33	-1.35	0.34	-0.31	-0.53	-0.29	-0.31	-0.11	0.01	0.04
Big Five Levee System	-0.68	0.14	0.87	1.70	-0.29	2.13	-0.86	0.32	-0.05	-0.02	-0.03
Big Gum Drainage District	0.42	0.12	-0.04	0.77	-1.06	-1.18	0.23	-0.08	-0.27	-0.03	0.06
Big Lake and St. Francis Floodway East System	-8.49	-1.37	-1.28	-3.34	1.00	-1.53	-0.80	2.49	0.17	-0.01	0.10
Bois Brule Levee & Drainage District System	0.49	2.25	1.10	-1.18	0.67	0.17	0.14	-0.12	0.52	0.01	-0.05
Butler County Drainage District No. 12	0.82	-1.24	-0.75	-0.16	-0.12	0.17	-0.18	-0.10	-0.09	-0.01	-0.03
Cache River Levee System	0.46	-0.86	-0.88	0.13	0.05	0.35	0.43	0.35	-0.06	-0.02	-0.05
Cape Girardeau Flood Protection System	0.49	1.45	-1.57	-0.55	0.97	-0.22	-0.99	-0.39	-0.09	0.13	-0.02
Castor River Levee System	0.68	-0.42	0.10	-1.05	0.77	0.75	-0.60	-0.16	0.07	-0.02	-0.03
Cates Levee System	0.39	-0.39	-1.02	0.97	0.17	-0.20	-0.40	-0.16	-0.15	0.01	0.04
Central Clay Drainage District	0.97	-0.50	0.90	-0.68	-1.08	-0.04	0.64	0.07	0.02	-0.02	0.02
City of Millington Big Creek Levee System	0.74	-1.16	0.04	0.10	-0.18	1.14	-0.04	0.30	-0.40	0.03	-0.02
Clarendon Levee System	0.51	-0.30	-1.43	0.10	0.19	-0.39	-0.39	-0.22	-0.02	-0.01	-0.03
Clarksville Levee and Floodwall	1.12	-1.52	-0.15	-0.76	-0.21	0.79	-0.30	-0.07	-0.18	0.04	-0.03
Columbia Drainage & Levee District No.3 System	0.80	1.10	0.96	-1.21	-0.16	0.04	0.05	-0.14	0.20	0.00	-0.02
Commerce MO - St. Francis River System	-15.13	-0.80	0.33	-0.38	0.42	1.08	1.23	-1.71	-0.26	0.16	0.01
Conway County Drainage & Levee District No. 1	1.02	-1.10	-0.19	-0.39	0.03	0.97	0.22	0.16	-0.08	0.01	-0.01
Conway County Levee District No. 6	0.85	-0.53	-0.29	-0.10	0.29	1.18	0.73	0.41	0.00	0.00	-0.02
Dardanelle Levee/Carden Bottom Levee	0.54	-0.27	1.88	0.24	-0.07	-0.17	0.47	0.11	0.15	-0.02	-0.01
Des Arc Levee System	0.60	-0.07	-1.43	0.27	0.38	-0.33	-0.17	-0.16	-0.08	0.00	0.00
Des Arc Levee System	1.00	-2.19	1.72	0.21	2.32	-0.33	-0.17	-0.20	0.29	0.00	-0.04
East of Morrilton	0.47	0.07	1.34	0.40	-1.22	0.48	0.21	0.29	-0.45	-0.01	0.05
Elk Chute Levee System	0.71	0.12	1.14	-1.36	-0.71	-0.13	-0.37	-0.50	0.57	-0.01	-0.02
Faulkner County Levee District No. 1	0.72	-1.09	-1.35	0.29	-0.21	-0.48	-0.34	-0.32	0.01	0.02	0.05
Festus Crystal City Levee System	0.31	3.44	-0.63	-0.49	0.66	-0.94	0.13	-0.02	-0.10	0.10	0.01
Fort Smith Levee District No. 1	1.07	-0.08	-0.28	-1.46	0.34	0.92	-1.01	-0.29	-0.15	0.04	-0.01

Grand Tower / Degognia Levee System	0.07	0.73	1.24	0.39	-0.40	0.48	1.21	0.48	0.31	-0.06	-0.01
Greenville Harbor	0.81	-0.82	-0.27	-0.10	0.12	1.14	0.69	0.39	0.05	0.00	0.00
Harrisonville / Stringtown / Ft Chartres Levee System	-0.03	1.19	0.24	0.19	0.62	1.77	-0.70	0.10	0.08	0.01	0.00
Head of Fourche Island to Pennington Bayou	0.17	0.02	-0.02	0.67	-1.19	-1.18	0.11	-0.13	-0.04	0.10	0.04
Hempstead County AR	0.81	1.98	0.13	-1.57	-0.17	-0.60	-0.90	-0.57	-0.02	0.04	0.01
Honeysuckle White Levee	1.02	-0.56	-0.29	-0.73	0.17	1.02	-0.10	0.08	-0.13	0.04	0.00
Inter-River Levee System	0.63	-1.61	-0.09	-0.52	-0.36	0.94	-0.02	-0.10	0.42	-0.08	-0.05
Jasper County Levee District No. 1	0.66	-0.62	-1.29	0.66	0.32	-0.42	0.18	-0.05	-0.06	0.00	0.04
Kaskaskia Island Drainage & Levee District System	0.79	1.99	0.88	-1.47	0.26	0.14	-0.13	-0.15	0.11	0.02	-0.02
Little Red River Levee District No. 1	1.08	-1.59	-0.13	-0.48	-0.23	0.86	0.00	0.02	-0.03	0.01	-0.01
Little Red River Levee District No. 2	1.11	-1.95	0.04	-0.60	-0.26	0.69	-0.29	-0.17	0.03	0.01	0.00
Little River Drainage District Levee of Missouri System	-1.89	1.05	-1.58	-0.96	1.18	-0.19	-0.04	-0.65	-0.65	-0.53	0.01
Little Rock Flood Protection	0.71	-0.13	-0.26	0.27	-0.98	-1.43	0.47	-0.19	-0.03	-0.02	0.05
Little Rock to Pine Bluff (Tucker Lake)	0.72	0.22	0.27	0.08	-0.70	-0.59	1.02	0.19	0.02	-0.02	0.02
Long Prairie AR	0.62	0.53	1.10	-0.82	-0.92	0.23	-0.36	-0.19	-0.11	0.02	0.04
Lower Hartman Bottom Levee	0.43	0.06	-1.50	0.83	0.38	-0.10	0.56	0.10	0.17	-0.02	0.02
Massey Alexander Levee District	0.53	-0.34	-1.12	0.78	0.76	-0.46	0.27	-0.02	0.07	0.00	0.01
McKinney Bayou - Mid - North	0.82	0.22	1.27	-0.91	-0.81	0.02	-0.63	-0.30	-0.24	0.02	0.05
McKinney Bayou - South	0.91	0.45	1.00	-1.15	-0.46	-0.07	0.07	-0.17	0.07	0.01	0.02
McLean Bottom	0.10	0.25	-0.42	1.48	0.18	1.05	0.22	0.45	-0.31	0.00	0.03
Memphis - Nonconnah Levee System	0.81	0.68	0.76	-0.99	-0.49	0.05	0.50	0.37	-0.11	0.09	0.09
Memphis - Wolf River Backwater Levee System	-0.13	1.39	-0.47	0.01	-0.19	-1.18	0.78	0.15	-0.16	0.10	-0.39
Mississippi and Ohio Rivers Levee System at Cairo &	-1.06	2.84	1.26	2.09	-0.53	0.82	-0.62	0.72	-1.05	0.03	-0.02
Mississippi and White Rivers Below Helena System	-2.30	1.20	-0.25	3.01	0.07	1.17	-0.26	0.06	0.95	-0.08	0.06
New Madrid Floodway System	-0.31	-0.39	-0.65	1.19	0.41	-0.15	-0.30	-0.48	0.79	-0.05	0.11
New Madrid-Sikeston Ridge Levee System	0.33	-1.05	-1.40	0.40	-0.16	-0.43	0.01	-0.06	0.02	0.00	-0.04
Newport Levee District	0.26	-0.50	-1.47	0.38	0.12	-0.36	0.05	0.15	0.03	0.07	-0.01
North Little Rock Levee and Floodwall	0.82	-1.33	-1.34	0.20	-0.33	-0.56	-0.48	-0.39	-0.09	0.02	0.03
North Little Rock to Gillette	-1.02	0.28	0.28	1.10	-1.22	-0.90	-0.03	0.12	0.22	0.02	0.01

NSA Big Creek Levee System	1.08	-1.76	-0.02	-0.54	-0.12	0.72	-0.10	0.03	-0.14	0.04	-0.03
Point Remove Creek Drainage and Levee District	1.06	-0.48	1.21	-0.62	-0.53	-0.28	0.56	0.06	-0.08	-0.01	0.01
Prairie du Rocher / Edgar Lake System	0.18	2.46	0.37	0.01	0.11	-0.08	0.30	0.16	-0.05	0.00	0.01
Red River LB AR	0.64	2.23	0.78	-1.75	0.07	0.25	-0.44	-0.35	0.37	0.01	-0.01
Riverdale Private Levee	0.60	-1.03	-1.36	0.50	-0.06	-0.47	0.01	-0.07	-0.07	0.08	0.01
Rock Creek Levee	0.82	-1.07	-1.23	0.29	0.05	-0.60	-0.40	-0.35	-0.12	0.01	0.04
Roland Drainage District	0.67	0.27	-0.37	0.29	-0.85	-1.32	0.62	-0.09	-0.09	-0.02	0.05
Running Water Levee District	1.12	-0.82	0.96	-0.97	-1.21	-0.21	0.20	-0.12	-0.12	0.00	0.03
Russellville Dike and Pumping Station	0.31	1.63	-1.60	0.64	1.26	0.08	0.58	0.25	0.03	0.01	0.00
Sainte Genevieve Levee System No. 2	0.84	-1.18	1.57	0.74	2.92	-0.03	0.76	0.32	0.19	-0.01	-0.04
Sainte Genevieve No. 3 Levee System	0.39	1.56	-1.60	0.11	1.09	-0.03	-0.12	-0.08	0.02	0.02	-0.02
Southern Enterprise Private Levee	0.95	-0.99	-0.21	-0.16	0.12	1.05	0.56	0.31	-0.05	0.00	-0.01
St. Francis East to Big Lake West System	-3.79	-0.49	1.01	1.11	-1.81	-0.78	-1.13	0.04	0.21	-0.21	-0.28
Van Buren Levee District No. 1/Crawford County Levee	0.05	-0.65	-1.08	0.91	-0.11	-0.17	-0.37	-0.10	0.02	0.12	-0.08
Village Creek White River Mayberry Levee District	0.75	-0.40	1.07	-0.58	-0.80	-0.08	0.73	0.04	0.22	-0.03	0.03
Village of New Athens System	0.16	3.00	-1.75	0.35	1.85	0.30	0.44	0.28	0.06	0.01	-0.01
West Bank St. Francis Floodway System	-3.96	0.11	1.31	1.90	-1.56	-0.54	-1.24	0.65	0.26	0.07	-0.02
West of Morrilton	0.77	-1.69	5.11	1.50	3.82	-2.20	-0.54	-0.21	-0.41	0.02	0.02
Western Clay Drainage District	0.20	-0.09	-0.28	0.15	-0.98	-1.42	0.50	-0.02	0.15	-0.04	-0.02
White River Levee System	-1.07	0.16	1.27	-0.86	-0.55	0.12	0.38	0.03	-0.23	-0.12	0.01

Appendix B. Estimate Maintenance Cost for each Levee in Arkansas

System Name	Length	Height	Maintenance Cost (Thousand $)
AR River North Bank	56.16	22	$ 542.08
Batesville Levee and Floodwall	0.92	8.5	$ 3.53
Big Five Levee System	54.6	19	$ 456.42
Big Gum Drainage District	8.86	14	$ 54.97
Big Lake and St. Francis Floodway East System	122.47	14.5	$ 786.21
Bois Brule Levee & Drainage District System	33.09	22	$ 319.40
Butler County Drainage District No. 12	4.37	9.5	$ 18.64
Cache River Levee System	5.33	15	$ 35.37
Cape Girardeau Flood Protection System	1.51	17.5	$ 11.65
Castor River Levee System	14.6	11.5	$ 74.85
Cates Levee System	9.89	14.5	$ 63.49
Central Clay Drainage District	12.3	11	$ 60.41
City of Millington Big Creek Levee System	1.51	12	$ 8.07
Clarendon Levee System	6.18	13	$ 35.68
Clarksville Levee and Floodwall	1.16	7	$ 3.70
Columbia Drainage & Levee District No.3 System	19.96	15.5	$ 136.74
Commerce MO - St. Francis River System	277.32	29	$ 3,513.53
Conway County Drainage & Levee District No. 1	2.63	12	$ 14.05
Conway County Levee District No. 6	4.38	17.5	$ 33.78
Dardanelle Levee/Carden Bottom Levee	28.84	15	$ 191.36
Des Arc Levee System	1.42	15.25	$ 0.02
Des Arc Levee System	20.07	10	$ 9.57
East of Morrilton	13.63	14.5	$ 89.91
Elk Chute Levee System	40.66	8.75	$ 87.50
Faulkner County Levee District No. 1	6.73	9.5	$ 160.25
Festus Crystal City Levee System	0.7	27	$ 1.69
Fort Smith Levee District No. 1	1.81	9.5	$ 28.70
Grand Tower / Degognia Levee System	36.57	22.5	$ 8.27
Greenville Harbor	7.86	16	$ 7.72
Harrisonville / Stringtown / Ft Chartres Levee System	34.41	21	$ 360.87
Head of Fourche Island to Pennington Bayou	21.39	13	$ 55.54
Hempstead County AR	9.77	13.75	$ 317.31
Honeysuckle White Levee	0.49	12.5	$ 123.49
Inter-River Levee System	31.13	8.5	$ 59.56
Jasper County Levee District No. 1	1.05	15	$ 2.72
Kaskaskia Island Drainage & Levee District System	14.78	18.5	$ 119.34
Little Red River Levee District No. 1	6.52	8.5	$ 6.97
Little Red River Levee District No. 2	10.81	5.5	$ 120.36
Little River Drainage District Levee of Missouri System	19.29	20.5	$ 24.99
Little Rock Flood Protection	7.51	12.5	$ 27.46
Little Rock to Pine Bluff (Tucker Lake)	8.77	17	$ 173.72

Long Prairie AR	20.23	11.6	$ 41.74
Lower Hartman Bottom Levee	10.23	20	$ 65.75
Massey Alexander Levee District	6.3	17.5	$ 104.58
McKinney Bayou - Mid - North	13.94	9	$ 89.92
McKinney Bayou - South	15.07	12.5	$ 48.59
McLean Bottom	12.29	22	$ 56.44
Memphis - Nonconnah Levee System	3.8	16	$ 83.75
Memphis - Wolf River Backwater Levee System	9.5	21.5	$ 118.63
Mississippi and Ohio Rivers Levee System at Cairo & Vicinity	21.96	28.5	$ 26.85
Mississippi and White Rivers Below Helena System	106.24	28.5	$ 89.65
New Madrid Floodway System	57.01	16	$ 273.49
New Madrid-Sikeston Ridge Levee System	10.48	11.88	$ 1,323.12
Newport Levee District	8.51	15	$ 402.84
North Little Rock Levee and Floodwall	2.97	7.5	$ 55.44
North Little Rock to Gillette	53.27	16	$ 56.47
NSA Big Creek Levee System	2.67	7.5	$ 10.11
Point Remove Creek Drainage and Levee District	7.2	11.5	$ 376.42
Prairie du Rocher / Edgar Lake System	16.5	25	$ 9.08
Red River LB AR	28.09	17.5	$ 36.91
Riverdale Private Levee	2.89	12	$ 180.60
Rock Creek Levee	0.59	9.5	$ 216.65
Roland Drainage District	4.09	15	$ 37.63
Running Water Levee District	7.64	7	$ 15.44
Russellville Dike and Pumping Station	1.2	27.5	$ 2.52
Sainte Genevieve Levee System No. 2	11.06	20	$ 27.14
Sainte Genevieve No. 3 Levee System	3.52	23	$ 24.35
Southern Enterprise Private Levee	3.15	14.5	$ 14.43
St. Francis East to Big Lake West System	112.75	11	$ 97.22
Van Buren Levee District No. 1/Crawford County Levee District	21.51	13.5	$ 35.49
Village Creek White River Mayberry Levee District	22.75	12.5	$ 20.22
Village of New Athens System	1.31	33	$ 553.72
West Bank St. Francis Floodway System	115.9	16	$ 128.81
West of Morrilton	14.05	12.5	$ 126.43
Western Clay Drainage District	20.3	13.35	$ 18.86
White River Levee System	39.31	15	$ 818.97

Reference

1. “The Water Cycle and Climate Change | Center for Science Education.” UCAR, scied.ucar.edu/learning-zone/climate-change-impacts/water-cycle-climate-change.

2. Almukhtar, S., Migliozzi, B., Schwartz, J., & Williams, J. (2019, December 1). The Great Flood of 2019: A Complete Picture of a Slow-Motion Disaster. The New York Times. https://www.nytimes.com/interactive/2019/09/11/us/midwest-flooding.html

3. Denchak, M. (n.d.). Flooding and Climate Change: Everything You Need to Know. NRDC. https://www.nrdc.org/stories/flooding-and-climate-change-everything-you-need-know

4. Chaudhary, M. T. (n.d.). Natural Disasters—Origins, Impacts, Management. MDPI. https://www.mdpi.com/2673-8392/1/4/84

5. Arkansas. Flood Factor. (n.d.). Retrieved January 28, 2022, from https://floodfactor.com/state/arkansas/5_fsid \

6. New Orleans District. “Levee Safety Action Classification.” New Orleans District, www.mvn.usace.army.mil/LSAC.

7. Elzbieta Broniewics, Karolina Ogrodnik. Multi-criteria analysis of transport infrastructure projects, Transportation Research Part D Transport and Environment 83, 2020, April.

8. ShengJi Tee; Qiang Liu; Zhongdong Wang. Insulation condition ranking of transformers through principal component analysis and analytic hierarchy process, 2016, September.

9. Babatunde, M & Ighravwe, D. (2019). A CRITIC-TOPSIS framework for hybrid renewable energy systems evaluation under techno-economic requirements.Journal of Project Management, 4(2), 109-126.

10. U.S. Army Corps of Engineers Headquarters. “Civil Works Levee Safety Program.” U.S. Army Corps of Engineers Headquarters, www.usace.army.mil/Missions/Civil-Works/Levee-Safety-Program.

11. Hair, J.F., Black, W.C., Babin, B.J. and Anderson, R.E. (2010), Multivariate Data Analysis: A Global Perspective, Pearson, Upper Saddle River, NJ.

12. Salem, Nema, and Sahar Hussein. “Data Dimensional Reduction and Principal Components Analysis.” Procedia Computer Science, vol. 163, Elsevier BV, 2019, pp. 292–99. https://doi.org/10.1016/j.procs.2019.12.111.

13. Durmaz, E.; Akan, ¸S.; Bakır, M. Service quality and financial performance analysis in low-cost airlines: An integrated multi-criteria quadrant application. Int. J. Econ. Bus. Res. 2020, 20, 168–191.

14. Tu¸s, A.; Adalı, E.A. The new combination with CRITIC and WASPAS methods for the time and attendance software selection problem. OPSEARCH 2019, 56, 528–538

15. Yoon, K.; Hwang, C.L. Multiple Attribute Decision Making: Methods and Applications; Springer: Berlin/Heidelberg, Germany, 1981.\

16. Christine Sohn, Han Suk, “Analyzing Flood Protection Measures of Levee Systems in Arkansas” Journal of Multidisciplinary Engineering Science and Technology (JMEST) ISSN: 2458-9403 Vol. 6 Issue 12, December – 2019

17. Trey Miller (2022). Financing the Operation and Maintenance Costs of Hurricane Protection Infrastructure

18. Parnell, G.S. and Trainor, T.E. (2009), 2.3.1 Using the Swing Weight Matrix to Weight Multiple Objectives. INCOSE International Symposium, 19: 283-298. https://doi.org/10.1002/j.2334-5837.2009.tb00949.x