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Analyzing Water Resource Issues in the State of Mississippi

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Authors' contributions

This work was carried out in collaboration between all authors. Author ECM designed the study, wrote the protocol, and wrote the first draft of the manuscript. Authors JW, EN, SF and PI managed the literature searches and analyses of the study. Author MC compiled the recommendations and the challenges. Authors ST and CR assisted with the additional maps and formatting of the figures. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aims: The paper assesses water resource issues in the state of Mississippi using GIS mapping.
Study Design: Adopted a mixscale appoach.
Methodology: The aproach is applied to GIS and primary data connected to descriptive statistics by analyzing the impacts of water use through data collected at the state, county and regional level.
Place and Duration of Study: The counties of Mississippi between Spetember 2010-December 2013.
Results: The study shows a rise in pumpage among different sectors and a widening of boil water alerts triggered by pollution and standard violations. With the vulnerability to water stress, and potential scarcity from climate change. Regional comparisons point to the exposure to accumulative groundwater depletion since the past several decades. While the spatial analysis revealed the concentration of extensive groundwater water use

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and emergence of cone formation in the northwest region of the state, the threats of contaminated sites, *E. coli* and coliform outbreak were evident across space.
Conclusions: The assessment of these issues showed the capacity of mix scale approach in highlighting the susceptibility of Mississippi's water resources to degradation. From the spatial patterns, the northwest and the south west area showed more concentration of higher pumpage than other areas. Added to that is the notable presence of contaminated sites on areas adjacent to water resources. In the process, mix scale approach enhanced our research and basis for appraising water resource use. To mitigate the issues, the paper outlined five recommendations ranging from education to the need for data infrastructure design and more use of GIS in water resource management. The paper also outlined its contributions and areas for future research.

Keywords: Water use; water resources; ground water; GIS; degradation; pollution; Mississippi; impacts.

ABBREVIATIONS

MDEQ	*: Mississippi Department of Environmental Quality*
USGS	*: United States Geological Survey*
MDH	*: Mississippi Department of Health*
EPA	*: Environmental Protection Agency*
US	*: United States*
GIS	*: Geographic Information Systems*
MGD	*: Million Gallons Daily*
Cone Depression	*: The pattern that forms when a pumping well pumps from an an quifer*
Spatial Analysis	*: A study in depth of the patterns of the problems, lines, areas, and surfaces depicted on maps of some sort*
Mixscale	*: Analysis involving different scales*
USNGWA	*: Unied States National Ground Water Association*
MLGW	*: Memphis Light Gas and Water*
AL	*: Alabama*
FL	*: Florida*
MS	*: Mississippi*
RCRA	*: Resource Conservation Recovery Act*
CERCLA	*: Comprehensive Environmental Response Compensation and Liability Act*

1. INTRODUCTION

1.1 Background

Mississippi relies heavily on its ground water resources than other states. In fact more than 93% of the portable supply is extracted from water wells that tap aquifers in the state. With only 3 public surface water systems out of 1,535 [1], groundwater use remains widespread with some of it serving 100,000 acres of catfish ponds. Many of Mississippi's farmers also depend on ground water for the irrigation of crops such as rice and cotton. While natural springs are still in use; portable water supply comes from 3,400 public ground water wells and thousands of domestic wells [2]. Added to this, is the water deficits in most counties and the threats posed by 1,200 contaminated sites and brown fields to aquifers and water resources [3]. Considering the implications on ecological health, these problems merit analyses through a mix-scale approach including Geographic Information Systems (GIS). Given the risks posed to water resources, very little has been done to assess it using GIS. The applications of GIS in that setting can pinpoint the threats and competing land use practices impacting ground water resource quality and availability [4]. Many studies [5,6,7,8] exist in the literature with focus on water protection using GIS. In the context of the study area, these themes are essential as counties in the state search for the right tools for water resource management [9,10]. See Appendix A for more information.

In the last several years, the state has been facing the challenges of meeting rapidly increasing demand for water and the threats of contamination due to several factors such as population growth, unsustainable practices and erosion of natural deposits [1]. Part of the problems stem from uncontrolled urban growth creating demands for residential infrastructure including portable water pipelines and waste water lines [4]. Additionally, dilapidated infrastructure of water carriers continues to threaten water quality [1,2,10]. Other studies, highlighting these problems, not only identified the threats to ground water, but they reiterated the need for continued assessment [11,12,13,14,15,16]. Judging from current concerns by planners, growth not only fuels high demands for water, but it poses a challenge to city management and conservation [16,17,18]. Worried about the impacts of projected growth on the state's water resources, water management is emerging as a high priority among local governments [16-18].

Water level declines in aquifers and quality impairment in densely populated areas of Mississippi with concentration of farming and other activities are noticeable [1,16]. They merit monitoring and assessment. The fact that Mississippi is a non-water stressed state does not mean that water abundance is infinite. Litigations over ground water use between Mississippi and the city of Memphis, Tennessee was heard by a district Court. Notwithstanding the projected water scarcity from climate change stressors and the accumulative depletion and the impacts, there is a lack of access to spatially referenced information showing the threats. With the drinking water standards in place, boil water alert bulletins are continually issued in response to the outbreak of colifoams, e-coli and water contamination. This often results in limited access to safe drinking water for citizens and violations of drinking water standards. Dealing with these problems requires updating water resource information and ground water education by raising awareness of the risks through GIS mapping and mix scale approach. See section 3 and its sub sections for more information.

When used properly, GIS has the capability as a support tool to store, analyze and manage spatial information on ground water health and availability for decision making [16-18]. Other studies on water contamination and use with relevance to the study area and GIS can be found elsewhere [19,20,21,22,23,24,25]. This paper uses a mix scale approach anchored in GIS to assess water resource use in Mississippi. Emphasis is on the issues, factors and current efforts to deal with the problem and future lines of action. The paper has two objectives. The first aim is to device a decision support tool for management and conservation while the second objective is to analyze water use and the issues using mix-scale approach. The sections in the paper consist of the introduction,materials and methods portion, the results and discussions and the conlcusions.

2. MATERIALS AND METHODS

2.1 Study Area

The study area in the South East of the US (Fig. 1) has a population of 3 million with an average of 56 inches of yearly rainfall. Both the northern boundary and the Gulf areas average 50 to 65 inches of rain. The state not only has 14 aquifers supplying freshwater for domestic and industrial uses (Fig. 2), but 93 percent of its water supply come from ground water and public wells. While the state has abundant supply of fresh water groundwater, it is found in most locations at depths greater than 3,000 ft [13]. In 1980, 74% or 1,140 mgd of every ground water came from wells in the Mississippi alluvial aquifer. Withdrawals from the Tuscaloosa, Meridian–upper Wilcox, Sparta, Cockfield and Miocene aquifers characterized only 22% or 330 mgd of overall ground water used, while 8 other aquifers accounted for 4% or 65 mgd. For more on the Sparta aquifer, see Appendix B.

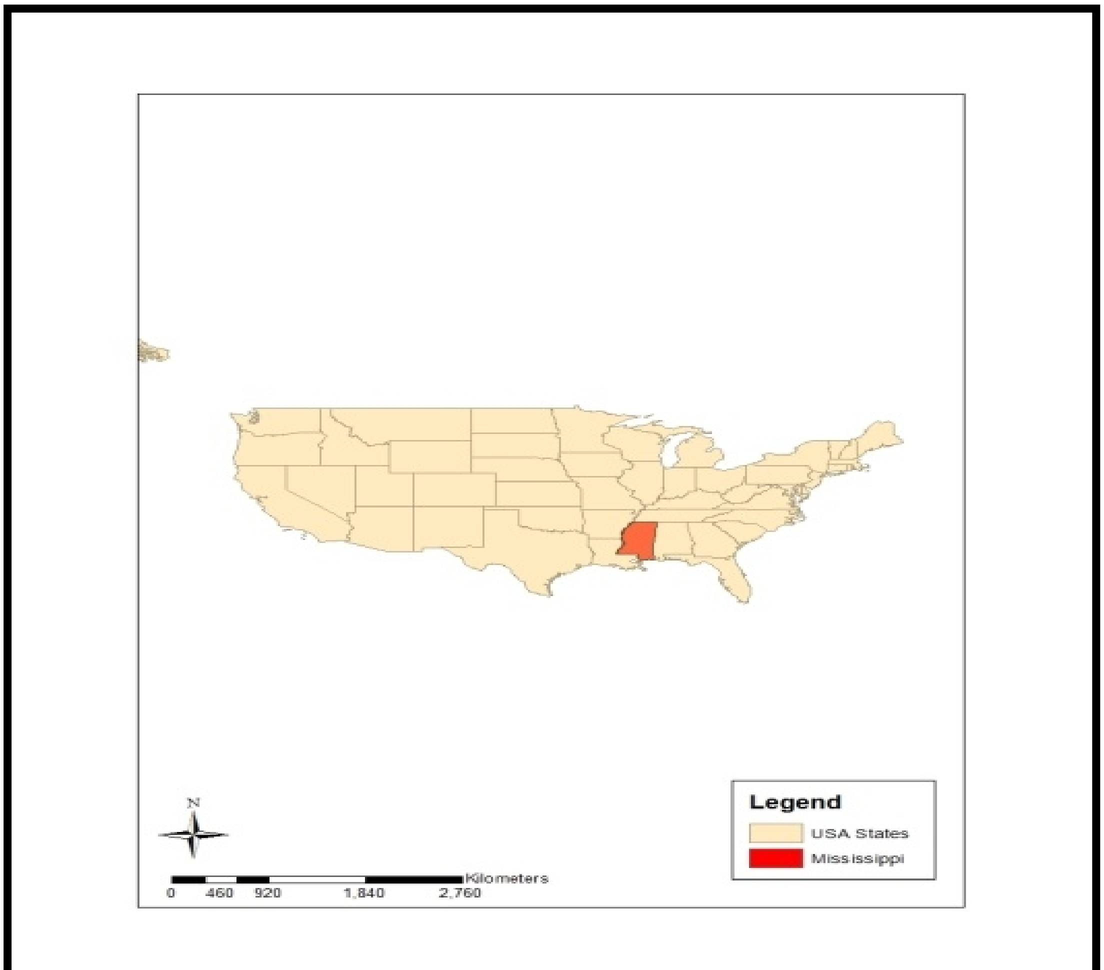

Fig. 1. The study area

Of the state's 14 main aquifer structures in Fig. 2, the Mississippi River alluvial aquifer in the northwest region as the most used, stretches over 7,000 square miles in 19 counties. Just as the area ranks highly as the agricultural hub accounting for close to 100% in rice and catfish farming, it is responsible for over 70% of the soybeans and cotton production in Mississippi. Nearly, 98% of water pumped from the aquifer serves agriculture—mostly for water-dependent catfish and rice farming. In fact, during the 2005 fiscal year, irrigation alone emerged as the principal user of freshwater pumpage at nearly 55 percent. It was followed by other entities most notably public and domestic supply with 15%, thermoelectric power at 12.5% as well as aquaculture at 10%. Seeing the scale of declines in aquifers in densely populated areas and in the northwest region known for crop irrigation and aquaculture, there are rising fears that water use from Mississippi aquifers is becoming unsustainable due to widespread deficit levels. These concerns should be monitored. With natural coloration in aquifers and climate change stressors emerging as issues in the state, without conservation, water abundance in the state could be unfeasible [26,27,28]. At the same time, as contamination threats of aquifers becomes noticeable [1], the risks from brown fields and competing land uses must not be overlooked [3,16, Appendix C].

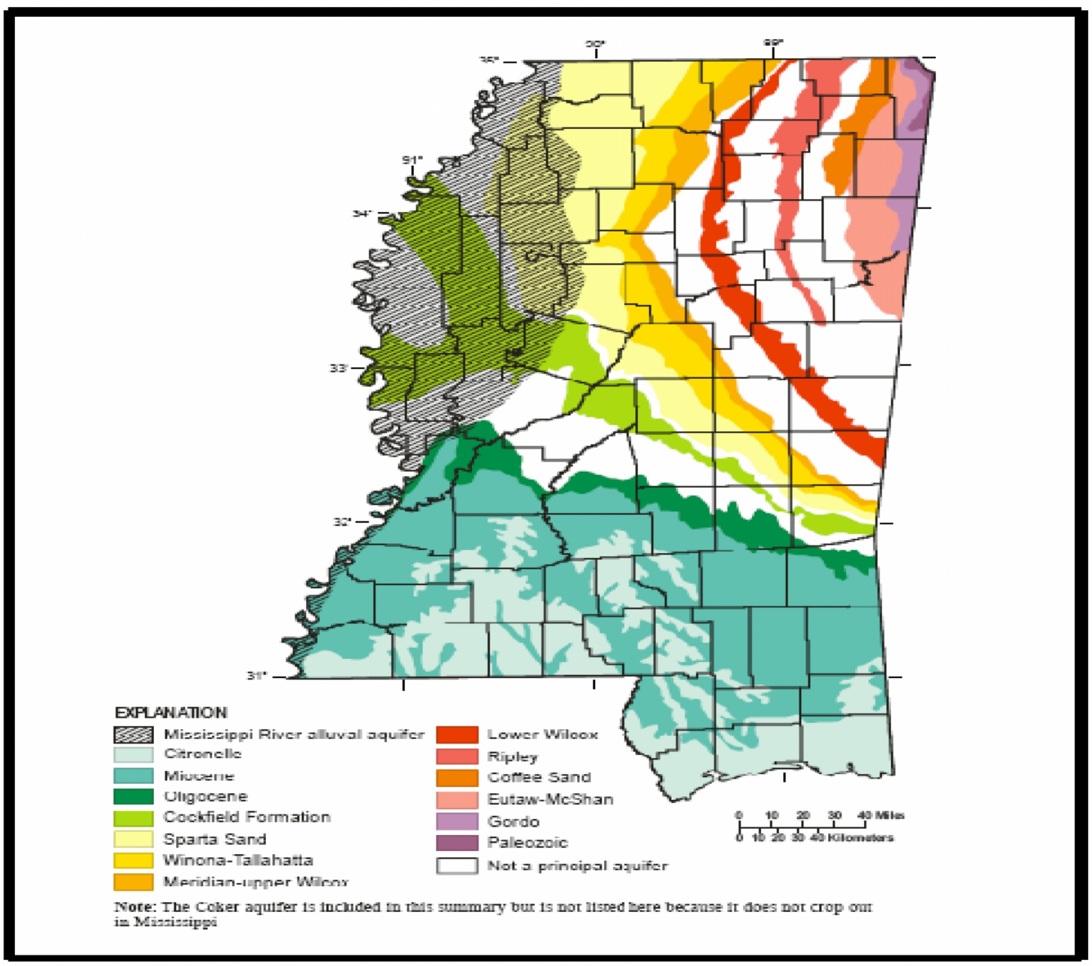

Fig. 2. Mississippi aquifers and their locations
Source: MDEQ, 2010

The same can be said of boil water notices from system maintenance failures. Another issue is the fairly large number of small rural water carriers in the state that are often plagued with non-compliance and minimal capacity to sustain healthy water supply [1]. In the context of the study area, it is obvious that assessing these trends will strengthen policy responses in water management in an eventual outbreak of crisis [16]. The belief is that the counties will benefit from the periodic use of mix-scale approach; [29,30,31] in sharpening their capability in pinpointing stressors and issues; [32,33,34,35,36,37,38,39,40,41,42,43,44,45,45,46,47-50] while ensuring access and water quality in Mississippi.

2.2 Methodology

The method used in the study stresses the application of GIS in the assessment of water resource use based on descriptive statistics and GIS mapping to display the trends spatially. The initial step involves the identification of variables needed at the county and state level from 2002-2010. This is intended to assess the temporal-spatial aspects of water resource use and the elements influencing quality. The variables consist of socio-economic and environmental data including the frequency of boil water, the causes, the dates, the number of violations, water pumpage volume, number of aquifers, contaminated and brownfield sites, stressors and others. The design of spatial data needed for the GIS analysis required the identification of appropriate digital county boundary lines covering the study periods of 2002-2012 and others. This entailed the assemblage of the electronic version of available hydrological and land cover maps containing aquifers and boil water alert distributions in the state of Mississippi for the periods of 2002-2011. Some of the information came from the MDEQ, MDH, USGS and the USNGWA. This was made possible by the retrieval of spatial data sets of shape and grid files from the Mississippi Automated Resource Information System (MARIS) in digital form using ARCVIEW GIS.

Given that the official boundary lines between several counties in the state stayed stable, it was possible to assign consistent geographic identifier code to the respective units in order to maintain analytical coherency. In the second stage, basic descriptive statistics was employed to transform the original data on environmental variables into relative forms. The statistical output of the variables from the spatial units were mapped and compared across time in ARCVIEW GIS. The process helped delineate the spatial locations and patterns of contamination and the sites of brownfields and the pollutants and the distribution of ground water use and other indicators associated with water use and quality declines.

3. RESULTS AND DISCUSSION

This section of the paper focuses on temporal and spatial analysis of ground water problems in the study area based on use, availability, violations and pollution risks. The other aspects touch on the vulnerability of ground water supply to stressors, accumulative depletion and diversions and spatial analysis of the trends and impact using GIS. This will be followed by the identification of factors, efforts and discussions.

3.1 Results

3.1.1 Water use 2002 and 2012

Assessing water use involves a highlight of the pumpage in 2002 and 2012 under various categories, their ranks, quantity and percentages (Table 1). The reported use outlined in

Table 1*[1] in 2002, comes with a ranking scale indicating the top three users most notably municipalities, industry and public water. Among the next group, note categories 4 to 5 in the middle followed by 6 to 9 at the bottom. With the total of 376 mgd and overall average of 41.77, the pumpage level of various categories puts industry and municipalities at 106.3-170.3 mgd as the 2 dominant users of water in 2002. From the Table, the pumpage of those 2 based on ground water deposits, outpaced the others therein (Table 1*[1]).

Table 1. Reported water pumpage by category and quantity for Mississippi 2002 to 2012

	2002*[1]		
Ranking	**Category**	**Quantity (in Mgd)**	**The percentages**
1	Municipal	170.3	45.29
2	Industry	106.3	28.27
3	Public Water	78.8	20.72
4	Commercial	8	2.12
5	Institutions	4.7	1.25
6	Fish Culture	3.0	0.79
7	Wild Life	2	0.53
8	Irrigation	1.8	0.47
9	Domestic	1.1	0.29
Total		**376**	**100**
	2012*[2]		
Ranking	**Category**	**Quantity (in Mgd)**	**The percentages**
1	Irrigation	1430	65.17
2	Public Supply	330	15.04
3	Livestock & Aquaculture	253	11.53
4	Industrial Self Supplied	77	3.50
5	Individual Household	56	2.55
6	Thermoelectric	37	1.68
7	Mining	11	0.50
Total		**2,194**	**100**

*[1], *[2] *Source: MDEQ, 2011, USNGWA, 2012*

Among the other category of users during that period, public water agencies at 78.8 mgd was closely followed by commercial, wildlife, fish culture, institutions and irrigation with water budgets estimated at 8, 2, 3, 4.7 and 1.8 mgd. Note also the amount of water estimated at 1.1mgd devoted to the domestic use category serving communities in the built environments of the state. From the percentage distributions of pumpage, the top ranked categories in Mississippi used up 45.29%, 28.27 to 20.72% of ground water compared to commercial and institutional entities who accounted for mostly 2.12 to 1.15%. Even though the rest of the classes maintained usage rates of less than 1%, when combined they are still significant enough to influence depletion rates (Table 1*[1]).

In the 2012 period, irrigation, public supply, livestock and aquaculture emerged as the top three users (Table 1*[2]). For the remaining group, industrial self-supplied, individual house hold, thermoelectric and mining held steady on the ranking column at 4,5,6,7. With a total of 2,194 mgd for the state, irrigated farming pumped about 1,430 mgd of water, public water supply on the one hand saw its pumpage climb to 330 in the same period. On the other side, about 253 mgd of Mississippi's ground water deposits found ample use in livestock and aquaculture. Additionally, thermoelectric and mining industries used up another 37 to 11 million gallons of water on a daily basis. This is somewhat below the levels consistent with the first group. Aside from an average of 313 mgd for all, the percentage distribution of the total ground water use shows irrigation with 65.17% at a level that outpaced (the 15.05-11.53% for) public supply and livestock and aquaculture. The other group of 3 users (industrial self-supplied, individual household, thermoelectric) maintained 3.50-1.68% in pumpage rates higher than the mining sector with 0.50% (Table 1[*2]). The thing to note is that different agencies that provided data used herein do it differently and we do not control the process. As a result, the paper identified this dimension as a vital task in future work. While the two data sets may differ, the analysis highlighted the state of water use in the state.

3.2 The Risks to Ground Water Supply from Climate Change Stressors in the Gulf

This section illustrates the projected ground water stress from climatic variability with focus on three coastal counties of Mississippi where it is imminent. Water use data was based on 2005 water use supply, prepared by the US Geological survey (2005), model projected climate records for the 21st century were derived using the climate wizard tool designed by Evan Giveta. This tool in turn utilized the set of downscaled result for the 21st century from the global climate models by Edwin Mauer and colleagues. With the assumption that global climate change could lessen water supplies due to diminished rainfall and other elements at levels different from the 20st century. The model involves water sustainability risk index which factors in water withdrawals, projected growth, susceptibility to drought, projected climate change and other elements for specific County for the period 2050. It takes into consideration the renewable water source from rainfall based on the most current downscale climate change predictions and assesses imminent uses for different human usages. This was then used to establish that climate change could create an extreme risk of water scarcities that may possibly emerge in counties of Mississippi [47,48].

Using a set of indicators comprising projected water demand, ground water use, and susceptibility to drought, projected increase in freshwater withdrawals, and projected increase in summer water deficit. Three Mississippi coastal counties in the analysis, Hancock and Harrison counties were classified as vulnerable to moderate risks, under criteria 2 of the 5 indicators. Jackson County however met the criteria for three and is considered to be at high risk [48]. Additionally, saline water intrusion into fresh water aquifers in the region has been detected, due to declining ground water levels along the coast and the injection of saline waste water from oil and gas production [49]. Jackson County exhibits also a high risk for losses in agricultural production while Harrison and Hancock counties show moderate risk for losses (Table 2). This could result in changes in crop yield, prevalence of crop diseases, and insect pests. Additionally, moisture defects and drought are likely to increase in southern Mississippi due to the projected increase in the number of dry days from climatic stressors [48]. This is not envisioned as a forecast that water scarcities will happen, but to some degree where they are more likely to arise. The belief is that wherever it occurs, there could be bigger pressure on decision makers and water consumers to better identify and clearly manage demand and supply [47].

Table 2. Water sustainability index for 2050 factoring climate change for coastal Mississippi

County	Extent of development of available renewable (> 25%)	Groundwater use index (> 25%)	Susceptibility to drought/ summer deficit< -10inchs	Increase in summer water deficit increase> 1inch	Growth in water demand (>10%)	Total index
Hancock	0	1	0	1	0	2
Harrison	0	1	0	1	0	2
Jackson	0	1	0	1	0	2

Source: National Resource Defense Council, 2012; Evans 2012

3.2.1 Accumulative ground water depletion

With the risks of water stress, the accumulative groundwater depletion in the Gulf coastal plain ecozone which covers Mississippi shows some convergence with the previous section. As part of a regional trend over different periods (1900-2000 and 1900-2008), Table 3 shows accumulative patterns of ground water depletion in the Gulf coastal plain ecozone in the southern region of the US which includes Mississippi. To buttress the water deficits over the years, the information in Table 3 outlines rising ground water decline in the ecozone. From the first and last columns of the sub areas that are associated with Mississippi, note that the total volumetric ground water depletion in square kilometers rose from 28.9-31.1 km^3 and 198.8-266 km^3 in 1900-2000 and 1900-2008 (Table 3). The severity of the accumulated groundwater depletion in adjoining sub areas to the state over the years is not only a troubling trend but a recurrent issue which should no longer be taken for granted [44]. With the constant exposures to high population densities and urban development potentials and robust migrations in these areas in the foreseeable future, the stress unleashed from climatic variability as seen previously can influence continual access to fresh groundwater in the region and Mississippi.

Table 3. Ground water depletion in individual systems, sub areas, of the gulf coastal plain 1900-2008

Gulf coast plain	Total net volumetric ground water depletion -Km^3	
	1900-2000	1900-2008
Coastal Low lands of AL, FL, Louisiana, Mississippi*	28.9	31.1
Houston Area, Northern Texas, Gulf coast	4.8	4.8
Central Gulf Coast Aquifer, Southern Texas	9.5	9.6
Winter Garden Area, South Texas Gulf Coast	117.6	182.0
Mississippi Embayment*	198.6	266.0

**Sub areas associated with Mississippi. Source: USGS, 2013*

3.2.2 Ground water resource diversions

Ground water diversions by Memphis Light, Gas and Water (MLGW) Company stemmed from pumping activities out of the Sparta sand aquifer from its westerly direction to a northern flow path toward the steepest part of the cone underlying Memphis. The process involved altering the natural flow gradient and rate which resulted in a northward movement of Mississippi's water to Memphis without authorization. Prior to that, there was a constant volume of water physically present under Mississippi and more particularly in Desoto County. With the diversion process predicated on aquifer water inventory such as changes in storage, ground water in flow and out flow and other factors [33].

The ensuing stress from MLGW pumpage at Shelby County Tennessee produced a cone of depression (Fig. 3). Notwithstanding the stable condition of ground water system in the Desoto county area of Mississippi earlier, this cone slowly extended deeper onto the county, and accelerated water diversion to MLGW wells and subsequent ground water declines [33]. Interestingly, Memphis and MLGW have at no time questioned both the presence of a massive funnel created by their pumpage and impacts on Mississippi's ground water. The cone emerged from the impacts on Mississippi's ground water through several wells owned by MLGW to sustain demands in the Memphis area. In the process, separate cones that formed sparked extensive network of depressions over a vast geographic area (Fig. 5). The magnitude of this big cone, from MLGW's accumulative well field pumpage is represented in cream color (Fig. 3) just for illustration purposes. While water diversions on a continual basis began in1924, the daily pumpage went from 13.64 mgd to 23.33 between1965 to 2006. This equates to 15% to 22% of MLGW's ground water supply from Mississippi. All in all, over 363 billion gallons of water was diverted from Mississippi from 1965-2006. Even though the diversions are continuing; the daily flow estimated at 24 mgd since 2007 runs till 2016. With estimated damages of $713-$973 million from 1965-2006 [33], and the scale, unlawful pumpage of this scale, adds to depletion, limited access and major impacts like subsidence and salt water intrusion into the fresh water environments of the state [50]. Illustrating the cone depression serves a meaningful purpose in providing information for planning and for those unaware of it.

The significance of the cone depression illustration is that local plan upgrade in cities today requires citizens' participation in open house process in which wish lists for improvement are tabled. If individuals in either side see what transpired as an issue, water conservation and planning would be on their agenda since some may be hesitant to revisit it even though it happened in one county. It may also be difficult to attract industries or people to such a place since cities rely on these variables to collect taxes and raise their profile among competing cities as well. More so, Shelby county is a large county with 52.8% African American [51], and considering the history of race relations in both states, Black counties on both sides would benefit through such illustrations from a cone depression so that they are better equipped ahead of time in dealing with the eventuality from a planning perspective. Additionally, if Shelby county is experiencing, widespread growth in the face of this trend, chances are that the state may use available growth management tools such as transfer development rights (TDR), to direct growth [52]; elsewhere hence the benefits of the illustration herein.

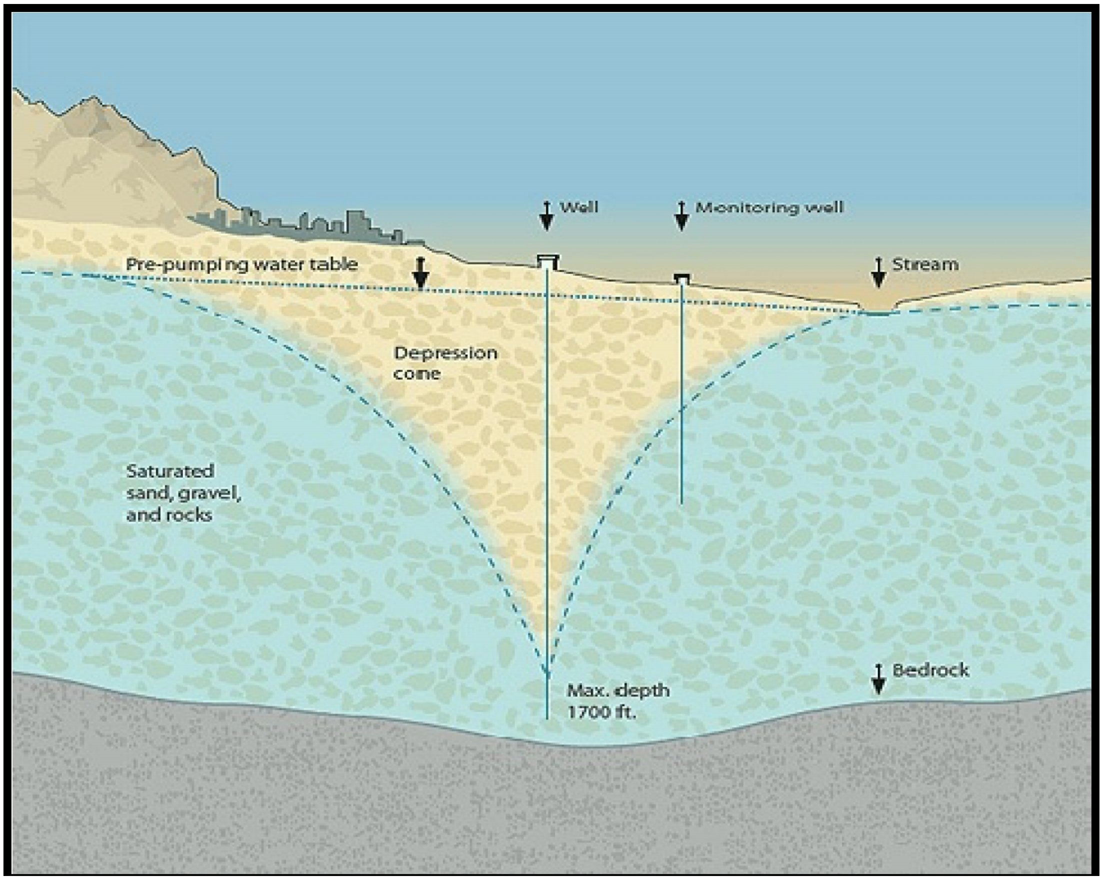

Fig. 3. Cone depression formation from water diversion.
Source: Cameron, 2009

3.2.3 Water pollution and violations

Declining quality and contamination has quickly emerged as great concerns in the management of water resources in the study area [53,54,55]. This is manifested with recurrent boil water alert and frequent safe drinking water violations. Based on the information in Table 4, between 2003 to January 2005, the state of Mississippi raised the boil water alert level 17 times in 15 counties mostly from public water sources [54]. While a total of 8,224 individuals were affected in the area during this period, the Port Gibson Township at Claiborne County accounted for 4,845 or 58.91% of the cases of water contamination (Table 4). In the periods of 2007-2010, the state of Mississippi experienced a recurrence of boil water alert lasting several days in 24 of its counties. Of the contaminants, coliform and E-coli emerged as some of the leading causes in affected counties. Among the counties, Lee had 16 cases of impaired water alert at a level much higher than the others while Harrison and Washington each reported similar problems 5 times. Another group of 7 counties had a boil alert frequency rate of 4. Within these periods, a group of other counties that enforced boil water alert order 3 times were those at Clarke, Jackson, Copiah, Leflore, and Warren. Additionally, over half dozen other counties from Newton to Simpson also enforced boil alter order 1 to 2 times (Table 5). Turning to the extent of violations, the data also revealed the occurrence of safe drinking water violations in selected counties. In the 2002 fiscal year alone, the state recorded 75 cases of water quality violations due to the high level of coliform bacteria in 29 of the selected counties [53,54,55]. The other violations involved situations in which nitrate and bacterial content of drinking water exceeded the prescribed levels (Table 6).

Table 4. Boil water alerts in the counties 2003- 2005

Year	County	No. occurrences	No. people affected	Reason
2003	Carrol	1	N/A	Coliform
2003	Lee	1	324	Pressure Loss Contaminants
2003	Quitman	1	N/A	Contaminants
2004	George	2	250	Coliform, Contaminants
2004	Franklin	1	137	Pressure Loss Contaminants
2004	Marion	1	125	Pressure Loss Contaminants
2004	Greene	1	474	Pressure Loss Contaminants
2004	Jackson	1	45	Pressure Loss Contaminants
2004	Jefferson	2	100	Pressure Loss Contaminants
2004	Kemper	1	940	Pressure Loss Contaminants
2004	Dekalb	1	520	Pressure Loss Contaminants
2004	Marion	1	125	Pressure Loss Contaminants
2004	Perry	1	95	Pressure Loss Contaminants
2004	Yalobusha	1	244	Pressure Loss Contaminants
2005	Clairborne	1	4845	Coliform
Total		17	8,224	NA

Source: Mississippi Department of Health, 2005, Merem 2005

Table 5. The summary of boil water alert among Mississippi counties 2007-2010

Counties	No occurrences	Reasons
Lee	16	Coliform and *E. coli*
Harrison and Washington	5	Coliform and *E. coli*
Bolivar, Forest, Hinds, Jefferson , Lafayette Forest, and Marion	4	Coliform and *E. coli*
Clarke, Jackson, Copiah, Leflore, and Warren	3	Coliform and *E. coli*
Newton , Panola, Scott, Tishomingo, Tunica, Union, Walthall	2	Coliform and *E. coli*
Yalobusha, Yazoo and Simpson	1	Coliform and *E. coli*
Total	31	NA

Source: Mississippi Department of Health, 2010, Merem 2010

Table 6. Water quality violations in selected counties in 2002

Coliform	2002	Microbiological	2002
County	**Number of violations**	**County**	**Number of violations**
Bolivar	3	George	2
Choctaw	2	Lee	2
Claiborne	2	Marshall	6
Desoto	2	Pearl River	2
Forrest	2	Tallahatchie	2
Hinds	2	Total	14
Jackson	2	Nitrate	2002
Lafayette	5	County	Number of violations
Lowndes	3	Desoto	2
Monroe	3	Hancock	2
Oktibbeha	2	Harrison	4
Pearl River	2	Hinds	2
Pike County	2	Jackson	2
Potomac	3	Tate	5
Sunflower	2	Walthall	2
Tallahatchie	3	Total	19
Yazoo	2	NA	NA
Total	42	Total	75

Source: Mississippi Department of Health, 2002, Merem 2005

3.3 Spatial Analysis

3.3.1 The spatial distribution of water use

Fig. 4 on water use by counties in Mississippi in 2010 provides a highlight of the spatial distribution of the trends. The breakdown of water use cover many categories represented in dark to light brown, as well as orange and pink. The scales of water use in the map has the dark brown in the north west on the high category level followed by the light brown in medium and orange and pink rounding up the other levels. The geographic trend reveals a concentration of large water use category 106-500 in the northwest corner of the state along the Mississippi Delta at levels that surpassed the others. The other category represented in light brown (5-100) held steady in Yazzo and Warren counties along the central Mississippi region adjacent to major urban counties known for human activities and impacts on ground water use. Note also a pocket of other counties across the state where ground water use remained extensive (Fig. 4).

Surely, heavy water pumpage seems concentrated in the northwest and southwest areas of the state followed by a few spots in the south east known for shallow aquifers and surfaces prone to contamination. On the upper north side, lies a set of counties classified under the 0-5 and 6-25 levels of water use. This is somewhat different from the south, northwest and the central part of the state known for more use. The implication is that over pumpage has a tendency to inhibit water quality in fresh water environments due to the intrusions of salt water especially when development and water demand are on the rise.

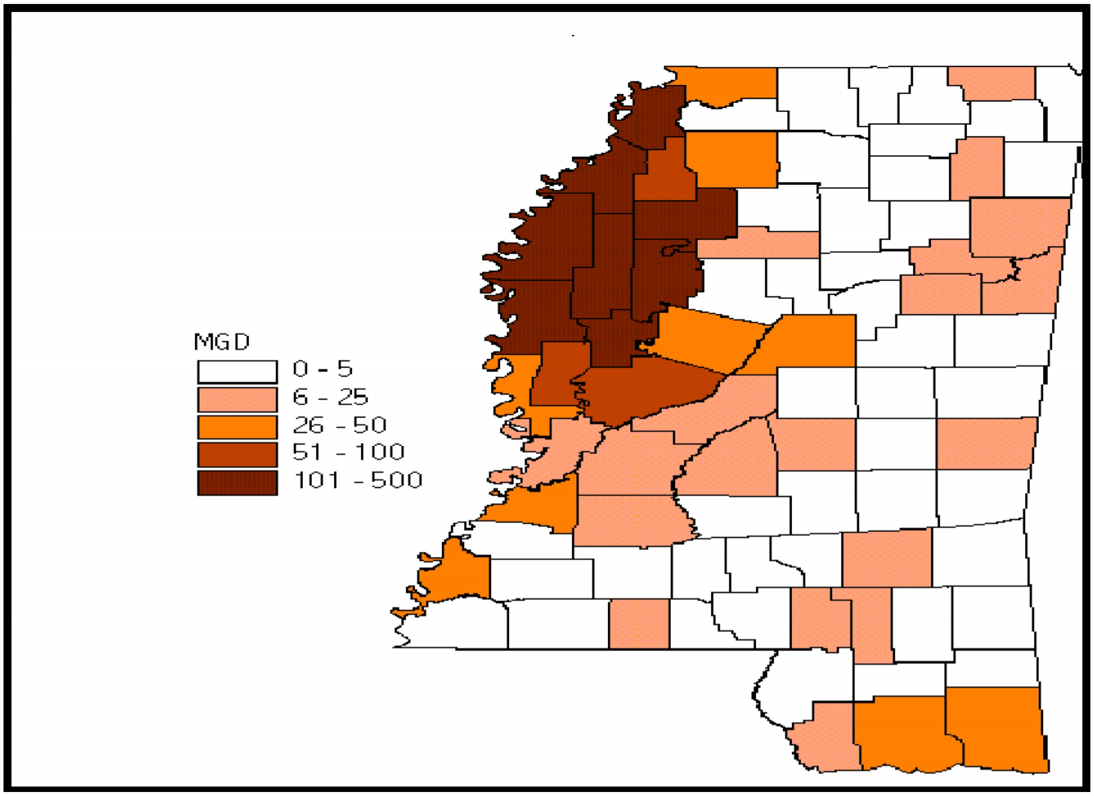

Fig. 4. Water use by County in Mississippi, 2010

3.3.2 The spatial distribution of cone depression

The map in Fig. 5 shows the geophysical trend of cone or funnel shaped depression attributed to ground water diversions from Mississippi. Note the adjoining areas in Mississippi and Tennessee counties of Shelby and Desoto where several decades of groundwater diversion created the funnel shapes or cone. Looking at the middle portion of the map, one notices elongated depressions in milky color pierced underneath the surface bordering Mississippi. In locating this geophysical state spatially, GIS mapping helped pinpoint the occurrence in the adjoining areas of Mississippi and Tennessee where decades of water diversion went undetected. Another thing from the map is the geographic identification of the affected areas and the parties to the dispute over water rights between Mississippi and Tennessee. Interestingly enough, the appearance of the four cones on the map implies that the diversion of ground water was clearly obvious along the Desoto county area of Mississippi as alleged by Mississippi. As mentioned earlier, the resulting damages claimed by Mississippi valued at hundreds of millions occurred from 1926 to 2006. At a time when groundwater depletion is occurring nationwide, geographic identification of the cone depression as indicated herein, enhances the capability of managers in tracking the scale of ground water withdrawals essential for continued access, planning and sustainable use in Mississippi as well as risks such as subsidence and the threats of salt water intrusion [33].

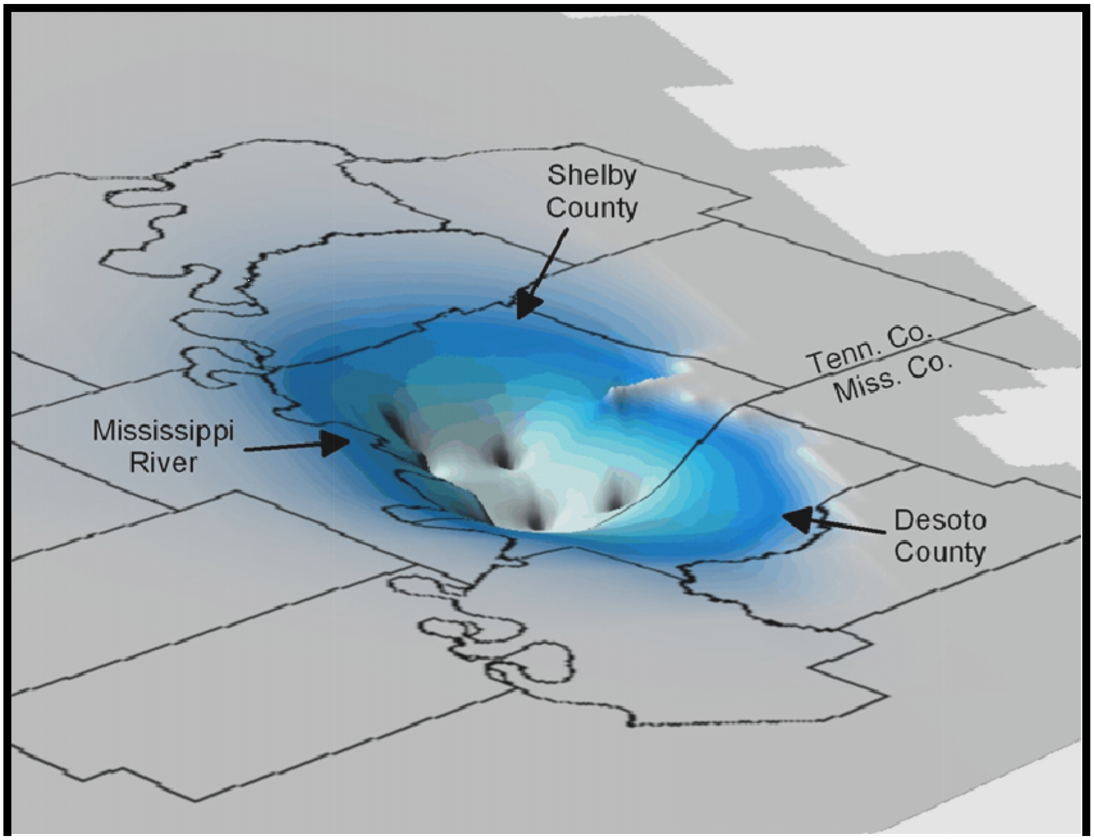

Fig. 5. Cone formation from water diversion
Source: Cameron, 2009

3.3.3 The geography of accumulative groundwater depletion

The map in Fig. 6 highlights the geographic distribution of accumulative groundwater declines in the US between 1900-2002 and 1900-2008. The scales of the map as represented in various colors ranged from-40to-10 to 150-400 in cubic kilometer units. While depletion has rapidly accelerated over the years nationwide posing severe consequences for irrigation and surface water sources, the critical colors of dark red and orange as measures of medium and highest levels of ground water depletion not only reaffirmed the trend in comparison to the other regions of the country, but the study area remains vulnerable. Just as depletion thresholds held steady in the study area during the periods in question. The breakdown of the geographic scales puts the initial depletion levels for the Mississippi area in the Deep South region of the map at categories 12 and 8km^3 of ground water depletion. Given the heavy pumpage of water over years, it is not surprising that the vast concentration of 25 to 50 and 150 to 400km^3 ground water depletion evident in the area are fully manifested in the northwest and southwest region of the state (Fig 6). Being the area where the Mississippi Alluvial aquifer has come under extensive use for farming and other uses, the accumulative depletion rates over the years held firm in the state. This is consistent with other analogies already stated in this research. With the geographic display of accumulative depletion and the continued spread across different regions including Mississippi and the impacts, the risks are quite serious to be ignored [44].

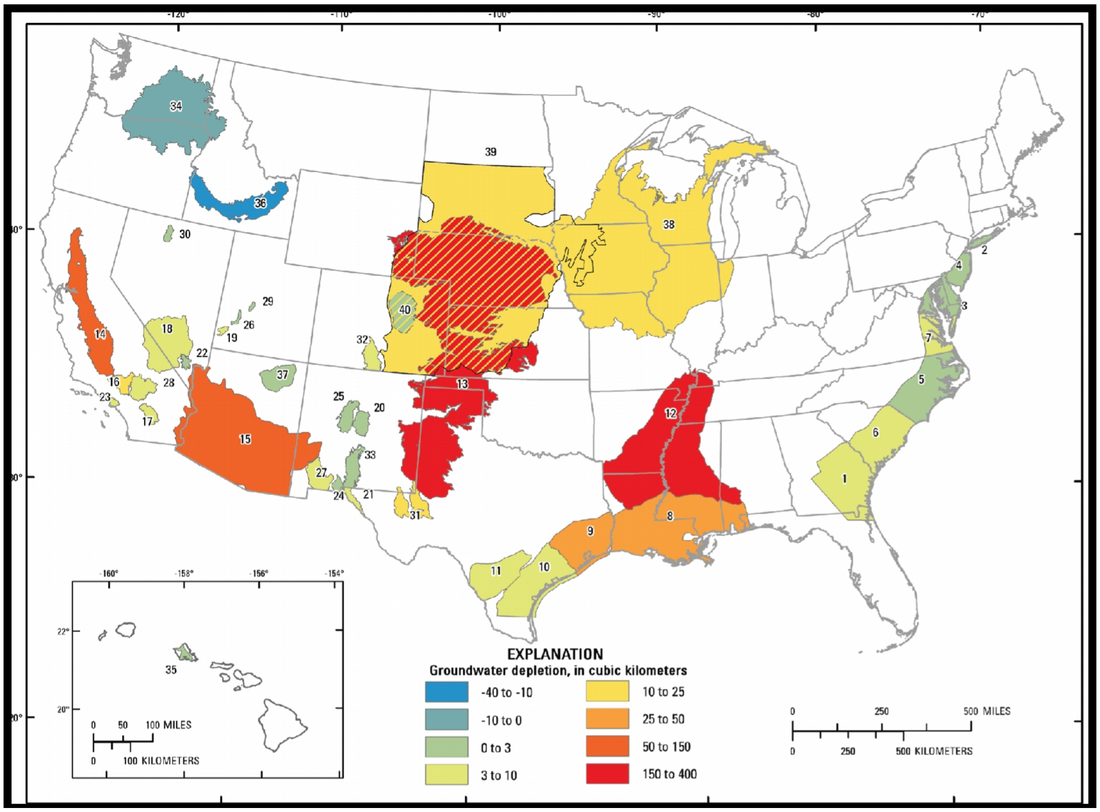

Fig. 6. Accumulative ground water depletion in the US 1900-2008
Source: Konikow, 2013

3.3.4 The threats of water contaminants and pollution

In addition to the previous analysis, the study area faced the risks of contamination coming from different types of pollutants and the outbreak of E-coli and coliform across the state. These contaminants made up of mercury, TPH, PCBs, Toluene, benzene, Trichloro methyl, arsenics, pesticides and methyl–ketoide are concentrated in the different counties of the state where ground water sources such as aquifers and others are located. In 2008, the Delta region of the state in the northwest saw vast presence of mercury, benzenes, arsenic and PCBs. The central region followed up with a cluster of counties contaminated by mercury and Toluene as well [3]. Elsewhere both the north and southern regions of the state had their share of areas contaminated by PCBs, Benzene, Mercury and TPH (Fig. 7).

The same thing can also be said of brownfields listed in different areas of Mississippi (Fig 8). In that setting, runoffs from underground storage tanks when discharged have a tendency to percolate into shallow ground water sources. With a network of over 12,000 brownfields sites, groundwater supply faces serious threats [3]. Over the years, saltwater contamination of freshwater aquifers from oil fields disposal had been reported in numerous sites mainly in the central and southern parts of the state. During the 2003 -2005 period, two counties saw their water infested by contaminants and coliform respectively. With extensive spread of boil water alert all over the state in 2007-2010, the geographic pattern show e-coli and coliform outbreak more in the central, the north west and south east region as well (Figs. 9-10).

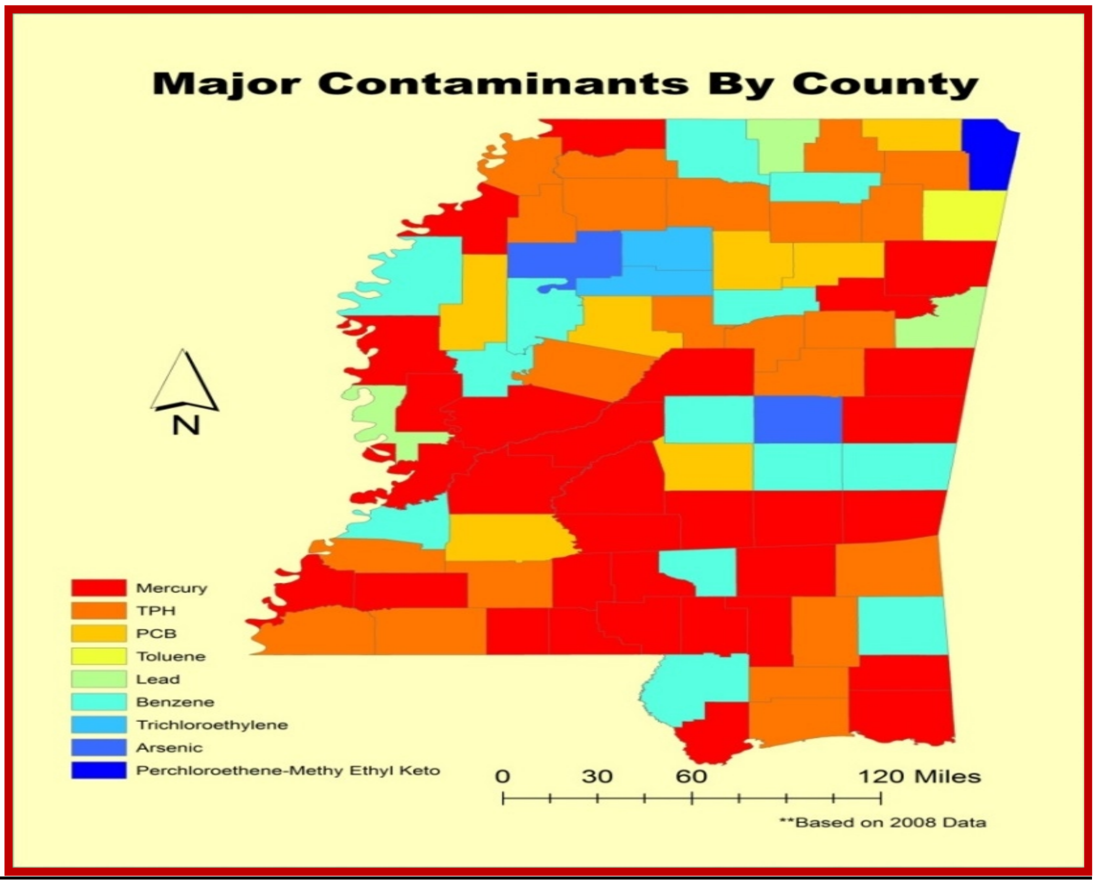

Fig. 7. Locations of the Potential Sources of contamination, 2008

The occurrence of pollution in some sites caused by a mix of physical elements such as porous soils, low aquifers and heavy precipitation makes the state's ground water prone to contamination. Consequently, the shallow deepness to water, the frequent applications of agro-chemicals, and high precipitation are settings in the Delta fuelling vulnerability of shallow ground water to pollution, hence the threats [40].

3.4 Emerging Spatial Patterns

Regarding the spatial patterns that emerged, in the 2010 period the highest and medium scales of water pumpage were more concentrated in the northwest and the south west area of the state. While the emerging patterns showed more presence in the two regions already mentioned, there exist a few more spots in the northern edge of the map where pumpage stayed soft (Fig. 4). Considering the intense water use and activities in the Delta region of the state and the fact the area experienced transboundary diversions of water from the Sparta aquifer for years (Figs. 5-6). It came as no surprise that the ensuing cone depression formation occurred in an area adjacent to Desoto County in the northwest region of the state. In looking at the map in Fig. 6 with one in orange and another in red, one notices that the accumulative depletion scenario of ground water between 1900 to 2008 appeared more in the northwest and south west of the state where the problem seemed quite pronounced. The patterns for contaminated sites showed pockets of areas in the northwest, central and southern region with mercury contaminants. For the others, Benzene PCB, TPH and Tolune contaminants seemed spread across the counties in 2008 where chemical contaminants threaten water resources (Fig. 7). Brownfields on the other hand, maintained a very visible presence across the state (Fig. 8). With e-coli and coliform outbreak evident across space, the patterns in 2007-2010 show e-coli and coliform outbreak more in central, northwest and the southeast region (Figs. 9-10).

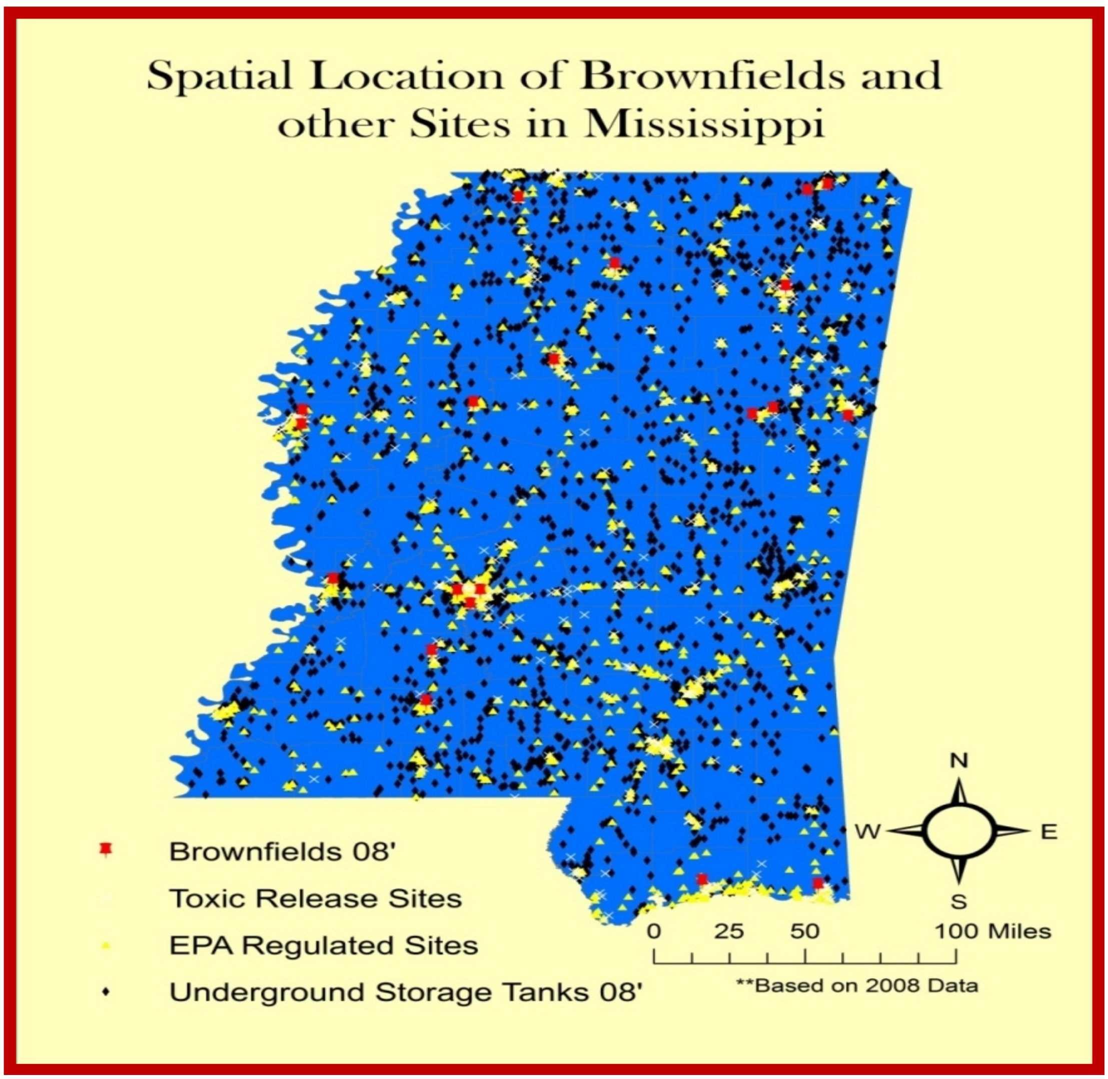

Fig. 8. Major brownfields threatening water quality, 2008

Mapping the stressors influencing water use required GIS analysis. With the emergence of GIS and its ability to locate environmental hotspots across time and space, analyzing the spatial patterns and concentration of usage, pollution threats and exposure to cone formation and the accumulative depletion known to influence water access and availability serves a meaningful purpose. Surely, various sectors and regions of the state have been quite active in water pumpage between 2010 and 2012 along with the exposure to cone formation in the northerly area of Desoto.

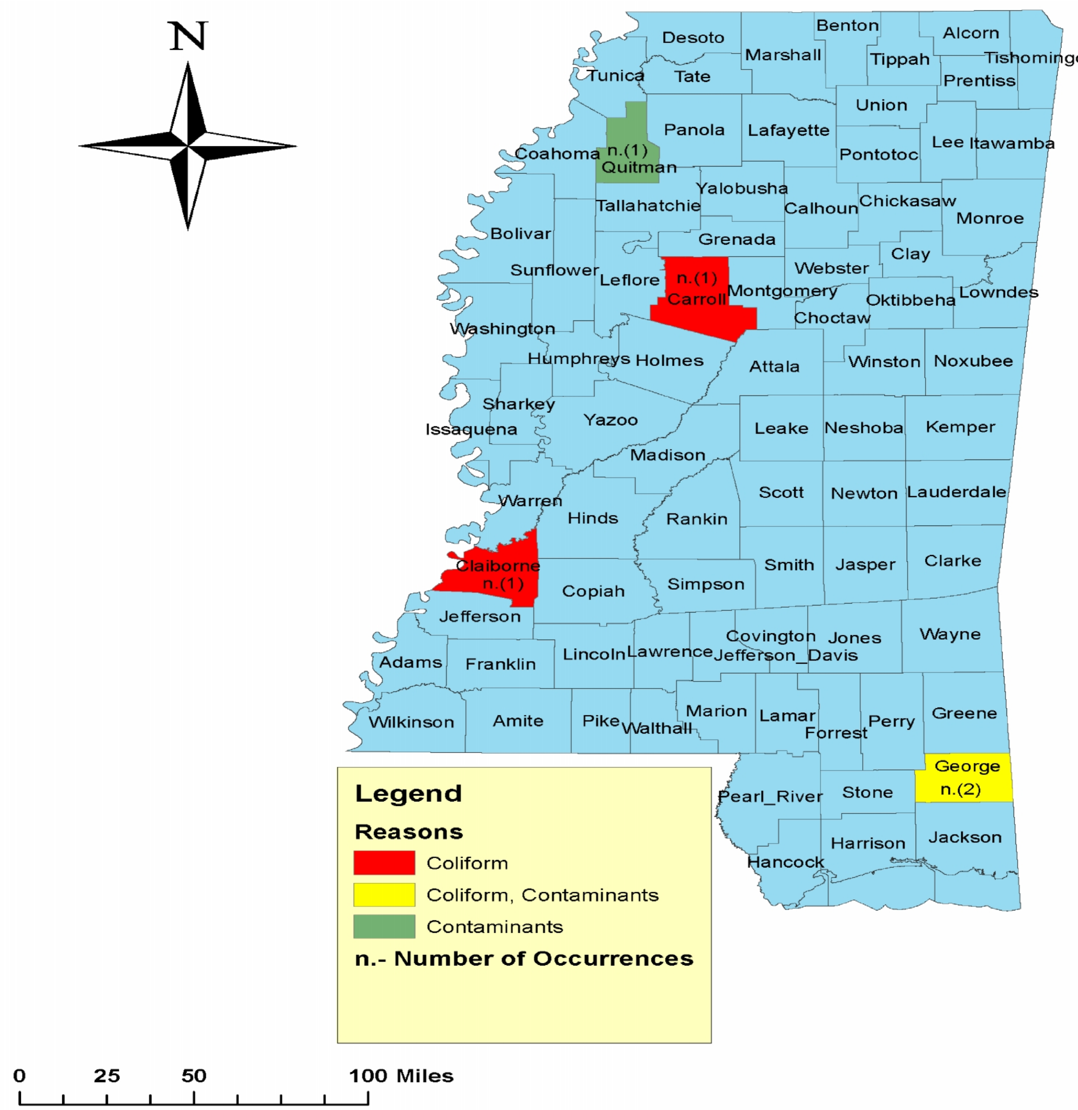

Fig. 9. Coliform and contamination outbreak and the number of occurrences 2003-2005

The magnitude of these trends is indicative of the patterns of water use and the activities of various sectors as well. A case in point is the northern region where two of its counties

(Washington and Issaquena) received almost a half a billion dollars in agricultural related subsidy requiring more use of water than others. As a very active region in water use and farm nutrients application adjacent to the Mississippi Alluvial plain aquifer, the emergence of these spatial patterns could not have happened without human activities in the region. Considering the northwest' heavy dependence on water and fertilizers and the impacts on quality and continual access. The patterns of accumulative depletion in the past and the probability of a potential scarcity from climate change remain a major concern. Pinpointing the varying patterns is quite critical as the counties grapple with the risks.

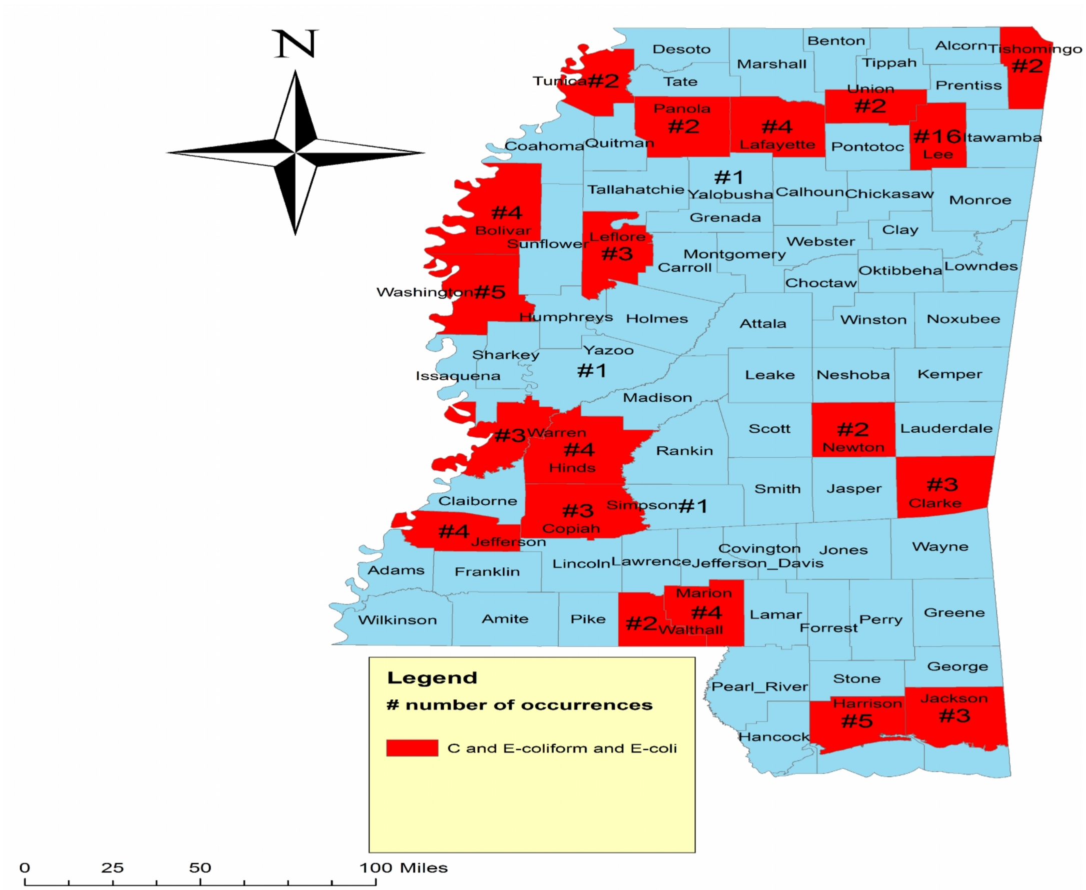

Fig. 10. Coliform and *E. coli* outbreak and the number of occurrences 2007-2010

3.5 Factors and Efforts

To a great extent, the water resource problems facing Mississippi do not operate in a vacuum. The threats to ground water quality and availability can be attributed to a wide range of factors that are predicated upon physical and socio-economic elements of urbanization and agricultural farming. At the same time, agencies in the state and others have initiated various programs to deal with the problems. For details of these factors and the efforts in place, see Appendix E-F.

3.6 Discussion

The paper highlighted the state of water use and the heavy dependence of the state on ground water sources and the current issues impacting water quality, usage and availability. Of great concern is the role of various elements including the growth and development of cities coupled with the decaying state of water infrastructure and limited capacity of state water carriers in ensuring access and quality. The paper showed justifications for the research using a mix scale approach connected to GIS and descriptive statistics and primary data at the county level. In the context of the study area, the linkages of water use to agriculture and other categories, coupled with a synopsis of the major aquifers of the state and their current challenges was presented. From the results, irrigation not only emerged as the biggest user of water in 2012, but municipalities and industries pumped more water than the other categories in 2002.

The synopsis of the projected impacts of climatic change on ground water and the accumulative trends in the Gulf coastal plain eco-zone from 1900-2000 and 1900-2008 indicated on the one hand the exposure of coastal Mississippi to water stress in the coming decades. On the other, accumulative depletion of ground water along the Mississippi side of Gulf coastal plain eco-zone showed rising water deficit levels as well. Other aspects of the results showed occurrence of contamination and the growing threats of water pollution often manifested with recurrent boil water alert bulletins, and compliance violations from 2002-2005. With the localized nature of ground water problems in the state, it came as no surprise that they occurred in towns, where water associations, institutions, public parks and play grounds, residential homes and water districts emerged as partial sources of the problem. The analysis also uncovered the physical impacts of ground water diversions on Mississippi by one of its neighbors. Notwithstanding, the formation of cone depressions on the landscape, there were the potentials for trans-boundary conflicts over water rights and limited access to water for Mississippians.

The spatial analysis of the trends using GIS mapping, highlighted the geographic spread of water pumpage, geophysical impact of unauthorized water diversion and the mounting threats to water quality from contaminated sites across counties of the state. The regional context of the accumulative nationwide depletion over the years identified the levels of groundwater water deficit for Mississippi in comparison to other areas of the country. The interesting point about the geographic locations of water pumpage among counties under different categories is that, substantial withdrawals on a daily basis seemed fully concentrated in the agricultural hub of the state along the northwestern region or the Delta within the Mississippi Alluvial Plain aquifer. Of great importance in the spatial analysis is the precise mapping of both contaminated and brownfield sites spread across numerous areas of the state with ground water sources. Another promise stems from the capability of GIS mapping in pinpointing the veracity and gravity of physical impacts of undetected ground water diversions which created the geophysical state of cone depression.

Considering that water resource issues outlined herein did not operate in a vacuum, the paper identified several elements responsible for it. The factors include the declining state of water infrastructure and hydro-geology, urbanization and population, waste disposal and industrial activities as well as agriculture and farming activities in the state of Mississippi. Aside from current efforts by some of the state's agencies and the USGS to address water issues, the paper offered many recommendations in Appendix F ranging from regular assessment, sustainable use, and education to monitoring and infrastructure design. With the growing incidence of water quality decline including threats of contamination, deficits in ground water volume and ground water depletion threats across the country and the geographic diffusion of the problem. Water resource issues outlined here on Mississippi should no longer be overlooked [53,54,55]. The applications of mix-scale approach in analyzing the water resource issues in the state not only holds promise for future policy research, it reaffirmed the capability of GIS mapping as essential decision support tool for water resource management for counties at the state level. Consistent with the mapping is the ability to track water resource issues as communities grapple with decaying infrastructure and other factors impeding continuous access and water quality across counties in Mississippi.

4. CONCLUSION

In a state where most citizens rely on groundwater for various use, mix-scale approach of descriptive statistics and GIS mapping offered insightful directions. The model helped capture the temporal-spatial dimensions of water use, location of stressors and the exposure to accumulative depletion and other risks necessary for effective management. The spatial display of pollution and contaminated sites revealed a cluster of counties that are at risk from stressors spread across the state with implications on water quality. Other aspects of the study consistent with the study area stems from the exposure to accumulative depletion over the years and the probability of water scarcity from projected climate change scenario. Consistent with the findings is the occurrence of cone formation attributed to transboundary diversions.

Accordingly, some important conclusions can be drawn from the analysis. Despite existing efforts by different agencies, the study area experienced growing pumpage among different sectors. There were also the threats of pollution evident with recurring boil water alerts and the presence of contaminated sites. Specific patterns that emerged, point to a growing water use and large concentration of pumpage in the northwest portion of the state. Of great importance is the exposure of the northwest county of Desoto to cone formation triggered by the transboundary diversions. The accumulative depletion that emerged showed the levels for depletion exposure significant in the northwest, the central region and the south as well.

The geography of accumulative deficit showed the scale and spatial spread for Mississippi in comparison to other sub areas of the country over different periods. This trend raises the spectra of responsibilities for planners and those charged with water management. With the emergence of GIS and its ability to locate environmental hotspots across time and space, analyzing the spatial-temporal patterns of water issues and various elements known to influence it in Mississippi comes with many benefits. This capability remains crucial in the design of data infrastructure best suited for water resource analysis. The geographic display of the trends is also essential in shaping the contours of best management practices including stewardship efforts and conservation measures necessary for effective policy. Seeing that water problems of the state do not operate in a vacuum, the paper identified a host of factors associated with the use of water in the state. To deal with some of them, government agencies have been quite active with monitoring activities and surveys related to water resources, but have not eradicated the problems. As a result, the paper offered five recommendations ranging from the need for more education to raise awareness of water issues to the design of infrastructure and more GIS use. Accordingly, mix scale methods as used here not only provided the policy tool for managers, but as a decision support mechanism, it furnished information and awareness for enabling managers track water quality, usage and the risks that can inhibit access. The belief is that decision makers are provided opportunities for best management practices in their responses to identifiable risks like potential scarcities and accumulative depletion. This approach remains pertinent as counties grapple with efforts to manage their water resources.

Additionally, part of the study contributions stems from a broad range of benefits for county managers and those in government agencies longing for effective decision support tools. This will enable counties prepare long range plans for sustainable use of water resources. Finally, the paper provides the preamble necessary in the design of spatial decision support tools for water management. In closing, it is our belief that successful implementation of some of the strategies outlined herein could lead to effective water management. While the merits of the research, limitations and areas for future studies are outlined in Appendix G-H. The use of a mix scale approach in analyzing water resource issues stands as a timely update to current literature with a legitimate research call that is scientifically motivated.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX A

1.1 Background

In implementing a framework for modelling the impact of land use practices on groundwater in watersheds [5] used GIS to identify spatial dispersion of ground water nitrogen sources and resultant loadings. Russell examined the role of GIS in selecting sites for riparian restoration based on hydrology and land use [6]. Elsewhere Liu developed a GIS interface that integrates soil and water assessment tool for estimating water quality benefits for watersheds [7]. In another work, cartographic modelling tool and GIS statistics found valuable use in measuring the links between water quality, land use and distance from stream on a watershed [8]. Furthermore, Davis focused on water issues using GIS analysis and land use composition in catchment areas [9]. Realizing these benefits, scholars are channelling their GIS data management expertise towards the calibration of water quality models [7].

APPENDIX B

2.1 Study Area

Another major aquifer, Sparta stretches over a subterranean area underneath northwest Mississippi and the western portion of Tennessee. Because both states maintain jurisdiction over the aquifer waters inside their boundaries, none of them has control over each other resources. However, Mississippi uncovered the daily diversion of 20 to 40 million gallons from the Desoto area in the northern part of the state by the city of Memphis. In February of 2005, Mississippi took Memphis and MLGW to the United States District court, over an unlawful diversion of 363 billion gallons of its ground water for over 45 years [33].

APPENDIX C

2.1 Contd.

Regarding pollution and degradation, several studies that highlight, the problems of pollution in the aquifers identified the occurrence of nitrates in the Mississippi River Alluvial aquifer at a site in Bolivar County [41]. Another study in that fashion confirmed the occurrence of nutrient loads of pesticides and fertilizers in the same aquifer from agriculture [42]. One of the most current studies highlighting water level declines from climatological and cultural factors in the aquifer puts the rate at 500,000 cubic feet in the Mississippi Alluvial aquifer [43].

Based on a statewide study in 2011, water quality testing data of all public water systems are in compliance for volatile organic chemical (VOC), synthetic organic chemical (SOC) and nitrate (NO_3) concentrations within the 0-5mg/1 limit. From ground water quality data collected between1990 to 2010 under limits stipulated by the EPA. Only three systems (Cockfield Sparta, Meridian-Upper Wilcox, and the Eutaw-McShan) showed traces of maximum contaminant level (MCL) violations for the metal thallium. Of great importance in the study are two other aquifer systems in Southern Mississippi, the Great Gulf Aquifer System, often referred to as Miocene Aquifer and the Citronelle (Terrace Deposits Aquifer). The Miocene Aquifer contained dissolved solids above the recommended 1,000mg/l in some wells in Jackson county, within a predominantly small area. Other thresholds like the levels of iron, nitrate and color all stayed within permissible limits. The Citronelle Aquifer or Terrace Deposits had elevated iron and manganese levels in quite a few places coupled with probably large traces of total disallowed solids close to the coast. Elsewhere, phosphorous levels in the Mississippi River Alluvial groundwater appeared in elevated levels than the natural background concentration of 0.03mg/l more than the EPA aims of 0.1mg/L for phosphorous in streams [34].

Another thing to understand is that because the aquifers used for drinking water in the state are mostly confined to a certain degree by sheets of clay that inhibit extensive cases of groundwater pollution. Much of the recognized cases of ground water pollution in Mississippi have occurred in low unconfined aquifers often used in certain places as the source of domestic drinking water. Additionally, part of the key causes of groundwater pollution in Mississippi usually can be linked to leaky underground storage tanks (USTs) containing petroleum-based materials and defective septic systems. One major issue in Mississippi localities known for petroleum activities and production is the prevalence of localized brine (saltwater) pollution of low or shallow aquifers. However, much of the previous issues linked to the oil and gas sector have been corrected through the implementation of tougher guidelines in the state [34].

APPENDIX D

3.4 Factors Fuelling Water Resource Problems

3.4.1 The declining state of water infrastructure and hydrogeology

The declining state of water infrastructure and inadequate access to capital for the upgrade of rural and urban water systems are associated with the current water quality problems in the study area. In some cases, run-down infrastructure among water carriers and faulty sewer pipelines in the municipalities lacking maintenance continue to impede water quality. The other problems stem from the relatively large number of small rural water carriers operating in the state that are often plagued with non-compliance citations and minimal capacity and the resources to sustain healthy water supply [1,16,34]. Notwithstanding the occurrence of pollution in some sites adjacent to ground water sources, the combination of physical factors made up of very permeable soils, low aquifers and heavy rainfalls keeps Mississippi's ground water susceptible to contamination. Additionally, the shallow deepness to water, the frequent applications of agricultural chemicals, and high precipitation are conditions in the Delta driving the susceptibility of shallow ground water to pollution. All these elements in the Delta region create bigger probability for the movement of pollutants and hence the linkages to water quality decline [40].

3.4.2 Urbanization and population

The Gulf coast and the Jackson metro area of the state have all experienced extensive urbanization ever since the 1970s [36]. With urban development and growth, cities face the possibility of groundwater contamination during run offs from streets prompted by heavy rains and fertilizers and other chemicals used in the treatment of lawns [32,36]. Other notable problems center around the likelihood of shallow groundwater pollution linked to sewer systems in the country side and a few urban centers. These fears are directed at microbiological and nitrate pollution, and more recently on complex organic substances often found in septic tank cleaners. When a lot of systems operate for years surpassing their designated life span, steady flow of harmful materials onto water sources follows. Population density as a factor within the Mississippi Alluvial plain aquifer is increasing in several areas. Growing population and the movement of people from rural to urban areas have increased the need for more pumpage centers like Jackson which pumps 41 million gallons from surface and ground water sources [16]. With billion gallons per day pumped out of nearby aquifers along the Mississippi Alluvial Plain, groundwater pumping has resulted in water level declines. Change in the water level along the alluvial plain aquifer was notable in 2007 with 0.7 of the alluvial area 216 square mile units exhibiting decline levels of more than 100 feet [39].

3.4.3 Waste disposal and industrial activities

Hazardous wastes are processed and stockpiled at 23 RCRA spots that represent a recognized danger to ground water value in the state. In fact shallow ground water sources are known to have been contaminated at different levels on 13 of the RCRA locations. The perceived pollutions came from wood handling preservatives like pentachlorophenol or creosote. With 9 of the RCRA sites full of organic substances (such as nitro benzene, dintrobutyl); phenol, and phenolic compounds were found at 3 other sites while nickel surfaced at another. Other cases resulted in shallow ground water contamination in the Centreville area of Wilkinson County due to rubber wastes stored on a 35 acre facility. Other notable pollutants present in ground water at depths of less than 15 feet since the 1970s include carbon tetra chloride, chloroform, and acetone. With the finding of oil and gas in Mississippi since 1939, numerous wells were drilled in the producing areas in the southern region where drilling came with brine production. While Federal regulation proscribes underground insertion of brine and drilling fluid, techniques of permeable removal pits and waste injection created localized pollution of many fresh water aquifers. Aside from the vulnerability of shallow aquifers, the pollution of water wells within deeper aquifers has been identified. Over the years, saltwater contamination of freshwater aquifers from oil fields and brine disposal had been reported in sites mainly in the central and southern parts of the state [40].

3.4.4 Agricultural practices and farming

In a state where agro-chemicals are applied heavily on 6.6 million acres of cropland, about 7000 m^2 area of arable land in the alluvial plain of north western Mississippi, called the Delta ranks as the most highly farmed in the state [32,40]. In the area, about 2 billion gallons per day of fresh water are withdrawn from the Mississippi River alluvial aquifer to meet communal needs [16].While the Delta contains over half of the state's cropland, it uses nearly more agro-chemicals than other areas. The Mississippi River alluvial with an average of over 80-200 ft in thickness, lies beneath the Delta and generally it is inundated. In 1983, 2 million acres of crops in the Delta primarily cotton, soya bean, and rice were treated with 8,000 tons of pesticides. When agro-chemical use on crops reached higher levels in 1978, it involved 10,000 tons of 55 brands of pesticides and 500 tons of sodium chlorate. Other chemicals that were devoted to crops and soil yearly include fungicides, defoliants, emulsifiers, pesticides and solvents, lime and fertilizers [40]. In the region, agriculture relies heavily on ground water from the Mississippi alluvial valley aquifer; ranked 3rd in the nation for total withdraws or 12% of ground water pumped [36]. With the profound effect water use and chemical treatment has on water quality and availability. Like in other areas in the US, there are concerns about declining water quality and the depletion of the aquifer hence the linkages to the water issues in Mississippi [39].

For more on the factors, see Table 7 for other sources of ground water contamination emanating from land use. As you can see, they come from a whole range of activities including agriculture, industrial storage and oil and gas activities as well as waste disposal.

Table 7. Major sources of ground water contamination

Contaminant source	Ten highest priority sources	Contaminants
Agricultural activities		
Fertilizer Applications	X	Nitrates
Pesticide Application	X	Various Pesticides
Storage and treatment activities		
Storage tanks above ground	X	Petroleum products
Storage tanks underground	X	Petroleum products
Disposal activities		
Land fills	X	Various contaminants
Septic systems	X	Nitrates, pathogens
Other		
Hazardous Waste Generator	X	Various Contaminants
Hazardous Waste Sites	X	Various Contaminants
Industrial Sites	X	Various Contaminants
Oil and Gas Production	X	Chlorides

Source: MDEQ, 2010

APPENDIX E

3.4.5 Current efforts

Several initiatives have been put into place by state authorities with the active involvement of the Mississippi Department of Environmental Quality and the Mississippi Department of Health. This includes ongoing efforts made up of water protection measures, source water assessment and Agchem Program in selected sites and ground water rule. The ground water rule is intended to reduce the disease incidence associated with disease causing microorganism in drinking water. Of great importance in containing some of these problems, is the role of the Mississippi Department of Health in monitoring activities through its boil water alert bulletins in affected counties. As part of its national mandate, the USGS has also been very active in conducting periodic surveys outlining the state of groundwater use in the state. However, these initiatives still have not eradicated the threats of quality decline and unsustainable use in the state.

APPENDIX F

3.5 Recommendations

3.5.1 Regular assessment of water resources

Considering the mounting threats of degradation and accumulative depletion, water authorities should carry out regular assessment to track the state of water resource use under their domain. Continual update of the rate of water outtake and the potential hazards associated with use are essential dimensions of effective water management for the safety and welfare of communities and their ecological health. Had the state of Mississippi carried out regular assessment of its ground water assets for years, exposure to repeated diversion of its water resources by a neighboring state which went undetected for decades and mounting deficits in groundwater volume across the state should have been averted. Such initiatives could have spared the state the ordeals and discomfort of lengthy litigations as witnessed in Memphis, Tennessee vs the state of Mississippi and the continual vulnerability of its water assets. In order to manage the resources properly, the paper supports the need for regular assessment of water resources in the state.

3.5.2 Sustainable use, conservation and regional cooperation

In the context of the study area, no renewable resource such as water is infinite or less vulnerable from scarcity and contamination. In a setting in which quality decline and the associated hazards and conflicts over water rights transcend political boundaries it is clear that no area or community can manage water resources alone successfully without involving others outside of its boundaries. As a result, there is a need for sustainable water use built on conservation and regional cooperation involving known users such as farmers, households, industry and institutions and public works and municipalities who often shape the use of water in most areas. Sustainable planning built on changing attitude on water usage in the spirit of wise use and conservation principles of reuse and recycling would go a long way in curbing the adversarial tone water management had taken in the past in the southeast by pitting states like Florida and Alabama against Georgia and now Mississippi versus Tennessee over underground fresh water diversions.

3.5.3 Education

There is always a false sense of water abundance in the south yet the reality shows growing concerns over recurrent ground water depletion rates and the widespread contaminations that come with boil water alert bulletins. With very little awareness about over pumpage, there are threats like nutrient loads in ground water aquifers and projected stress from climate change. Going by all these indicators, the current state of water use in the state of Mississippi needs the infusion of educational and enlightenment campaigns for the general public as counties grapple with the management of the resource. Targeting such groups from farmers to land owners, and institutions helps raise awareness of the issues and it could go a long way in acquainting communities and consumers including industries and municipal authorities on how their actions impact water use. Doing so through workshops, trainings, use of electronic and print media provides a platform for charting the most efficient ways of managing water resources under new a framework where consumers should assume the role of good stewards of water resource use.

3.5.4 Continuous monitoring of water resources

Considering what transpired, it would be a mistake to overlook the periodic monitoring of water resources and how various sectors are impacting quality and quantity of the resource in the state of Mississippi. Because no state can stand by and watch its essential resource varnish without doing something, it becomes very imperative to regularly monitor water resources. Such an approach offers opportunities for assessing the quality, deficits and increments in water budgets and deposits in a state where over 90% of water use comes from ground water sources. The risk of inaction raises the exposure to hazards such as subsidence, sink holes and salt water intrusion into fresh ground water aquifers as a result of depletion and cone formation. Seeing the role of competing land uses and new settlements in water withdrawals and the resultant hazards from contaminated sites, the paper recommends continued monitoring of water resources and land use practices threatening access. The expectation is that monitoring activity provides the parameters for articulating best management practices suited to the various sectors whose activities threaten water resource assets of the state. This will go a long way in addressing the threats to water resources.

3.5.5 Improve data infrastructure and design water resource information system

During this study, there was no centralized data clearing house on water and ground water resourcse assets such as aquifers and the impacts of growth on them. The available facts on groundwater resourcse use and degradation were scatterred in diffferent places. To improve the situation, it is suggested that Mississippi improve existing environmental technologies and strengthen public access to data on water use, depletion trends, degradation and the risks from climate change stressors. This would enhance the ability to carry out impact assessment and monitoring of water use and the threats from conntaminated sites and brownfields adjascent to water sources in the state. There is also a need for more GIS data on water use and the impacts of human activities. Without access to a spatially referenced system, decision makers and water managers and the carriers of well water serving communities would not know the location and severity of degradeded areas adjacent to water resources. This will sharpen the readiness of regulators in reviewing policy violations while ensuring compliance with GIS mappping as a management tool in future endeavors.

APPENDIX G

4.1 Contributions of the Research

4.1.1 Ushered decision support tool for management

At the writing of this research paper, the state of Mississippi lacked a centralized regional water resource information support system pertinent for effective management. As a result, the comprehensive analysis as presented herein ushered in the much needed tool for supporting communities manage the challenges of water resource use in the state. The effectiveness of the paper in that direction in detailing the extent and nature of sectorial use, the location of intense pumpage, depletion trends and the mounting threats of pollution and human activities to water quality in the area over the years serves a useful purpose in decisions pertaining to water resources. In the absence of such a support tool in the face of current fight against the threats of climate change and degradation and the need for effective mitigation measures. The management of water resource problems in the state would not only be hampered, but it will leave policy makers unprepared in effectively evaluating the threats water quality decline and pollution pose to communities. The significance of such a decision support system tool stems from the optimal display of temporal-spatial information pertaining to water use, pollution and other elements influencing access to water resources in the state. This support tool strengthens the ability to formulate informed decisions necessary for addressing the challenges of quality declines and access to water resources. For ushering in such a decision support tool for management, the effort here remains timely.

4.1.2 Reechoed the state of water use in Mississippi

One of the major benefits of the research stems from the emphasis on the state of water use in Mississippi. While previous efforts did not result in the outright mitigation of water problems in the state. The approach in this study not only helps in putting issues that were long overlooked back into the public policy and research agenda, but it reechoes the need to continue work in that area in the 21st century. In the absence of a comprehensive analysis herein, little would have been known about the vulnerability of counties in Mississippi to water stress. Because the ideas behind this study are still relevant to water resource planning, they will influence in some degree ways in which consumers and elected officials manage water resources. As water planners deal with resource problems affecting different areas in the state, the search for present-day solutions demands an understanding of the state of water use in answering similar questions in the past. The display of water use matrix as presented here is vital. This is quite essential in arriving at the conclusions that serve the needs of the state under changing climate scenario in which the threats of water scarcity in the coming decades continues to loom larger than ever. Policy responses in that setting also require knowledge of patterns of water resource extraction, and consumption and the threats to water quality. Reechoing the state of water use in that setting enhances the prospects of optimal management.

4.1.3 Generated a template for future research

The fact that we never came across any analysis on the study area that captured the state of water use and the climate change dimensions, spatial analysis, and the threats posed by trans-boundary diversions in a comprehensive fashion in the same place. The results of this project can be used to sustain water research efforts not only in areas where they are overlooked, but also in places with programs to rekindle interest in implementing standards for addressing impending water scarcity and quality declines. The lack of consistent time series on water issues in the state as identified in this study has the potential to spark vivid interests in filling the apparent data voids through future research. Notwithstanding, little coverage of issue based studies, stressing the periodic display of pumpage and water pollution index across time and space through research as done here is a worthy step. Such an approach affords the general public and the policy makers, ways of tracking hidden threats and the impending problems that are too costly to ignore for communities. Accordingly, there are great opportunities in such an approach for the research community to refocus the agenda on water management and policy models that place high premium on water quality and wise use on a sound footing within the policy arena in order to improve standards, best management practices and stewardship.

4.1.4 Provided an analytical tool

Using the techniques of mixscale, descriptive statistics and GIS mapping as methodological tools injected another dimension to the analysis of water issues. Because effective management of water resources requires integrated approach like the mixscale —as applied in the research, the approach has been useful in delineating the study area and pinpointing the locations of water over use, and the spatial distribution of environmental externalities of contamination and brownfields sites in the surrounding areas. This approach is highly effective in helping researchers undertake spatial monitoring of the impacts of human activities on water resources in areas adjacent to contaminants. In the case of spatial diffusion of contamination and depletion risks in some areas of Mississippi, GIS mapping as a management tool proved quite useful in unveiling the occurrences, the levels and challenges across space. Such application reflects a major step in ensuring sustainable water resource use. The provision of such information strengthens the ability of water resource planners and others to identify areas likely to be exposed to stress, cone formation and impending water scarcities. It also provides effective benchmarks for assessing the critical conditions of counties in the state. The practical applications of a mix scale approach involving spatial mapping along with climate risk data, as analytical tools has added the Mississippi experience into the literature. This tool has been effective in detecting the vulnerabilities of coastal areas of Mississippi to the dangers of change that could affect society.

4.1.5 Offered insights for improving water conservation

Having identified the risks, the study generated insights for improving conservation efforts. This offers planners immense opportunity to track water use and appraise the risks to quality and quantity of water resources in the state. Being a step forward for conservation, the study quickens the preparedness of policy makers in being kept abreast of the state of water use in terms of quality and quantity that would enable them craft best management practices and stewardship measures in critical situations. The geographic dispersion of water pumpage and stressors and the presence of accumulative depletion over time in the state have potentials to garner the attention of those charged with conservation. The fact that the occurrence of these issues in space were at levels large enough to impact water access makes the analysis herein an additional insight for improving the current approach to conserving available water resources in different areas especially the northwest known for extensive usage. Accordingly, the study provides planners with a better grasp of the threats to water resources they would not have known. This they can use in future decision making associated with water demand and supply in communities. Thus, the paper provides a yardstick for weighing critical thresholds that may arise especially when a region's water resources are threatened by potential scarcity in the coming years. The benefit is that it offers a set of parameters which managers can draw from as they craft measures best suited for their counties in order to ensure continued access. In so doing, conservation managers are made cognizant of issues arising they would not have known in the areas under analysis.

APPENDIX H

4.2 Challenges and Areas for Improvements in Future Research

4.2.1 Data constraints and rooms for improvement

As an issue oriented research, part of the constraints revolves around the lack of access to a centralized spatial data clearing house from providers on the topic. Notwithstanding the existence of MARIS, the state data infrastructure still lacks a very comprehensive information base. Furthermore, the compilations of most water data from the original government providers are not available annually on a consistent basis. This does not provide the opportunity to glean the time series on water issues regularly. This may be attributed to the multiplicity of jurisdictions involved in the collection of water data, the different approaches and the costs of doing it, the time required and the immense resources involved. While the data used in this research came from the actual government sources that supply these data, I should have liked to see a complete time series of water information across time and space from these providers to enable one glean other problems in the respective areas. Given these constraints, it is necessary for data agencies to start according water information the same priority given to socio-economic and energy indicators as done in the annual balance sheet of the nation. This will enable researchers access time series of water issues the way it exists for other socio-economic indicators. The format and structure of current data infrastructure for the state of Georgia is comprehensive enough and can serve as a model for improving what is currently available. Other areas that merit attention and an improvement through future studies include the emphasis on a regional water atlas for Mississippi, and more coverage of trans-boundary water issues, the state of water trends and the comprehensive analysis of water quality threats, climate change influence on water access. There is also an urgent need for future studies on water issues in African American communities in the US. Having said that the paper stands out as scientifically motivated and driven by a justifiable research call with worthy contributions.

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